

**NEGOTIATION-BASED RISK MANAGEMENT FOR
PPP-BOT INFRASTRUCTURE PROJECTS**

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DECLARATION

I hereby declare that the thesis is my original work and it has been written by me in its entirety. I have duly acknowledged all the sources of information which have been used in the thesis.

This thesis has also not been submitted for any degree in any university previously.

A handwritten signature in black ink, appearing to read 'M. ATTAR', is positioned above a horizontal line.

Meghdad Attarzadeh

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SUMMARY

The impact of financial difficulties, technical inefficiency, incorrect pricing, and poor quality of services under traditional public procurement, has led to large scale infrastructure project procurement turning to the private sector for financing, construction and operation. This is known as Public Private Partnership - Build Operate Transfer (PPP-BOT).

Successful implementation of a PPP-BOT project is subject to appropriate risk management and successful negotiations and renegotiations especially in the development phase. Appropriate risk management is tied to risk and uncertainty modelling whereas successful negotiations and renegotiations are tied to the consensus of the main parties involved in the project.

The major and key parties involved in PPP-BOT projects are concessionaire, government, sponsors and lenders each of which have diverse and conflicting objectives. Finding or arriving at an equilibrium solution as a strategically stable position that meets all parties' objectives simultaneously within the PPP-BOT negotiation process avoids costly and lengthy negotiation and renegotiation processes. Consequently determining the negotiation positions in the development phase of PPP-BOT project and incorporating risk and uncertainty in the simulation process is crucial to achieve the project objectives.

The general view in current literature is that game theory (GT) is a suitable method to simulate negotiations between parties and analyse their behaviour. In game theory, a cooperative game is a game where groups of players may enforce cooperative behaviour. An example is a coordination game, when players choose the strategies by a consensus decision-making process. On the contrary, a non-cooperative game is one in which players make decisions

independently. Pareto efficiency is a situation in which it is not possible to make a player better off without making other player(s) worse off.

Additionally, it shows that Monte Carlo simulation (MCS) is an appropriate technique for risk and uncertainty modelling. Moreover, Real Options Valuation (ROV) and Analysis is a mechanism that has the capability to improve negotiation results of a PPP-BOT project. From this it can be seen that PPP-BOT projects suffer from a lack of a systematic methodology that could help both the public and private sectors to find or arrive at a consensus solution as a strategically stable position. Likewise there is a lack of a comprehensive method for simulation that incorporates and addresses both risk and uncertainty simultaneously in the model.

This thesis proposes a systematic negotiation mechanism for PPP-BOT infrastructure project based on the game theory, hybrid simulation and Real Options Valuation and Analysis which address the aforementioned gaps and shortcomings.

Firstly, this mechanism helps parties to find equilibrium solutions based on the fuzzy game theory approach especially in the development phase. Consequently, it follows by determining each party's negotiation position and corresponding payoff through applying an appropriate game type. This determination helps parties to analyse other parties' behaviour and also mitigate the effects of costly and lengthy negotiation process.

Secondly, the proposed fuzzy randomness Monte Carlo simulation (FR-MCS) technique helps both parties to incorporate risk and uncertainty in the simulation simultaneously, which is a main limitation of conventional Monte Carlo simulation (MCS). FR-MCS results lead to well defined negotiation bound

(bargaining interval) of decision variables i.e. financial and contractual negotiation parameters which are called negotiable concession items (NCIs) and its associated cumulative distribution functions (CDFs) corresponding to specific confidence level for simulation output. Conversely, conventional MCS results in just one CDF and consequently a deterministic value corresponding to specific confidence level for simulation output.

Finally, the financial viability of PPP-BOT project was assessed. The Real Options mechanism was proposed to retain the project financial viability at an acceptable level by all parties especially under the impact of catastrophic risks. A case study was conducted to examine the systematic negotiation mechanism for validation of models.

By using the proposed systematic negotiation mechanism both public and private sectors could take advantage of its flexibility at the negotiation table. The proposed mechanism could facilitate negotiations on the verge of break down as well as accelerating ongoing negotiations that have been slowed down. It supports to manage and also allocate risks between all parties in such a way that is fair to all.

However, as this research did not consider third parties, more research is needed to identify and address the role of third parties such as insurers in addition to major and key parties, i.e. concessionaire, government, sponsors and lenders in PPP-BOT projects.

Keywords: Negotiation, Fuzzy Game Theory, Simulation, Fuzzy Randomness, Uncertainty Modelling, Financial Viability Mechanisms, Financial Modelling, Real Options Valuation and Analysis, PPP-BOT Projects.

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LIST OF ABBREVIATIONS

PPP	Public Private Partnership
BOT	Build Operate Transfer
NCI	Negotiable Concession Item
VFM	Value For Money
PSC	Public Sector Comparator
MCS	Monte Carlo Simulation
FR-MCS	Fuzzy Randomness Monte Carlo Simulation
MCDM	Multiple Criteria Decision Making
CDF	Cumulative Distribution Function
PDF	Probability Distribution Function
GT	Game Theory
NE	Nash Equilibrium
ROA	Real Options Analysis
SPV-SPC	Special Purpose Vehicle/ Company
PC	Project Company
COD	Commercial Operating Date
ED	Effective Date
CD	Closing Date
NPV	Net Present Value
IRR	Internal Rate Of Return
PP	Payback Period
WACC	Weighted Average Cost Of Capital
MRG	Minimum Revenue Guarantee
PRA	Probabilistic Risk Assessment
FSV	Fuzzy-Stochastic Variables
DSCR	Debt Service Cover Ratio
ADSCR	Average Debt Service Cover Ratio
LLCR	Loan Life Cover Ratio
SLR	Self-Liquidation Ratio

CSF	Critical Success Factor
PIRR	Project IRR
EIRR	Equity IRR
O&M	Operation And Maintenance
DCF	Discounted Cash Flow
EFG	Early Fund Generation
PV	Present Value

NOMENCLATURE

Symbol	Description
Π_p	Private sector (concessionaire) objective function
Π_g	Public sector (government) objective function
IDN_{α}^{μ}	Indicator-at-risk and uncertainty
$NPV_{t\alpha}^{\mu}$	Net present value of financial benefit in year t at given confidence (α) and uncertain (μ) level
I_t^{μ}	Investment cost in year t of construction period at given confidence (α) and uncertain (μ) level
$Rev_{t\alpha}^{\mu}$	Project revenue in year t of operation period at given confidence (α) and uncertain (μ) level
$RY_{t\alpha}^{\mu}$	Royalty payment to government in year t of operation period at given confidence (α) and uncertain (μ) level
RY_t	Amount of royalty at year t
$C_{t\alpha}^{\mu}$	Project costs in year t of operation period at given confidence (α) and uncertain (μ) level
I_t^{μ}	Investment cost in year t of construction period at given confidence (α) and uncertain (μ) level
I_0	Initial investment cost including: feasibility studies and financial viability analysis costs, proposal preparation and bid costs, bank fees for project financing
I_{α}^{μ}	Total investment at given confidence (α) and uncertain (μ) level
VFM_{α}^{μ}	Value for Money at given confidence (α) and uncertain (μ) level
$\Phi_{\alpha}^{CP\mu}$	Present value of the royalty payment to the government during the concession period at given confidence (α) and uncertain (μ) level
$\Psi^{PCP\mu}_{\alpha}$	Present value of the financial benefits of the project after concession period till Project economic life
NPV^{PSC}	Net present value of the Public Sector Comparator (PSC)
NPV^{PPP}	Net present value of the bid PPP delivery

SLR_{α}^{μ}	Self-liquidation ratio at given confidence (α) and uncertain (μ) level
$NPV_{\alpha}^{R\mu}$	Net present value of the net revenue in the operation period as discounted to the end of the of the concession period at given confidence (α) and uncertain (μ) level
$NPV_{\alpha}^{C\mu}$	Net future value of the construction cost as discount to the end of the construction period at given confidence (α) and uncertain (μ) level,
Tax_t	Taxes in year t of operation period,
$DSCR_{t\alpha}^{\mu}$	Debt service cover ratio in year t of operation period at given confidence (α) and uncertain (μ) level
$LLCR_{k\alpha}^{\mu}$	Loan life cover ratio in year k of operation period at given confidence (α) and uncertain (μ) level
$EBIT_{t\alpha}^{\mu}$	Earnings before interest and taxes in year t of operation period
D_t^{μ}	Debt in year t at given confidence (α) and uncertain (μ) level
ρ	Minimum acceptable level of DSCR and LLCR by lenders
$O\&M_{t\alpha}^{\mu}$	O&M costs in year t of operation period at given confidence (α) and uncertain (μ) level.
$DEP_{t\alpha}^{\mu}$	Depreciation in year t of operation period
$r_{\alpha}^{\mu} = WACC_{\alpha}^{\mu}$	Discounted rate
R	Minimum expected return on investment by investors
V	Maximum return on investment acceptable by government
CP	Concession period
CD	Construction duration
OP	Operation period
N	Loan repayment period
t	a year in operation period
t_e	Project economic life
D	Annual equal debt instalment including principal and interest of loan
C_r	Cost of regulation for government
C_p	Cost of profit maximization for private investor

RY	Royalty
DM_t	Demand in year t
PL_t	Peak load in year t
R_t	System reserve in year t
Q_t^U	Total electricity supply of the utility in year t
Q^{BOT}	Minimal annual electricity delivery from the BOT plant stipulated in the energy contract
Q_t^{BOT}	Actual electricity delivery from the BOT plant in year t
X_t^U	Capacity of the utility in year t
X_t^{BOT}	Capacity of the BOT plant in year t
IC_t^{BOT}	Investment cost of the BOT plant in year t
VC_t^{BOT}	Variable cost of the BOT plant in year t
FC_t^{BOT}	Fixed cost of the BOT plant in year t
FC_t^U	Fixed cost of the utility in year t
VC_t^U	Variable cost of the host utility in year t
P_B	Breakeven cost for BOT's electricity- marginal cost
P_A	Average cost of the host utility
C^0	Total cost of power generating without the BOT contract
C^{BOT}	Total cost of power generating with the BOT contract
Rev_t	Revenue of BOT plant in year t
C_t^p	BOT plant Production costs in year t
f^U	Total payment to BOT plant
a, b, c	Coefficients
k	Biding strategy coefficient
C^r	Cost of regulation for government
C^p	Cost of profit maximization for private investor
α	Confidence level
μ	Uncertain level
CF_t^a	Actual revenue in year t

r^f	Guaranteed minimum return on equity (Min-GEROR)
r^c	Guaranteed maximum return on equity (Max-GEROR)
CF_t^{gmin}	Guaranteed minimum revenue in year t
CF_t^{gmax}	Guaranteed maximum revenue in year t
SF_t	Shortfall in revenue in year t
R_t	Excess cash flow as repayment in year t

CHAPTER 1 INTRODUCTION

Infrastructure development is a crucial target for a country's economic development. Traditionally this target was fulfilled solely by the government. In the last decades, due to barriers such as shortage in financing, governments especially in developing countries have moved to use private sector capabilities to meet demand for infrastructure development in a timely manner. On this movement the governments focus on new collaboration methods.

A popular project procurement method, the Public Private Partnership - Build Operate Transfer (PPP-BOT), has been drawing increasing attention from not only developing countries but also developed countries. There are many reasons for this. First, there are ever-growing pressures on public budgets as public borrowing is increasing. Second, there is evidence that the private sector is usually more efficient than the public sector, even in developed countries.

This chapter initially reviews the concept and characteristics of PPP-BOT projects. After identifying the difficulties and challenges in implementation of PPP-BOT projects, the research gaps, objectives and scopes are presented. This chapter will proceed to present the research methodology followed by a description of the thesis structure.

1.1. Concept of PPP-BOT Projects

Under the PPP-BOT scheme the client, usually a government agency, grants a concession under concession agreement to the concessionaire, usually private sector consortium, who has the obligation to finance, design and builds an infrastructure project. In return, the concessionaire is entitled to operate the

completed project for a specified period, called concession period (fixed or variable), at the end of which the project must be transferred to the agency free of charge. During the concession period, all the revenues generated from the project go to the concessionaire's account in order to repay the financing and investment costs, cover operation and maintenance costs, and make a margin of profit to concessionaire (Delmon, 2009; Levy, 1996; Tiong et al., 1992). On the one hand, the government is concerned with the purchase of services/products rather than acquiring assets in order to meet the demand for the services/products with reasonable and justifiable price and cost to end users. The government's objective is to build sufficient infrastructures for public usage. The strategy adopted by government is to procure a project by the project's anticipated revenues rather than by borrowings or budgeted funds. The goal of the PPP-BOT scheme is therefore to ease the infrastructure development without increasing the financial burden of the public sector (Delmon, 2009; Levy, 1996; Tiong et al., 1992).

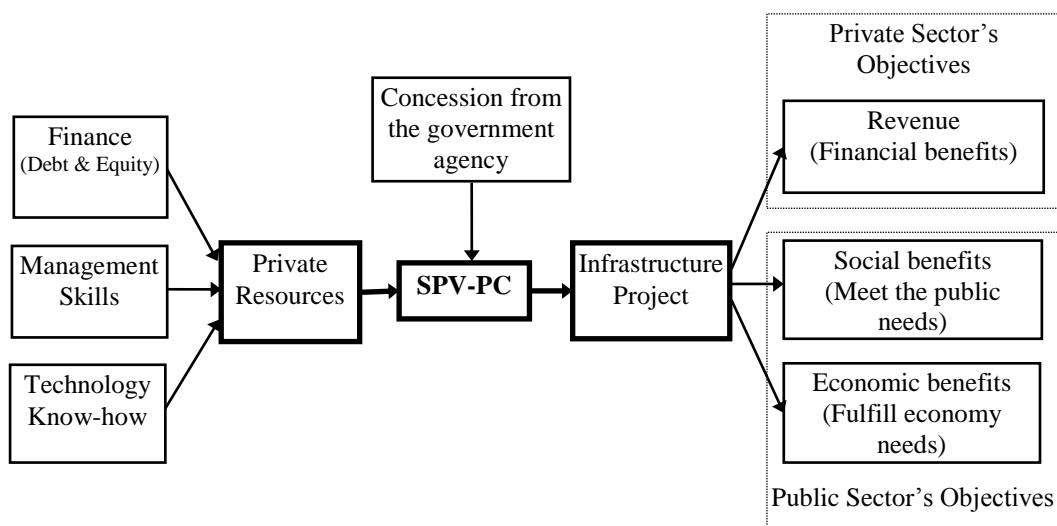


Figure 1-1 the concept of the PPP-BOT scheme

From the private sector's viewpoint; the concern is the financial viability of the PPP-BOT project and the concessionaire's objective is financial benefits. The

private sector wishes the PPP-BOT project provide investment opportunities that will meet the needs of enough end users/customers to cover the financing and investment costs and earn a reasonable profit as well. If a project is not only financially viable but also economically viable, PPP-BOT scheme can offer win-win solutions to government agency, concessionaire, lenders and end-user through a joint effort aiming at the realization of financial, social and economic objectives. The financial viability is referred to financial return i.e. return on capital (equity) which is the concern of the private sector and economically viability is referred to economical return i.e. cost-benefit analysis which is the concern of the public sector and end user. The concept of discussion thus far can be diagrammatically expressed in Figure 1-1.

1.2. Characteristics of PPP-BOT Projects

Compared with traditional project procurement methods, the PPP-BOT scheme has a number of unique and specific characteristics. The major ones are listed as follow:

- Lengthier and costly development period;
- More complex contractual arrangements and agreements;
- More complex project packages and financing;
- Negotiations dominated by the financial viability;
- Balanced risk allocation.

PPP-BOT schemes consist not only design and construction phase but also pre-concession (development) and operation phases. Thus they require more participants because of the need for finance and expertise. This makes the contractual arrangements and agreements more complex. In PPP-BOT

projects, the initial private promoters to whom the concession is awarded to them form a joint venture or a consortium Project Company (PC) which is also called Special Purpose Vehicle/ Company (SPV/SPC). A typical PPP-BOT project usually includes main parties involved in the project, namely, a *government agency* (public sector), who grants the concession and ultimately owns the project after transfer; a *concessionaire* (private sector), who is responsible for financing, designing, building and operating the project; *lenders* (banks and financial institutes), who provide fund in the form of loan/debt to the project; *investors* (stakeholders), who provide fund in the form of equity to the project; a *constructor*, who undertakes the design and construction work; an *operator*, who undertakes the operation of the project; *end users* (off takers), who purchase the off take or use the facility itself; *suppliers*, who supply equipment and/or raw materials; and finally *insurer* (insurance company), who insure the project. The basic structure of a PPP-BOT project with important agreements involved in its negotiations and implementations as the relationship between these parties are illustrated in Figure 1-2.

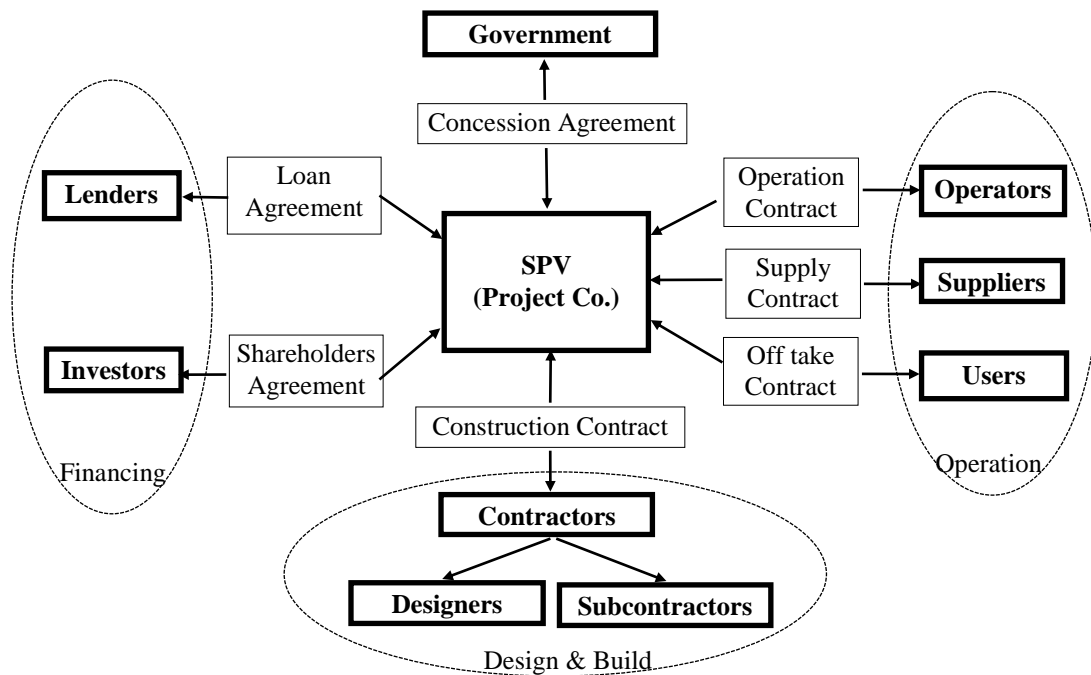


Figure 1-2 Typical PPP-BOT Project Structure

Based on this structure, the essential contracts of PPP-BOT projects are presented below:

- Concession agreement:** The government grants the concession to the *concessionaire* (Project Company). The concession is the right to build, own and operate the facility and often acquire most or all of the service provided by the facility. One of the most important issues in a concession agreement is the length of the concession agreement “*concession period*”. The *concession period* (CP) consists of *construction duration* (CD) and *operation period* (OP). Concession period is the company’s operation timespan of the facility needed to compensate the front end equity investment and repay the debt and interest borrowed from the lenders. The first type of project is *contract-led* project e.g. *power plant* which sells power to the power grid operator. The revenue is generated via the concession agreement. On the other hand, the second type of project is

market-led project e.g. *toll road or toll bridge* which generates the project's revenue.

- *Loan agreement*: It is a contract between lenders and the project company, the purpose of which is to provide debt. It is a critical contract particularly for a successful PPP-BOT project financing. In practice, the average of debt to equity ratio is 70/30 (Chang and Chen, 2001; Buljevich and Park, 1999; World bank, 2014). The equity capital complements debt financing. Equity investment is compensated by dividends, but equity investor is last in priority for its repayment. So it is called a risk capital compared to credit capital provided by the lender.
- *Off take contract*: If the operational output of the PPP-BOT project cannot be sold directly to end users, off take contracts are used to ensure the sale of products/services usually in the form of “*take or pay*” or “*take and pay*” agreements, user-fee and availability-based PPPs.

The concessionaire is involved in the life cycle of PPP-BOT project development. In the development phase from initiating the project to signing the concession agreement (*effective date (ED)* and *closing date (CD)*) and *commercial operating date (COD)*, the concessionaire may have to be involved in various time-consuming and costly activities and negotiations. Usually, a long development period may result from one or more of the following:

- Feasibility study process: estimate the project demand under risks and uncertainties;

- Investigate technical feasibility and assess financial viability: estimate capital and operating costs and predict revenue streams under risks and uncertainties;
- Set up a project company and provide required funds for the project; convince investors and lenders that the project is financially viable in order to raise funds required. Usually complicated negotiation would be required on financing;
- Convince the government to adopt PPP-BOT strategy (unsolicited project); usually, unsolicited proposals for PPP projects offer new technology. For instance, the Philippine PPP Centre as government agency only accepts unsolicited proposals that are innovative and offer new technology as mandated by the Philippine BOT law. The reviewing process and its mechanism for unsolicited proposals for infrastructure projects are not same as planned and solicited projects. So it typically leads to a long development period.
- Bid for the project: a tender including technical solutions and financial package;
- Proceed in problematic and unwieldy negotiation process with the government in order to sign the concession agreement.

So, PPP-BOT project is characterized with long maturation and development period. The development phase is a time-consuming and costly process to award the concession and includes high front-end costs. In short, the negotiations in the development phase, especially between public sector (government agency) and private sector (concessionaire), play the crucial and

essential role, and it will be focused more in the following sections of this thesis.

PPP-BOT scheme raises the capital through project financing instead of direct financing. So it comprises complex project financing packages. Project financing is also called off-balance sheet (OBS) financing. Off-balance sheet financing means a company does not include a liability on its balance sheet. In PPP-BOT schemes, the capital costs are normally reimbursed just from the project revenues. A reliable revenue stream projection provides security for lending banks and will encourage equity participation. Therefore, financial viability of the project is dependent upon the ability of the revenue stream to sustain a satisfactory profit margin over the project costs such that the *equity* and *loans* can repay within the *concession period*.

Various risks and uncertainties exist in PPP-BOT projects. Figure 1-3 shows a diagram categorizing the risks and uncertainties found on PPP projects from literature. Table 1-1 shows the identified main risks specific to PPP versus common risks in all construction projects.

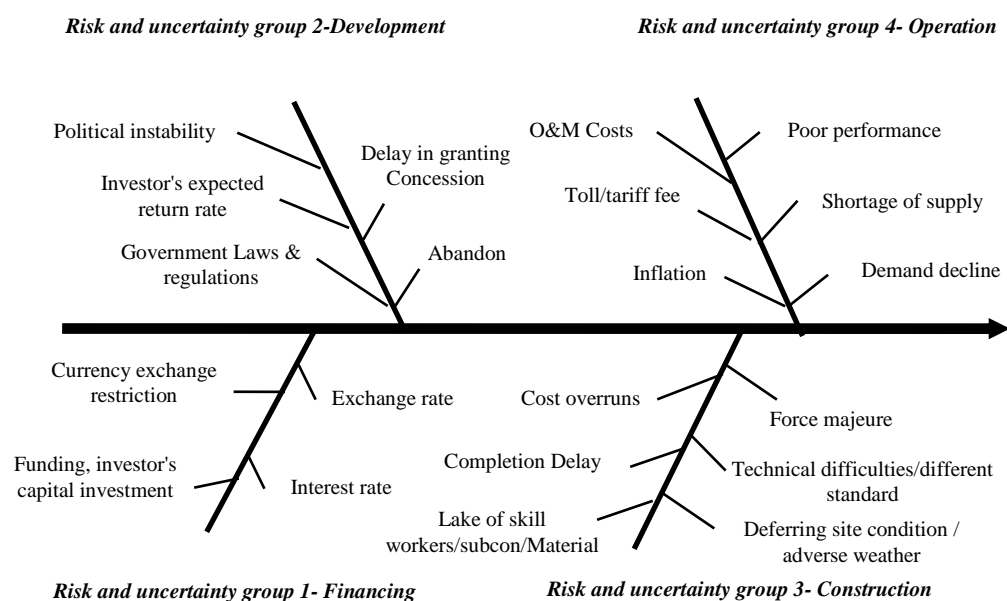


Figure 1-3 Risks and uncertainties in PPP-BOT Project, Fish bone diagram

Table 1-1 Main risks in PPP Project versus construction project

PPP project	Risk category	Construction project
Currency exchange restriction and rate, interest rate, Funding (High finance cost), Inflation rate volatility	Financing	Delay in payments for claim, cash flow difficulties, lack of financial resources
Political risk, Change in government laws and regulation, Poor public decision-making process, Investor's expected return rate	Development	Bureaucracy, delay in project approval and permit, improper design, change of scope
force majeure, Geotechnical conditions, cost overruns, completion delay	Construction	Land acquisition, Poor supervision, design variation (by the client), , inadequate scheduling (tight project schedule) and cost estimation, site safety, insolvency of supplier, Lack of coordination between project participants
Operational revenue below expectation, demand decline, Low operating productivity, O&M cost overrun, Expropriation or nationalization of assets	Operation	Compliance with law and regulation for environment issues, pollution

Risk allocation among parties involved is the centre of risk management process. The generally accepted principles of risk allocation are (Tan and Tiong, 2011; Smith, 1995):

- Risks allocate to those parties who are best able to evaluate, control, manage, bear the cost, and benefit from the assumption of risks;
- Assumed risk has an associated and unavoidable cost which must be presumed somewhere in the cost-revenue model; the allocation should be symmetrical (balanced) in terms of benefits and liabilities; and
- Remained risks and liabilities are best shared.

Proper allocation of risk reduces the overall cost to the project and promotes *Value for Money (VFM)* to the public sector. However, in PPP-BOT schemes, the private sector is expected to take the substantial burden of risk. Since the responsibility of project financing is shifted from public sector to private sector, the concessionaire have to take financial risks such as foreign exchange

and interest rates fluctuations. Furthermore, a long operation and maintenance period makes the concessionaire exposed to revenues risks and political risks such as sovereign risk and instability risk, besides the risks encountered in traditional methods such as cost overrun and completion delay resulting from construction difficulties.

The life cycle process of a BOT-PPP project development is classified into following stages: feasibility study to submit the initial proposal; tender to negotiate concession and contracting; design and construction; operation and maintenance; transfer and post-concession operation.

The host government plays an important role in PPP-BOT scheme not only to take up a successful project, but also to rescue and being the insurer of last resort for unsuccessful projects. The government must make sure that the project is feasible and suitable for PPP-BOT scheme. If a project is not self-financing, the government must provide motivations and incentives to make project financially attractive to the private sector. The following incentives proved to be effective for PPP-BOT scheme: Provide revenue stream guarantees, improvement of cash flow e.g.: government involvement in equity investment, retain some risks, provide direct loan or loan subsidies and loan guarantees, provide some coverage for outstanding debt and other financial obligations for uninsurable risks, and other incentives such as tax exemption.

Many common decision problems can be thought of as a game. For example in the development phase, before effective date milestone, both parties (concessionaire and government agency) meet each other around the negotiation table, maybe on several occasions, in order to make decision to promote project and allocate of responsibilities, risks and benefits to each

party. This game has been called *bargaining-game*. This bargaining-game can be categorised by types of objectives and decision variables.

The first and most famous bargaining are negotiations over negotiable concession items (NCIs): *concession period*, *tariff/toll* and *royalty* which are the most important concession items. Although there are few methodologies available for helping to determine the value of these variables, risk and uncertainty modelling techniques, especially financial risk and uncertainty management simulation, can help to determine concession period, tariff/toll and royalty under risks and uncertainties. The second bargaining is over subsidy and claim. If both risk management (financial risk management tools) and bargaining process simultaneously have been considered, it is possible to achieve a model with multi-objectives and best allocation of risks.

This research seeks to show how the bargaining process and financial risk management can influence the project development and each party's final gain and payoff. Further it also identifies various approaches that can be adopted to manage the problems previously discussed.

The aforementioned characteristics of PPP-BOT scheme present difficulties and challenges with high risks and uncertainties for the project. This is more significant in negotiations especially in the development phase. As a result it makes negotiations longer and more costly. This study evaluates the above problems and proposes a comprehensive method and mechanism to find or arrive at the solutions that are equitable for main parties involved under uncertainties and risks and simultaneously performing the risk management that meet the parties' objectives.

1.3. Research Gaps, Scope and Objective

1.3.1. Research Gaps: Motivation for Required Studies

A literature review was conducted to examine the current state of knowledge with respect to the development of long term infrastructure projects (PPP-BOT projects), and risk management. Over 100 journal articles and other publications pertaining to PPP-BOT projects were collected and reviewed. In light of the above literature review, some research gaps have been identified. These gaps have led to the current research. These research gaps are discussed below.

1.3.1.1. Negotiation-Based Risk Management

According to research records on failure and success in PPP-BOT projects, interviews with the PPP-BOT project experts and managers and also the author's experiences in some PPP-BOT projects, the crucial and essential part of the long term infrastructure projects is negotiation and renegotiation. Study on negotiation and renegotiation is helpful to simulate the negotiation aimed to analyse, characterize and forecast parties' behaviour in the negotiations and observe players' tendency and characteristic of behaviour. So, risk management of these projects must be done from a negotiation perspective. To the best of the writer's knowledge, few researchers have viewed risk management through this perspective. There is a lack of framework and modelling methods that capture and interpret the negotiation standpoint in risk management process. To this end, models and tools that are able to demonstrate and simulate negotiations between parties and their behaviour are needed.

Consensus of all players in negotiations is critical and important to ensure the success of PPP-BOT project. Although Delphi method has been introduced to address this issue, there are still some limitations including uncertainty

modelling. There is a lack of systematic approach/method that can find or arrive at consensus negotiation positions in PPP-BOT projects under uncertainty and risk. To the best of the writer's knowledge, the research in this area is sparse.

1.3.1.2. Uncertainty and Risk Modelling

PPP-BOT project as a long term infrastructure project is exposed to both risk and uncertainty. Risk (randomness characteristic) that refers to probabilistic features is expressed by stochastic models (probability theory and statistical methods) and uncertainty (fuzziness characteristic) that refers to non-probabilistic features is represented by fuzzy sets (possibility theory). Although the existing approaches represent how to overcome the risks, there is a lack of framework and modelling methods that demonstrates how uncertainty can be modelled properly to overcome it. Also, there is a lack of framework and modelling methods that interprets what is the best combination method for risks and uncertainties propagation in the whole model, particularly in simulation and financial model. To the best of the writer's knowledge, the research in this area is sparse especially its application in the research area of PPP-BOT projects.

1.3.1.3. Negotiable Concession Items (NCIs)

In viewing PPP-BOT project through the negotiation perspective, the determination of *negotiable concession items (NCIs)* as well as decision variables from different perspective under uncertainties and risks is important. This enables the management of uncertainty and risk in a structured manner. Furthermore, it helps to answer the commonly asked question which is "how to pursue a win-win-win scenario among the public sector (government), the private sector (concessionaire), and ultimate general public users (end-users)". The research in this area needs more consideration and works to incorporate

group decision making (multi criteria decision making) and uncertainty and risk modelling.

1.3.1.4. Financial Viability Mechanisms

Financial vulnerability is crucial and critical in PPP-BOT project as a long term infrastructure project. PPP-BOT project is exposed to uncertainty and risk especially the catastrophic risk which may leads to project bankruptcy. In order to address this issue, methods, models and tools are needed to move on dynamic situation properly to evaluate financial mechanisms for PPP-BOT project. Further these methods are also required to manage and mitigate the risks and uncertainties involved. Dynamic situation means the changing situation that permits simulation inputs follow either probability distributions (objective parameters) or membership functions (subjective parameters) or even their combination. The significant of the dynamic situation compare to the static situation is relied on taking uncertainties and risks into account for decision making process. The uncertainty and risk's analysis is in such way that simulation outputs reflect any probable and possible scenario for simulation inputs. To the best of the writer's knowledge, few researchers have worked on it.

1.3.2. Research Scope and Objectives

The main aim of this research is to develop an integrated negotiation-based risk management framework as a systematic approach and a corresponding mechanism which is able to manage both risk and uncertainty involved in complex infrastructure development. Another aim is to develop and propose a method to find or arrive at consensus negotiation positions for the main parties involved in the project. By using this mechanism and method, the parties' behaviour in negotiations can be realized and analysed properly. The main

research objective is to develop an integrated risk management methodology which generates and evaluates scenarios in uncertain situations and establishes the solutions that are equilibrium solutions for main parties (e.g., based on the win-win-win strategy for public sector, private sector and end users). To achieve this overall aim and objective, the main sub-objectives are to:

Sub-objective 1: Develop a framework for Negotiation-based risk management in PPP-BOT projects

After developing a conceptual and practical model to enhance the understanding of parties' behaviour in PPP-BOT projects using game theory, a framework and mechanism for negotiation-based risk management in PPP-BOT projects is developed to find superior negotiation positions based on Pareto optimality under uncertainty. This framework and mechanism improve the understanding of the negotiation position of the main parties involved. It also contributes to facilitate analysing the parties' behaviour.

Sub-objective 2: Develop a simulation model under uncertainty and risk for both static and dynamic negotiation scenarios

The main goal in developing this simulation model is to demonstrate mathematical modules to determine optimal *negotiable concession items (NCIs)* and decision variables based on knowledge and experiences under uncertainties and risks. As mentioned, existing methods for risk evaluation mostly employ risk modelling approaches. The proposed method explains the approaches of overcoming the uncertainty and risk. Furthermore, it shows uncertainty and risk combination method in simulation by considering fuzzy randomness. Finally, it estimates the payoff for both public and private sectors under uncertainty and risk.

Sub-objective 3: Use the decision making model under uncertainty and risk to evaluate financial mechanisms for PPP-BOT project in order to manage financial vulnerability of project financial return

Methods and models will be examined and proposed to move on dynamic situations and negotiations properly which is crucial to overcome the financial vulnerability especially under catastrophic risk events. Moreover, the final step is considering Real Options Valuation (ROV) as a mechanism to secure the return for both main parties, particularly the concessionaire.

The results of this research contribute to:

1. Understanding the negotiation positions of both public and private sectors in development phase of PPP-BOT project in order to determine the feasible negotiation space and find the superior equilibrium solutions.
2. Proposing fuzzy randomness simulation to find the optimal negotiable concession items under uncertainties and risks.
3. Proposing and examining the proper mechanisms tailored for PPP-BOT negotiations that could arrive at consensus negotiation positions as equilibrium solutions in the case that no solution is found.

The scope of this research covers the three main areas in development phase of PPP-BOT projects: Negotiation based risk management, equilibrium solutions for main parties involved in the project simultaneously and decision making under uncertainty and risk in development phase of PPP-BOT projects.

It is understood that there is a wide range of uncertainty and risk in PPP-BOT project. From the negotiation perspective, the uncertainty and risk can be

considered as negotiable concession items (NCIs) in development phase and are also incorporated in this study in the form of risk with financial consequence. Detailed analysis on these types of uncertainty and risk in other phases is beyond the scope of this work.

1.4. Research Methodology

The big research problem that this thesis tries to address (deal with) is negotiation problems in development phase. The thesis proposes a mechanism to find or arrive at an equilibrium solution as a strategically stable position. The thesis tries to apply and connect three techniques: Game theory, Simulation, and Real Options Valuation under uncertainty and risk for PPP-BOT projects.

The flowchart shown in Figure 1-5 depicts the research methodology adopted in this study to achieve the research objectives. In the initial stage, different types of research data related to PPP-BOT projects were collected for the subsequent studies. The collected data could be classified into three main categories: academic publication, case studies and project data collected via designed survey, and practice knowledge and experiences obtained through expert interview.

The author visited different parties involved in PPP-BOT projects including the public and private sectors as well as consultant companies. The author also attended coordination meetings between the government and concessionaire to understand the current practice of infrastructure development through PPP-BOT approach as well as to collect project data. Personal interviews were arranged individually with project managers and

experts over two study trips to actual projects site in Iran.

These interviews and visits were required to understand the current gaps in PPP-BOT projects implementation process and to identify potentials for improvement. By presenting the contributions of this research, the author could motivate the public and private sectors to apply the research results in infrastructure development using PPP-BOT approach in Iran.

There are three major parts in this research. In the first part, game theory is used to develop a game model for negotiations in development phase to analyse the parties' behaviour and find superior equilibrium solutions. This model will be extended into uncertain environment, by proposing fuzzy game theory, which will be developed to capture the uncertainty feature of PPP-BOT projects negotiations. It fulfils the first research objective.

The second part is simulation. Long term infrastructure projects projection is subject to change due to both risks and uncertainties. Fuzzy randomness Monte Carlo simulation (FR-MCS) technique is proposed to cater both stochastic and fuzzy input variables. This leads to determine agreeable NCIs under uncertainties and risks. It addresses the second research objective.

The third part is Options and Real Options Valuation and Analysis. A major advantage of real options analysis is over NPV analysis. It highlights an appropriate procedure for analysing financial valuation under uncertainty. Real Options Valuation (ROV) represents a superior tool for capturing managerial flexibility. Also the advantage of Real Options technique is to facilitate and resolve tied negotiations. It meets the third research objective.

The last step will be implementation of the models and concepts developed in previous parts by developing an integrated model. At this step the validation

of models will be verified via real case studies and related projects experiences. Figure 1-4 shows a holistic approach to PPP-BOT negotiations management to find win-win solution. Figure 1-5 represents flow chart of research methodology. The answer to the question “why do we use Game theory, simulation, fuzzy and options?” will be discussed later in each related chapter in detail. Research stages of the proposed mechanism to find or arrive at censuses for PPP-BOT negotiation toward negotiation-based risk management is demonstrated in Figure 1-6.

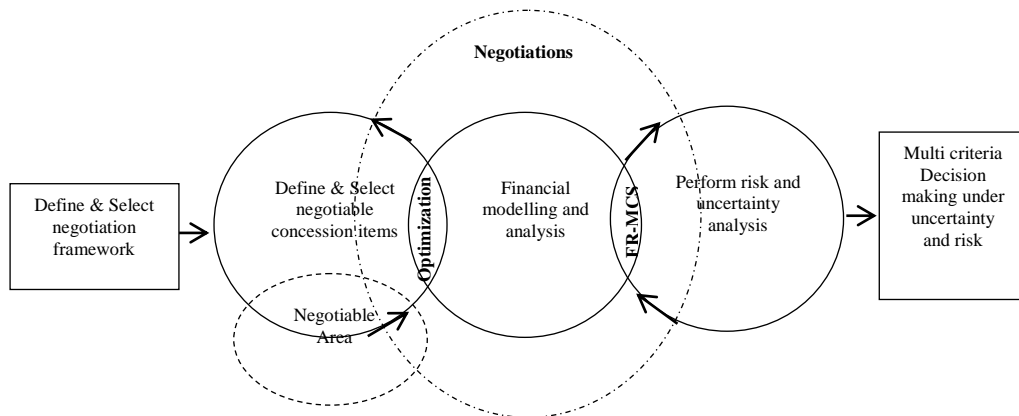


Figure 1-4 A holistic approach to PPP-BOT negotiations management

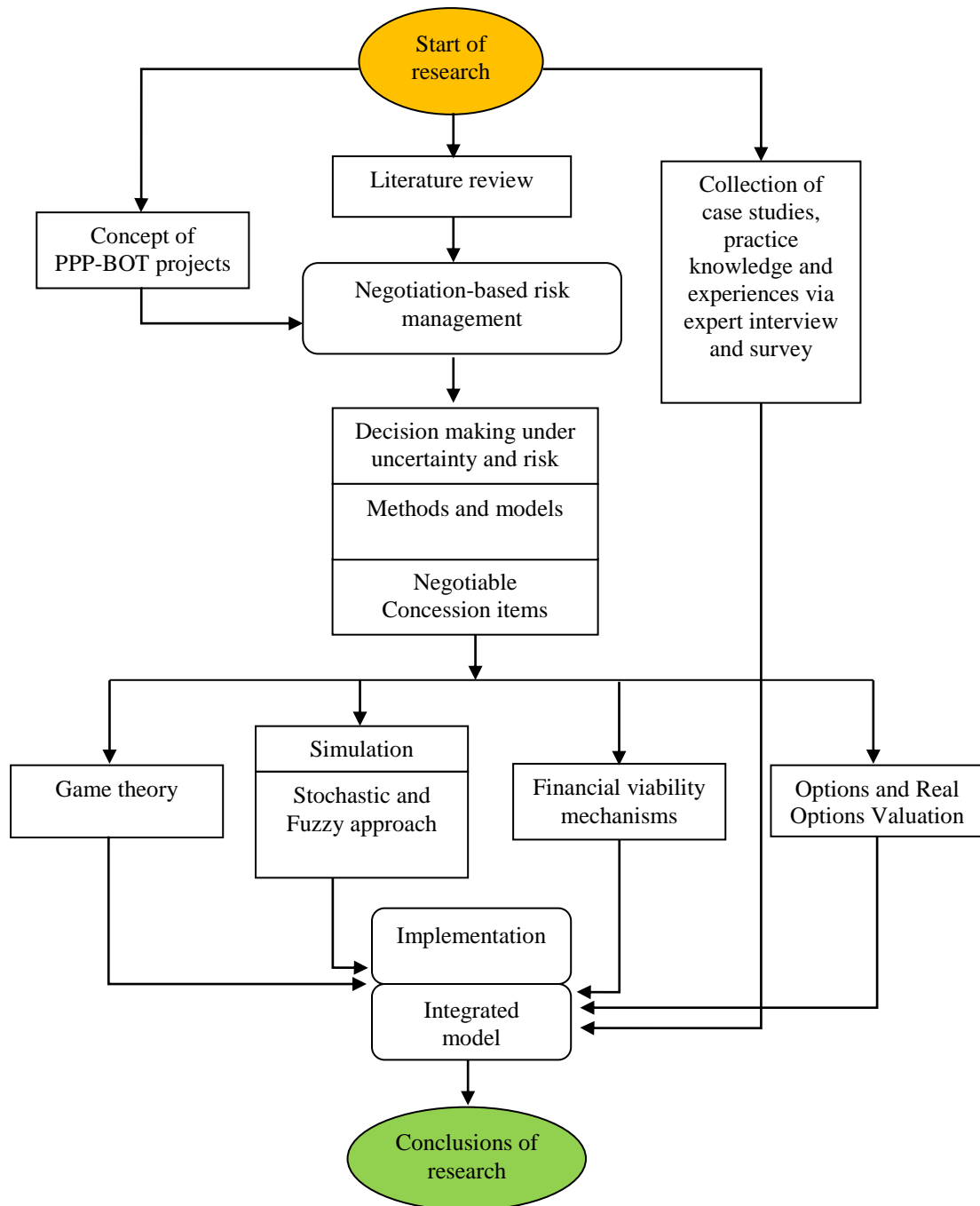


Figure 1-5 Research Methodology Flow Chart

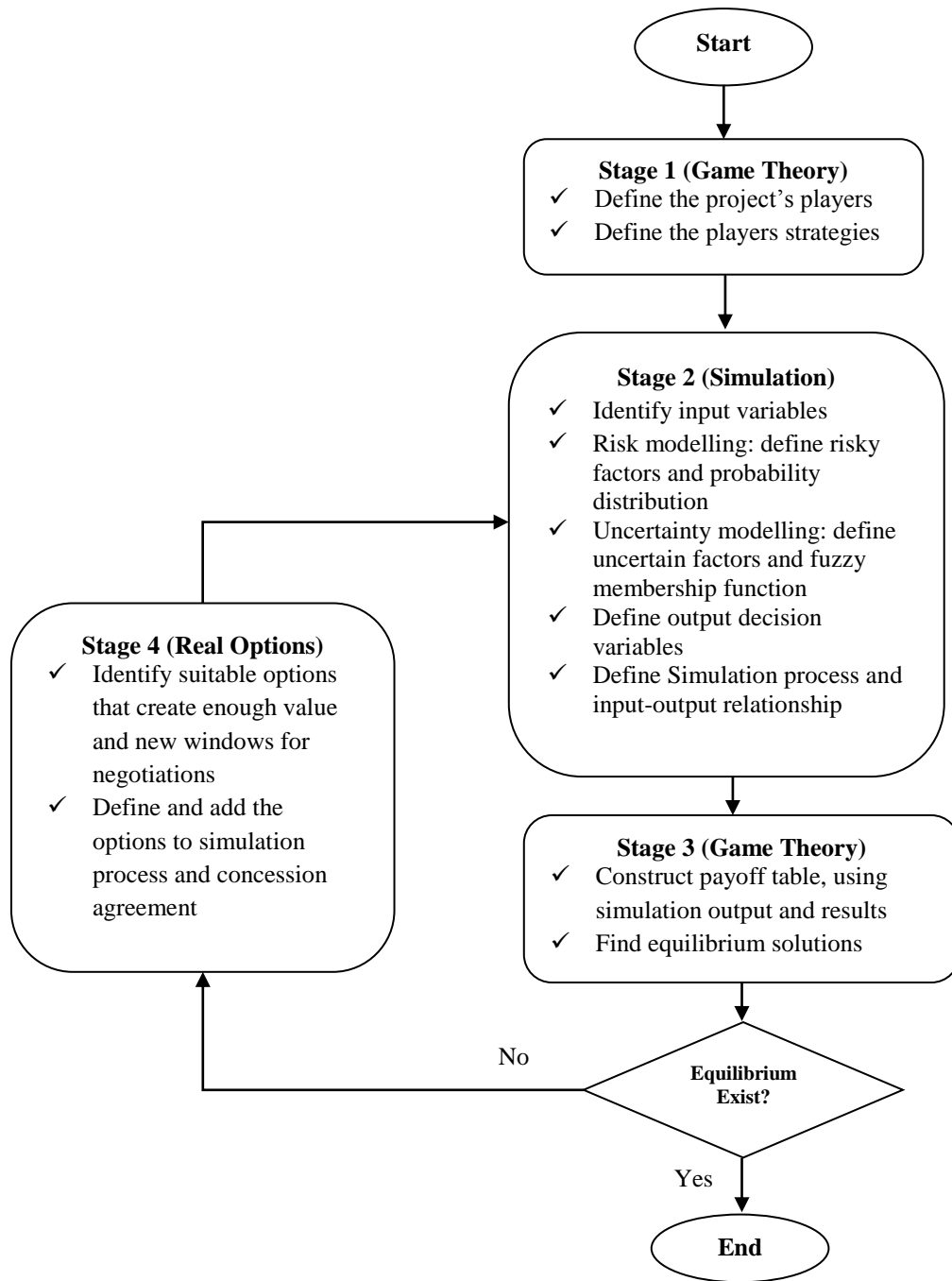


Figure 1-6 Research stages of the proposed mechanism to find or arrive at censuses for PPP-BOT negotiation toward negotiation-based risk management

1.5. Thesis Structure

The dissertation is organized in eight chapters, as shown in thesis outline represented in Figure 1-7. First, the background of the research is introduced in Chapter 1, introduction. This chapter also presents research gaps and

purposes. It ends by the research methodology. Second, the literature review is presented in the next chapter, Chapter 2. Chapter 3 is to develop a game theory model aim to determine the superior negotiation position under uncertainty and risk. The detailed description on fuzzy randomness simulation-based risk management (FR-SRM) and its application in negotiation simulation to determine negotiable concession items (NCIs) are presented in chapters 4 and 5 respectively. Options-based negotiation management is considered in chapter 6. Chapter 7 is the case study. The last chapter, chapter 8, is conclusion and future works. This chapter concludes the research findings and recommends what could be done as further studies. The general structure of this dissertation is shown in following flow chart.

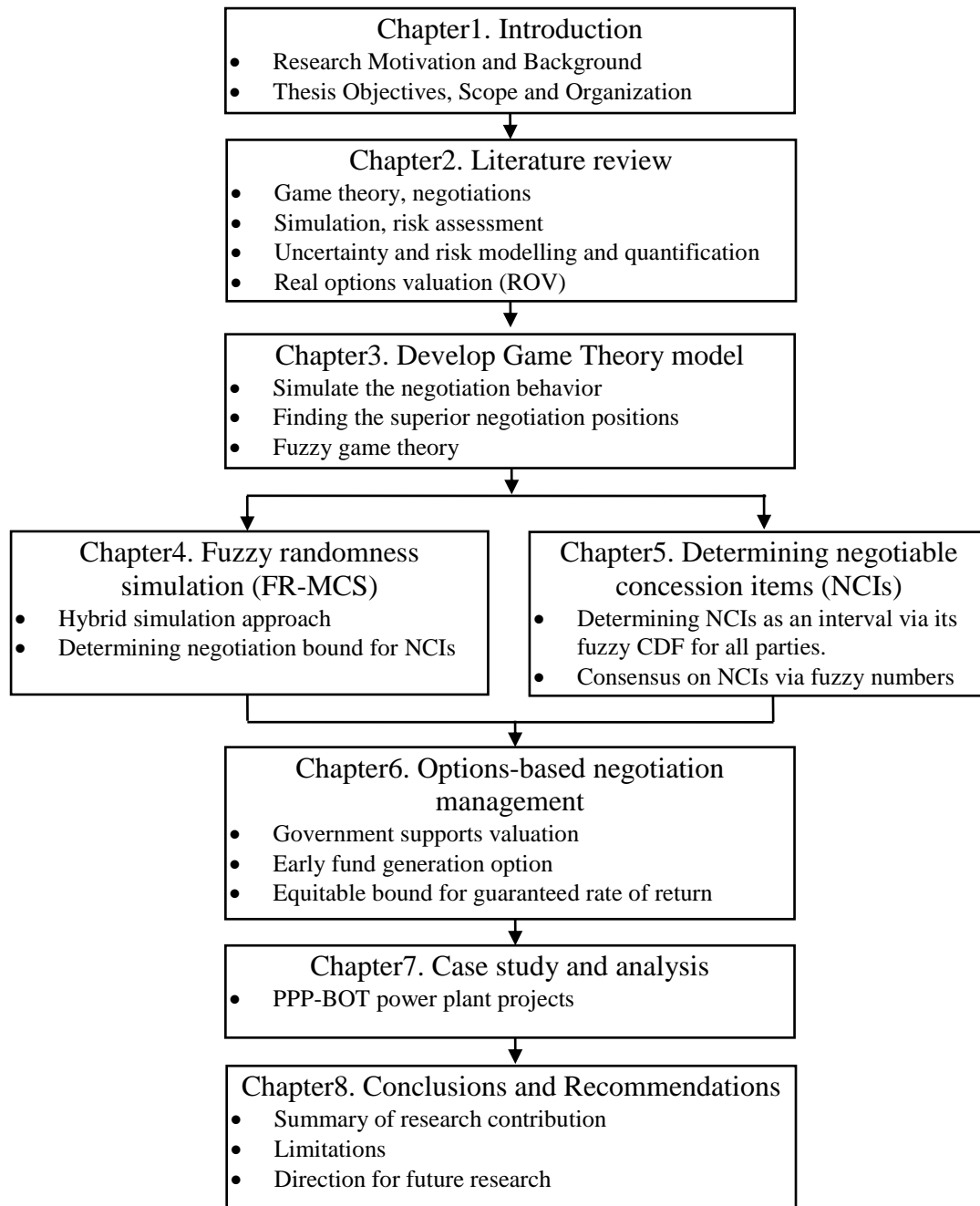


Figure 1-7 Thesis organization

CHAPTER 2 LITERATURE REVIEW

This chapter presents a broad overview of the background relevant literature in order to allow readers to understand underlying concepts employed in PPP-BOT negotiations analysis and risk management methodologies and mitigation mechanisms in the development phase. Furthermore, it helps readers to assess how these methodologies and mechanisms incorporate risk and uncertainty modelling for determining feasible negotiable concession items (NCIs). Future chapters will present more detailed aspects of literature relevant to the content of the chapters.

2.1 General Discussion

Long term infrastructure projects such as PPP-BOT projects are one kind of contract strategy, which has been applied to diverse kind of projects/sectors in different countries with varied level of economic development and different legal systems. This requires researchers to study PPP-BOT project from various perspectives and aspects by use of different methods.

PPP-BOT scheme has captured many researchers' attention recently since this kind of project was introduced in the infrastructure development. A number of scholarly works have studied PPP-BOT project from diverse perspectives. From a research methodologies perspective, some literature reviews the PPP-BOT scheme from an overall standpoint. Some literature highlights special problems. Some researchers utilize case-based research methodologies, by which the complexity and problems of implementing a PPP-BOT project and adopting this strategy are illustrated through case studies. Some use survey-based research methodologies, by which the impact

of different PPP-BOT contract components is evaluated through questionnaires and/or interviews. Occasionally the combination of case-based and survey-based research methods is used. Also some models are developed by some researchers.

In this review, journal papers relevant to PPP-BOT projects published in the following six leading construction management journals within the last two decades were mainly considered: the *ASCE Journal of Construction Engineering and Management (JCEM)*, *Construction Management and Economics (CME)*, *International Journal of Project Management (IJPM)*, *Journal of Management in Engineering (JME)*, *Engineering Construction and Architectural Management (ECAM)*, and *Building Research and Information (BRI)*. Beyond these journal papers, some well-known conference papers and technical reports of Asian Development Bank (ADB) and World Bank (WB) are considered as well (See Table 2-1).

Table 2-1 Number of articles which are related to PPP-BOT studies in the selected journals from 1990 to 2014

Journal title	Number of papers
Journal of Construction Engineering and Management	45
Construction Management and Economics	30
International Journal of Project Management	30
Engineering Construction and Architectural Management	18
Journal of Management in Engineering	8
Building Research and Information	5

According to Tang et al. (2010), there is a growing research interest in PPP-BOT (e.g. there were 15 published papers in 1998 and 1999, while this rose to 34 in the years 2006-07).

Tang et al. (2010) classified the papers of interest under the research methodologies they used. Case study has been mostly used (60 papers),

because it is easier for scholars to draw some implications from real cases than from other research methods. Additionally, survey and literature review ranked second and third with 45 and 35 papers respectively, followed by interview (20 papers). There are also two papers using workshops to get opinions from academic scholars and industry practitioners. Many researchers have attempted to improve the operation of PPP-BOT projects by identifying key aspects of these projects (Tiong, 1996; Erridge and Greer, 2002; Grimsey and Lewis, 2002; Li et al., 2005a, b, c). One of the most important issues in PPP-BOT scheme is to adequately identify, model and anticipate the behaviour of parties involved in the project. This is especially true during the negotiations of the development phase. Consequently, it is necessary to carry out research into these issues. In addition to lessons learned from case studies (James et al., 2005), researchers have suggested the advantages of various aspects of PPPs, which include:

- Understanding and improved partnership between the public sector and the private sector (Erridge and Greer, 2002; Ysa, 2007; Kumaraswamy et al., 2005; Zhang and Kumaraswamy, 2001a, b; Zhang et al., 2002; Zhang, 2004a, b).
- Improved maturation of contract in the development phase (Ho, 2006; Tranfield et al., 2005).
- Proper risk management and allocation (Grimsey and Lewis, 2002; Li et al., 2005a; Shen et al., 2006; Ng and Loosemore, 2006; Wibowo and Mohamed, 2008).

- Appropriate financial viability analysis (Akintoye et al., 2003a,b; Norwood and Mansfield, 1999; Huang and Chou, 2006; Saunders, 1998).
- Clearer government policies and strategies (Hart, 2003; Chen and Subprasom, 2007; Qiu and Wang, 2011).

In the current research, based on the research gaps and purposes discussed in chapter 1, the topics and problems of the PPP-BOT research area that are focused by researchers in the literature review, are categorized and discussed in five main categories: *relationships and partnership, risk management and allocation, financing mechanisms under risk and uncertainty, simulation and concession items optimization (such as concession period), and Real Options Valuation and Analysis*. Various research methodologies have been used to solve research problems of these categories. A detailed review of these categories is presented in the following sections.

2.2 Research on Relationship, Partnership and Negotiation

The relationship between organizations within the public and private sectors is perceived to be crucial to the success of PPP projects because a poor relationship, partnership and negotiation would easily lead to misunderstanding and conflict. Therefore, the existing literature has mainly focused on examining what factors facilitate or inhibit the relationship, partnership and negotiation.

For example, Chan et al. (2003), when conducting an industry-wide survey study, found that “improved relationship and communication amongst project participants” were the most significant benefits obtained from the use of

partnering in PPP projects. Through interviews, Consoli (2006) found that various demands of stakeholders, contractual arrangements, and different philosophical standpoints created friction between the parties involved in PPP project. Apparently, friction is the major course for poor relationship and partnership.

Furthermore, researchers have found that public and private sectors relationships in PPP projects were determined by the nature of relational contracting and relationship management (Erridge and Greer, 2002; Ysa, 2007; Smyth and Edkins, 2007). Through a Malaysian case study, Abdul- Aziz (2001) claimed that once privatization has taken place, re-involvement of the public sector, particularly through the injection of new funds, should be refrained as much as possible because of its lack of expert experience and possible social impact of the project.

Since a fair deal is what project parties should achieve, researchers have studied the success factors of how to create win-win relations by comparing various kinds of PPP-BOT infrastructure development in the United States, the United Kingdom, and China (Wang et al., 1999, 2000 a,b,c; Wang and Tiong, 2000; Zhang et al., 1998; Zhang and Kumaraswamy, 2001b). Their studies were intended to identify the strengths of successful approaches and provide lessons from less successful or abortive projects. In consequence, proper maintenance of relations can be achieved through effective management of political risks, foreign exchange, and revenue risks.

Zhang (2004a, b, 2005a, b) carried out a knowledge-mining process to draw experience and lessons learned from international PPP practices and to refine experiential and expert knowledge underlying the subconscious

decision-making process in the field of project financing. Zhang (2005a) developed five main critical success factors (CSFs) including favourable investment environment, economic viability, and reliable concessionaire consortium with strong technical strength, sound financial package, and appropriate risk allocation via reliable contractual arrangements for a win-win relationship, each of which includes a number of success sub-factors.

Researchers have also related the relationship issue to concessioner selection. For choosing suitable concessioner, researchers have not only suggested benchmarking the 'best' selection practices, but have also emphasized 'innovative' concessioner selection approaches to be used by large public agencies, in which relationship is always regarded as a key criterion (Zhang, 2004a,b; Palaneeswaran and Kumaraswamy, 2000a,b).

Han and Diekmann (2001) discussed current approaches related to entry decisions into international construction markets. They developed a comprehensive approach by adopting the cross-impact analysis (CIA) method. The CIA-Based Go-No-Go Decision Model is proposed to make stable and systematic go/no-go decisions for international and traditional competitive public sector projects, which are either financed by governments or funded by international agencies. They focused on essential risks, current approaches used to make go/no-go decisions and most appropriate approach for risk-based go/no-go decision formalism associated with international construction projects. They highlighted the necessity of finding the primary sources of risks and uncertainties and their resultant impacts on project cash flow and probable cost.

Research shows that the game theory principles have been applied in PPP procurement, particularly during negotiations that immediately precede the concession agreement: pre-contract negotiations. Ho. (2005 and 2006) applied game theory to analyse the information asymmetry problem during the procurement of a BOT project (bid compensation) and its implication in project financing and government policy (Financial renegotiation model). Ho and Liu (2004) developed a game theoretic model for analysing the behavioural dynamics of builders and owners in construction claims. In PPP-BOT projects, conflicts and strategic interactions between public and private parties are common, and thus game theory can be a natural tool to analyse the problems of interest.

Usually, a series of negotiations and renegotiations may arise and come after the award of project, especially in the case that financial risks lead to the project's failure due to revenue shortage or increasing costs, e.g. if an unexpected event causes a decline in revenues or sharp rise in costs. This would hinder the SPV/PC to pay the project debts, operating expenses or dividend payment. In this case, the concession period may be lengthened, user fees may be adjusted upwards, and tax breaks may be given, and so on. In many cases, only one item is negotiated, e.g. lengthening concession period. This simplifies the negotiation, and if adjusting a variable will restore a reasonable return, it is the best way forward. Here, the onus is on the SPV/PC to show that it requires a lengthening of the concession period by x years, and why a certain rate of return to equity is required. To do this, the SPV/PC needs to show how its return on equity is affected by variations in critical variables. Shen et al. (2007) utilized

game theory to find equilibrium solution for negotiation over concession period, one of the most important negotiable concession items (NCIs).

Generally, need to determine when and how the government would rescue a distressed PPP-BOT project. Typically, government agency provide incentives supports, guarantee support and financial and incentives support, to avoid the loss to SPV. Research on rescuing plans and capacity choice, has also been conducted. For instance, Ho (2006) developed a game theory based model, which determines when and how the government would rescue a distressed project and what impacts the government's rescue behaviour on project procurement and management. By establishing an effective rescue model, the government would be able to map out the blueprint for the public, develop policies, and negotiate with the concessionaire (Chang and Chen, 2001).

Javed A.A. et al. (2014) adopted an experimental approach based on game theory to evaluate the effectiveness of different strategies for negotiating changes. A multi-stage bargaining process using the 'z-Tree' software was designed to simulate four change scenarios with three output specification versions encompassing different change management strategies in a computer laboratory. Under each change scenario, pairs of public and private participants negotiated on the sharing of additional costs incurred by changes in the life cycles of fictitious PPP projects based on the different versions of output specification. The time taken to reach settlement or negotiation breakdown was recorded together with the cost-sharing pattern, with feedback collected from the participants on the effectiveness of the specification strategies immediately after the experiment. It was found that a detailed and clear output specification incorporating a cost-sharing framework facilitates change negotiations.

Governmental Debt Guarantees (GDGs) are often used to encourage involvement by promoters and financial institutions in PPP projects. However, even after demonstrating the bankability of a project and reducing debt cost, the success of the project may be prevented by the lack of long-term commitment from shareholders. Equity contributions by promoters in the project company may be recovered from earnings on short-term construction activities. Based on lesson learned from early PPP projects with GDG, the hold-up problem for government in the view of transaction cost economic (TCE) theory may worsen if the designed contractual structure does not adequately manage opportunistic behaviours from promoters. Tserng et al. (2014) empirically examined the effects of a structured GDG mechanism with particular complementary measures applied in joint projects to develop the Taipei mass rapid transit (MRT) stations. A GDG game model was then applied to bridge the theoretical gap based on the Taipei MRT experience. The analysis shows that requiring the promoter to provide sufficient equity and ensuring the commitment of the lender to provide the loan are the appropriate proactive measures. This study demonstrates its practical value for policy makers by combining case study, TCE and game theory in contractual issues.

Recognizing and understanding the use of game theory when applied to PPP-BOT enables decision makers to reduce costs, reduce potential losses and mitigate the risks of the conflicts involved in a project. Two main aspects are ignored in the use of game theory when applied to PPP-BOT. They are finding the superior negotiation positions based on Pareto optimality and considering the PPP negotiations as a game under uncertainty and risk by utilizing fuzzy

game theory. These two aspects as research gaps are the concern of current research.

2.3 Research on Risk Management and Allocation

Because a PPP-BOT is a long-term arrangement of risks transfer that traditionally borne by the public sector to the private sector, proper risk identification and allocation is a key to successful PPP project implementation. This argument signifies the pivotal role played of optimal risk allocation. Risk taking by private sector is financially compensated for the willingness to bear the risks (Wibowo and Mohamed, 2008).

Risk management and allocation in PPP-BOT projects is fundamentally different to that in traditional projects. Research on risks (Shen et al., 2006; Akintoye et al., 1998; Li and Tiong, 1999; Yeo and Tiong, 2000; Zayed and Chang, 2002; Lam and Chow, 1999; Abednego and Ogunlana, 2006; Thomas et al., 2006) is of help to explore the appropriate ways for managing and allocating important and significant risks and its process associated with life cycle PPP-BOT projects. According to their studies, risks in PPP-BOT can be clustered according to the conventional risk management process: risk identification, risk analysis, and risk allocation and mitigation strategies. This process is stated and followed unanimously by most researchers (Zhang and Zou, 2007; Singh and Kalidindi, 2006; Day and Ogunlana, 2002; Songer et al. 1997; Imbeah and Guikema, 2009; Wibowo and Kochendorfer, 2005; Grimsey and Lewis, 2002; Ng and Loosemore, 2006). To improve the use of risk mitigation strategies, risks need to be identified and analysed properly and correctly.

Research has been carried out to identify the key risks, and to study how government agencies, promoters and financial institutions perceive risks. For example, previous studies have used questionnaires to collect data for identifying the key risks in PPP-BOT projects, such as political risks, financial risks, revenue risks, market risks, promoting risks, procurement risks, development risks, construction completion risks, and operating risks (Akintoye et al., 1998; Zayed and Chang, 2002). Chan et al. (1997) identified and categorized risks in BOT projects and proposed solutions for each risk category. Schaufelberger and Wipadapisut (2003), through a study of 13 cases, further found that project risks, project conditions, and availability of financing were the major considerations in selecting a financing strategy. The project risks that were argued to be most significant in financing strategy selection were political, financial, and market risks. Shen et al. (2006) used the case study of Hong Kong Disneyland theme park to analyse the risks affecting project performance. They grouped the important risks into the following 13 categories: site acquisition, unexpected underground conditions, pollution to the land and surroundings, land reclamation, development, design and construction, changes in market conditions, inexperienced private partner, financial, operational, industrial action, legal and policy, and force majeure. Moreover, these risk categories were further divided into three main factor groups: internal, project specific, and external.

Ng and Loosemore (2006) classified the risk in PPP projects in two main groups: general risks and project risks. Managing both general and project risks are equally important. For evidence on this issue, the reader may refer to some PPP project cases. For instance, the 2000 MW Dabhol Power Plant in

India was ordered to stop by new government in 1995 (Zhang, 2005), an incident in China on 1989 resulted in the syndication of loans for new super highway to be delayed till 1991 (Dehdashtian, 2007) and; a 45 km BOT toll road in Shenzhen was delayed because the consortium and government could not agree on appropriate toll charges (Chan et al., 1997). In other examples of poorly managed general risks, the USB\$ 2.5 Malaysia N-S highway suffered a 75% cost overrun largely due to inadequate allowances being made for inflation (Ng and Loosemore, 2006). Furthermore, in 1970s, the Spanish government guaranteed 75% of the loans on its new highway network and assumed the full exchange rate risk. This decision incurred US\$2.7 billion cost to Spanish taxpayers. To mitigate these risks, governments often guarantee exchange rate and undertake to compensate the SPV if income fell below a certain level (Ng and Loosemore, 2006).

Chan et al. (2014) identified and evaluated typical risks associated with PPP projects in the Chinese water supply sector. A literature review, a Delphi survey, and face-to-face interviews were used to achieve these objectives. Finally, a register of 16 critical risk factors (CRFs) of water PPP projects in China was established. The findings revealed that completion risk, inflation, and price change risk have a higher impact on Chinese water PPP projects, whereas government corruption, an imperfect law and supervision system, and a change in market demand have a lower impact on the water supply sector. The findings can help project stakeholders to improve the efficiency of privatization in public utility service and provide private investors with a better understanding while they participate in the enormous Chinese water market through the PPP mode.

Successful implementation of BOT infrastructure projects is dependent on a full and thorough analysis of factors that include social, economic and political, amongst others. Alongside the financially focused evaluations, qualitative factors will also have a strong impact on the project and so require specific techniques for the analysis. Fahad et al. (2014) presented a new evaluation framework, based on the analytical hierarchy process technique, for use in assessing the most common and significant decision factors relating to risks in BOT projects. Consultations with an expert group identified a series of risk decision factors. The results produced twenty-eight critical Risk Factors, which have a particular impact on the risks of BOT projects. The project risk framework was constructed by classifying the factors into five categories. The framework was successfully validated using a BOT project case study. This research seeks to make a valuable contribution to the field by having developed and validated a new risk evaluation framework, focused on BOT projects in Kuwait.

The longer the contract period, the higher the chance that major changes will arise. Thus a greater reliance on the established relationships is needed to maintain the contractual bond in PPP project. Relationship management (RM) can therefore be expected to be even more valuable in the PPP context. Zoua et al. (2014) investigated current perceptions and experiences of RM in PPP projects and more importantly, to identify the CSFs for RM in PPP projects. By means of an empirical questionnaire survey geared towards PPP practitioners with direct hands-on experience, the opinions were solicited, analysed and compared in relation to potential PPP RM success factors. The survey findings indicate that industry practitioners currently lack a general

understanding of concepts and applications of RM, given that it is relatively new in PPP. However, they do think that RM is very important to improve the present performance of PPPs. Future PPP business opportunities can also be increased by effective RM. The top four CSFs for RM are found to be commitment of senior executives, defining the objectives, integration of the different divisions and a multidisciplinary team. However, the relative importance presently assigned for each of the above factors is insufficient, and commitment from senior management is perceived as the most difficult factor to improve.

On the other hand, there are studies about the effective risk management, risk allocation and mitigation strategies in PPP-BOT scheme (Li and Tiong, 1999; Li et al., 1999; Yeo and Tiong, 2000). The findings of these studies showed the idea that the most critical risk factors are the financial aspects of joint ventures, government policies, economic conditions, and project relationship.

Risk management is critical for success in project-based construction industry. In current literature, various risk-based decision support systems have been proposed to systematically identify and assess risks. However, majority of these systems use the risk ratings assigned by the decision-makers, mainly, probability and impact ratings, as input values and quantify the level of risk associated with the project based on these inputs. However, in majority of the cases, these ratings are assigned based on the subjective judgment of the decision-makers and highly depend on their level of knowledge, risk attitude and assumptions. Yildiza et al. (2014) attempted to explore the process of assignment of risk ratings by the decision makers and question how the

reliability of the risk assessment process can be enhanced in practice. In this effort, a risk mapping tool that has been developed by the authors is used to conduct a case study that explains how the risk ratings are defined by different decision-makers and identify the reasons of possible divergence between assigned ratings. In this regard, a case study is conducted with three construction experts by using data of a real construction project and risk assessment exercise has been repeated using different strategies to collect expert opinion on risk ratings. The results of the case study show that although the subjectivity of ratings and sensitivity to risk attitude cannot be totally overcome, some strategies may be used to ensure a more reliable risk rating process. Those strategies mainly cover minimization of divergence of assumptions made by the decision-makers, clarifying what is included under the identified risk factors by defining sub-risk attributes and facilitating group decision-making.

PPP procurement was introduced into Singapore in 2003, and 10 PPP projects were successfully completed and have been in operation. Hwang et al. (2013) examined the critical success factors as well as the relative importance of positive and negative factors influencing the attractiveness of PPP projects in Singapore, and to identify the critical risk factors and preferred risk allocations for PPP projects in Singapore. The questionnaire survey results indicated that negative factors were more affirmative than the positive factors, and that 23 risk factors had significant criticalities. Eight risks would be preferably allocated to the public sector while 19 risks could be assigned to the private sector. 11 risks were preferred to be shared by both parties and the allocation of four risks depended on project circumstances. The findings of

this study provide valuable information for organizations that intend to participate in PPP projects in Singapore.

Ebrahimnejad et al. (2010) identified common risks in BOT projects, and then they defined the problem in fuzzy multi attribute decision making (FMADM) field. They introduced effective criteria for evaluating risks, and presented a fuzzy multiple criteria decision-making (FMCDM) model for risk assessment. The aim of the FMADM is to obtain the optimum alternative that has the highest degree of satisfaction for all of the relevant attributes.

Governments are major players in promoting green developments, with private finance being an ideal environment in which such promotion can take place. The financial collaboration between governments and the private sector through PPP can promote a widespread implementation of green initiatives. Two reasons make this possible. First, in order to respond to the growing green awareness, governments have a great leverage on how green investments can be developed by the private party while enjoying steady revenues and good services for the public. Second, the international community is promoting green growth in developing countries through PPP investments, and so PPP can play a major role in widespread green growth. Almarria and Blackwellb (2014) focused on improving the chances of success with PPP contracts, since more successful projects will lead to improved welfare and will improve the chances for greening the community. The study concluded with two recommendations to improve the success of PPP; the first one was to reconsider the design of PPP contracts to include a hybrid structure that allows for a put and call options with a very controlled renegotiation clause. The second was to improve the risk simulation approach to improve the investment appraisal process through improving the

type and quality of input variables, in addition to the creation of cost and events charters of all completed projects.

Songer et al. (1997) studied risk analysis for revenue dependent infrastructure projects e.g. PPP-BOT project. They utilized Monte Carlo simulation (MCS) for risk modelling in a case study.

Apart from risks that were studied in general terms, risks that affected individual project stages were also studied by researchers. For example, the effect of financial risks in BOT projects on different phases of procurement was investigated in a survey (Lam and Chow, 1999). Results suggest that “interest rate fluctuation” was the most significant financial risk in the pre-investment phase, while ‘currency exchange restrictions’ was moderately significant in the operational phase. With respect to practical applications, the above mentioned key risks should be studied carefully and corresponding contingency strategies should be developed when one intends to run a PPP-BOT project.

Researchers have also investigated the risk mitigation strategies adopted by the public and private sectors. For instance, Li et al. (2005c) conducted a questionnaire survey about risk allocation preferences in UK PPP projects. They found that risks could be distinguished by whether they should be retained by the public sector or shared with the private sector. As research finding, they further suggested that in PPP projects, site availability and political risks should be retained by the public sector partner, while relationship risks, legislation and regulation changes risks and the force majeure risks should be shared by both parties.

Some researchers focus more on risk management. For instance, Day and Ogunlana (2002) and Thomas et al. (2006) studied application of risk management tools and techniques in BOT projects through reviews of relevant literatures and developed a model for selecting risk management process for BOT projects. They established an outline for systematic risk management in BOT project. Table 2-2 summarizes the current state of knowledge in the area of risk management tools and techniques (RMTTs) for PPP-BOT projects.

Table 2-2 A summary of previous studies on risk management tools and techniques (RMTTs) for PPP-BOT projects

Method/ tool/theory	Keynotes	Previous study and application	
		Who and when	Topic/model name
Decision analysis	Impact assessment Systematic approach	Levitt et al. (1980)	Incorporate risk perceptions
		Yeo and Tiong (2000)	Positive management of differences for risk reduction
		Wang et al. (2004)	Qualitative risk mitigation
Influence diagram	Risk identification Brain storming and Delphi technique Relationship of variables Subjective expert opinion	Ashley and Bonner (1987)	Identification of political risks in international project
		Diekmann et al. (1996)	Political risks identification and cost assessment
		Jeljeli and Russell (1995)	Impact assessment on project cash flow elements
		Yingsutthipun (1998)	Liability assessment model
			Cost risk analysis
			External risk modelling
Bayesian probability technique and utility theory	Allocating risk		Identification of risks in transportation project in Thailand
		Ibbs and Crandall (1982)	Demand risk allocation in PPP project
		Li and Ren (2009)	Decision model for risky investment
		Imbeah and Guikema (2009)	Advanced programmatic risk analysis and management model
		Jin (2010)	Efficient risk allocation
		Farajian and Cui (2011)	Multi-Attribute utility theory
PERT	Distribution form variables' correlation Network scheduling	Hatush and Skitmore (1997)	Contractor's performance estimate for contractual purpose
		Dey and Ogunlana (2001)	Project time risk analysis through simulation
Sensitivity analysis	Deterministic variables' correlation	Yeo (1990)	Probabilistic element in sensitivity analysis for cost estimate
		Yeo (1991)	Survey on use of sensitivity analysis in UK BOT project
		Woodward (1995)	Scenario analysis and decision options evaluation
MCDM	Multi-objective Subjectivity	Han and Diekmann (2001)	Scenario analysis and decision options evaluation
		Moselhi and Deb (1993)	Project alternative selection under risk
		Dozzi et al. (1996)	Bid mark-up decision making
		Wang et al. (2000)	Evaluation and management of political risks in China's BOT project

		Ahadzi and Bowles (2004)	Relative significant of public and private attributes
		Chen and Subprasom (2007)	Demand uncertainty of BOT toll roads
		Ebrahimnejad et al. (2010)	Fuzzy multi attribute decision making
		Afshar and Fathi (2009)	Fuzzy multi-objective optimization
		Kvaraciejiene et al. (2010)	Multi-Attribute utility theory
		Farajian and Cui (2011)	
AHP	Systematic approach to incorporate both subjective and objective inputs	Mustafa and Al-Bahar (1991)	Risk analysis for international construction project
		Dey et al. (1994)	Assessment of project risks during the bidding stage
		Zhi (1995)	Risk analysis for contingency allocation
		Nadeem (1998)	Risk analysis for overseas construction project
	Consistency of judgment	Yun and Wei (2008)	Risk analysis for BOT project in Pakistan
	Hierarchal structural model	Hastak and Shaked (2000)	
			Appraisement of BOT risks and risks allocation
			Risk assessment for international projects
			Structured approach for evaluating risk indicators
Fuzzy set approach (FSA)	Vagueness of subjective judgment	Kangari and Riggs (1989)	Risk assessment by linguistic analysis
	Input subjectivity	Kangari and Boyer (1989)	Risk identification, allocation, evaluation, mitigation
	Risk break down structure	Diekmann (1992)	Combination of influence diagram with fuzzy set theory approach
	Linguistic environment	Loterapong and Moselhi (1996)	Network scheduling by fuzzy set approach
		Peak et al. (1993)	Risk modelling, estimation and allocation models
		Tah and Carr (2000)	Bid mark-up for construction risk
		Shaheen et al. (2007)	Risk pricing in construction project through fuzzy set approach
		Ebrahimnejad et al. (2008)	Fuzzy risk evaluation in Iranian power plant industry
		Jin and Doloi (2009)	Assessment of construction project risks
		KarimiAzari et al. (2011)	Balanced risk allocation
		Nieto-Morote and Ruz-Vila (2011)	Cost overrun risk assessment
		Chen et al. (2011)	Risk evaluation
		Ebrat and Ghodsi (2011)	
		Khanzadi et al. (2012)	
Neural network approach (NNA)	Implicit relationship of variables	Jablonowski (1994)	Loss assessment model
		Chua et al. (1997)	Development of budget performance model
		Boussabaine and Kaka (1998)	Cost flow prediction in construction project
Decision tree and Event tree	Expected value	Haimes et al. (1990)	Multi-objective decision tree
	Expedience	Ezell et al. (2000)	Infrastructure risk analysis model

Fault tree analysis	probability Accident analysis Safety management Reliability graph analysis	Tulsiani et al. (1990) Tsai et al. (1999)	Risk evaluator Evaluation of project life cycle risks
Risk checklist	From experiences	Perry and Hayes (1985)	Risk and its management in construction project
Risk mapping	Two dimensionality of risk	Williams (1996)	Two dimensionality of project risk
Cause/effect diagram	Risk identification	Dey (1997)	Symbiosis of organizational reengineering and project risk management for effective implementation of projects
Delphi technique	Subjectivity	Dey (1997)	Symbiosis of organizational reengineering and project risk management for effective implementation of projects
Combined AHP and decision tree	Probability, severity and expected monetary value	Dey (2001)	Decision support system for risk management
Monte Carlo Simulation (MSC)	Distribution form variables' correlation	Chau (1995) Songer et al. (1997) Wall (1997)	Distribution form for cost estimate Debt cover ratio (project cash flow) in a toll way project Distribution form and correlation between variables in building costs
	Value-at-risk	Winter (1999)	Liability assessment model for project disputes
	Variance and stochastic model	Ye and Tiong (2000) Ozdoganm and Birgonul (2000) Chiara and Garvin (2008) Sung and Kuo (2010) Kokkaew and Chiara (2010) Bagui and Ghosh (2011) Bagui and Ghosh (2012)	Evaluation of investment decision in infrastructure project (NPV-at-Risk, measure of minimum expected return at given confidence level) Effective risk mitigation and sharing strategies Financial risk analysis Completion risk modelling of BOT highway project Project investment evaluation under risks
Fuzzy randomness	Risk and uncertainty modelling, combined propagation and analysis, Fuzzy logic	Moller and Beer (2008) Sadeghi et al. (2010) Attarzadeh (2014) (this dissertation)	Non-traditional uncertainty models for engineering computation Non-probabilistic uncertainty modelling Fuzzy Monte Carlo Simulation (FMCS) Fuzzy randomness Monte Carlo Simulation (FR-MCS), risk and uncertainty assessment. Mixed probabilistic/non-probabilistic uncertainty modelling and analysis for PPP projects Fuzzy cumulative distribution function (CDF) Evaluation of investment decision in infrastructure project (IND-at-Risk & Uncertainty, measure of minimum expected return at given confidence and uncertain levels)

Tiong (1990) analysed the risks and securities involved in BOT projects and suggested what kinds of guarantees and incentives the government should provide in order to make a project more attractive. In later years he further addressed problems related to the PPP-BOT scheme, for example, critical success factors in winning BOT contracts from the promoter's stand (Tiong et al., 1992), and the conditions for successful privately initiated infrastructure (Keong et al., 1997).

Risks are always an active research topic for PPP projects. Thomas et al. (2006) proposed a risk probability and impact assessment framework based on fuzzy-fault tree and the Delphi method. The framework included extensive scenario modelling of critical risks in projects and systematic processing of professional judgment of experts. On the other hand, Zhang and Zou (2007) developed a fuzzy analytical hierarchy process model for the appraisal of the risk environment pertaining to the joint venture projects. Eaton et al. (2006) developed a theoretical model for the construction industry, which specifies the potential stimulants and impediments to creative behaviour in PPP projects.

Effective risk allocation between the parties is vital for the success of a BOT project. The complexity of financial and organization structure in a BOT project, makes decision-making problem, particularly related to risk allocation, more complicated. Ozdoganm and Birgonul (2000) proposed a decision support framework which helps the project company to check project viability against some predefined critical success factors, define the risk sharing scenarios under which a project becomes viable, incorporate risks into cash flow analysis and, finally, define effective risk mitigation strategies.

Consequently as can be inferred from the above discussion about the risk, the most important part of risk management process is risk allocation which is also the most important goal of negotiations and renegotiations. Although there is a good understanding of the risks associated with PPP-BOT projects, what is less known is how these risks allocate to parties in the negotiations at development phase.

While there have been some attempts to broadly define risk allocation and its profiles over the duration of a PPP project, such model remain rudimentary making it difficult and a main challenge to produce an overall risk allocation structure with mechanisms which coordinates main parties involved in all stages of a PPP project, especially for negotiations in development phase. Project risks should be allocated to the best competent party that bears it with lower cost through proper contractual arrangements or through government support. This support can be a kind of compensation and reward system as incentive method to increase private sectors' motivation. Subsequently a low toll/tariff for end-user is realized. Eventually the lowest project life cycle cost and best value for money (VFM) are achieved. These are the main concerns of this research and are addressed and considered in later sections. Moreover, uncertainty modelling has received less attention than risk modelling and few existing case study mainly rely on it. The application of PPP-BOT projects is considered from the viewpoints of the major project participants and parties involved.

In the previous works, the uncertainties affecting PPP-BOT projects are not properly considered. In the literature, probabilistic modelling of uncertainty is well established for risk modelling (Kalos and Whitlock, 1986;

Ahuja et al., 1994; Mun J., 2006; Vose, 1996 and 2008). However, the use of probability theory is not a reasonable approach to model the uncertainty.

Most researchers attempt to eliminate or transform one type of uncertainty to another before performing a simulation. Wonneberger et al. (1995) and Dubois et al. (2004) presented a possibility to probability transformation. Since fuzzy logic and probability theory reflect different types of uncertainty, conceptually this transformation is not acceptable (Pedrycz and Gomide, 1998).

Guyonnet et al. (2003) and Baudrit et al. (2005) proposed a hybrid approach for addressing uncertainty in risk assessment without transforming one type to another which is recently critiqued by Sadeghi et al. (2010). There are three main shortcomings on Guyonnet et al. (2003) and Baudrit et al. (2005)'s approaches. Firstly, the α -cuts of a fuzzy set cannot always be represented by Inf and Sup values. Secondly, they do not mention why a 5% probability of getting lower and higher values of the histograms of the α -cuts will generate the Inf and Sup of the output α -cut. Thirdly, if only random inputs are considered as the extreme case for this model, the result will not be similar to the traditional MCS approach (Sadeghi et al., 2010).

Alternatively Sadeghi et al. (2010) proposed a method for dealing with both fuzzy and probabilistic uncertainty in the input of a simulation model. However, it is not also free from limitations and shortcomings. A cautious study exposes some features of the approach that need further modification and improvement. Firstly, they didn't provide any method for fuzzy random generation to produce appropriate sample sets. Secondly, they have used the probability-possibility transformation method to transform some of the

probability distributions in the simulation input into fuzzy sets. Thirdly, they perform fuzzy arithmetic to calculate the output in the form of fuzzy set. Fuzzy arithmetic implementation is not easy and straightforward for a complex simulation such as a PPP-BOT project.

Since, our goal is not to convert probability density functions into membership functions or vice versa or to use one in place of the other, no proper direct numerical comparisons for the calculated risk estimates are provided, nor one should attempt to provide such a comparison due to inherent differences in the definition, meaning and treatment of the uncertainty as utilized in each method.

This study contributes to the establishment of a framework for systematic risk and uncertainty modelling and management in PPP-BOT projects, particularly in negotiations between parties involved. Furthermore, this research proposes to utilize hybrid simulation model, fuzzy randomness, to analyse the risk allocation arrangements of critical risks and uncertainties.

2.4 Research on Financing Mechanisms under Risk and Uncertainty

PPP-BOT projects are characterized by high capital outlays, long lead times, and long operation periods, which make the forecast of cash flows more difficult and expose participants to high level of financial risk and uncertainty. Financing plays an important role in PPPs. Studies that focused on model development addressed different financing issues.

Schaufelberger and Wipadapisut (2003) found that availability of financing influenced greatly the selection of a favourable financing strategy. Such a strategy can support participation from the private sector.

Tiong (1995c) carried out two questionnaire surveys in order to identify the threshold equity level in BOT tenders. One issue is “Evaluation of Proposals for BOT Projects” targeted at the government officials and their financial advisers. The other is “Experience in Tendering BOT Projects” targeted at project promoters and their financial and technical advisers. The surveys show that both governments and promoters shared similar opinions that high equity level, typically between 20% and 30%, is important and necessary.

Bakatjan et al. (2003) used a simplified model to determine the optimum equity level for decision makers at the evaluation stage of a BOT project. This model combines a financial model and a linear programming model to maximize the return of the project from the equity holder’s point of view.

The equity structure is of essence in a PPP-BOT project because it implies risk and profit sharing. Thus it must provide a mechanism of private incentive and public interest protection simultaneously. PPP-BOT project may not be fully self-financed through toll/tariff or other operating revenues from end-users for PPP-BOT market-led projects or from concession agreement for PPP-BOT contract-led projects due to insufficient revenue streams. Generally the reason of insufficient revenue streams is uncertainty included in expected cost/revenue estimation models and also long-term predictions involved. Sharma and Cui (2009) presented a structure approach for determining equity investment in PPP projects to reach the optimal equity structure.

Typically, PPP projects must repay any debt obligations through their own net operating income, and do not provide the lenders with any other collateral (off-balance-sheet financing). So, the possibility of costly bankruptcy becomes

much more likely. Dias and Ioannou (1995) have proposed a desirability model in the form of a multivariate evaluation model to examine the attractiveness of an infrastructure project. The model shows that the amount of debt a project can accommodate (its debt capacity) is less than 100% debt financing. The amount of debt that maximizes the investors' return on equity is less than the project's debt capacity, and the amount of debt that maximizes the project's net present value is even smaller.

Esty (1999) described value equity methods for project finance investment and proposed improved techniques for valuing large scale projects. It has been shown that Monte Carlo simulation can be used to analyse cash flow uncertainty. Furthermore, Real Options analysis as valuation tool which can supplement discounted cash flow (DCF) analysis for valuing large scale projects is discussed by Esty (1999).

A simplified model for total project cost is developed by Ranasinghe (1996) which can be used for the following purposes. Firstly, to estimate the total project cost from the estimated cash flows. Secondly, to check the accuracy of the project cost estimates in feasibility studies that require careful decisions.

Researchers have also studied the return and the value of PPP projects. For instance, Akintoye et al. (2003a, b) reviewed the literature and used qualitative analysis to examine factors that could continue to challenge the achievement of best value. They found that among others, the high cost of the PPP procurement process especially in development phase is a key factor, which is a burden on the PPP project effective implementation, and thus leads to a reduction in the private sector willingness to participate.

Zhang (2006a, b) argued that there is a need for establishing the best-value objective dimensions for innovative project delivery models. These models could offer the best value to the public sector. The models could also support the partnership between public and private sectors in continuously enhancing the best value through long-term contractual arrangements. Then, a methodology was developed for capital structure optimization and financial viability analysis that reflected the characteristics of project financing, incorporated simulation and financial engineering techniques, and aimed for win-win results for both public and private sectors (Zhang, 2005d, e).

Researchers have attempted to study the financial viability of PPP projects. For example, Ho and Liu (2002) used an option pricing-based model for evaluating the financial viability of a privatized infrastructure project. This quantitative model takes the views of the project promoter and the government into account to estimate when the project is at risk from bankruptcy.

Subprasom and Chen (2007) discussed the method of modelling and analysis of highway pricing and capacity choice of a BOT scheme. It was found that the combination of toll charge and roadway capacity regulation performed the best in terms of social welfare increment. Yet, in PPP highway projects, the regulation may cause a financial pressure against the private investors to operate a project. The government, therefore, may need to subsidize the private investors in order to make their participation financially viable.

Some researchers focus more on financial evaluation aspects. For instance, Ye and Tiong (2000a, b) studied capital investment decision making methods that can take risks into account and developed a new project evaluation method called the NPV-at-risk and attempts to show that this proposed NPV-

at-risk method can provide a better decision for risk evaluation of, and investment in, privately financed infrastructure projects and can potentially overcome these problems.

Moreover, Yongjian et al. (2008) present a comprehensive literature review that examines international practices. An equitable financial evaluation method was then developed taking into account the inherent characteristics of PPP projects using six separate indicators and the Monte Carlo simulations. After an overview of the current financial and investment evaluation methods, they discussed the selection of indicators based on the government's, lenders' and sponsors' perspectives.

Economic modelling and risk analysis are important processes for the appraisal of infrastructure and revenue-generating projects such as BOT projects. These processes have been commonly implemented using spreadsheets in which the analyst would build several models to analyse a project under varying conditions and risk assumptions. For better efficiencies in building economic structures and evaluation of projects, Abdel Aziz and Russell (2006) defined classifications of estimating and cash flow methods, and developed a generalized model. The presented model explained some concepts used in building a generalized economic model for project evaluation and risk analysis. The model has a hierarchical network-based continuous model structure that integrates the properties and estimating methods of common infrastructure project phases.

Malini (1999) developed a simulation model that permits the examination of financial viability of a BOT transport infrastructure project, as affected by various options relating to the toll structure, toll revision schedule, extent of the municipal grant, and duration of concession period.

Conventional methods in investment decisions include payback period (PP), internal rate of return (IRR), and net present value (NPV). While each method has specific advantages to different types of projects, all ignore the fact that the cash flows over the project life are varied rather than fixed. Consequently, they are not able to provide the decision makers with information on risk exposure involved, which is also as important as returns. Sung and Kuo (2010), adopted the concept of value-at-risk (VaR) to evaluate the level of significant risk in BOT project. With the help of Monte Carlo simulation as well as considering correlation among risks, decision makers are able to see a clear picture of risk involved in a BOT project and make better decisions.

There are several risks in a BOT project. Major critical risks are total project cost and revenue, toll/tariff and demand (e.g. traffic for toll roads). Bagui and Ghosh (2011) presented a sensitivity analysis for a BOT project with real case study varying equity from 10% to 90%. Traffic and cost are varied $\pm 20\%$ and financial analysis is carried out with spread sheet, and test results and prepared in graphical forms and presented.

As can be seen, two main aspects are ignored in the literature review and need to be addressed. First is analysing life cycle financial modelling of PPP-BOT projects under the combination of uncertainty and risk, which provide the much required level of detail from the perspective of main parties involved. Second is a suitable framework for decision making under uncertainty and risk and their management and control mechanisms.

2.5 Research on Simulation and Concession Items Optimization

With the help of the simulation model, the impact of risk can be taken into account when establishing ideal financial and contractual parameters which is called negotiable concession items (NCIs) in this research. Table 2-3 summarizes the current state of knowledge in the area of simulation and concession items determination.

Table 2-3 A summary of previous studies on simulation and concession items determination

Method	Keynotes	Previous study and application	
		Who and when	Topic
System Dynamic and fuzzy logic	Case-based reasoning (CBR)	Xu et al. (2012) Khanzadi et al. (2012)	Concession pricing model for PPP highway projects Concession pricing adjusting Concession period determination
Critical path method and Monte Carlo Simulation	Minimum and maximum acceptable rate of return	Zhang and AbouRizk (2006) Zhang (2009) Junrong (2012)	Concession period determination Concession period determination and adjustment for BOT transportation projects
NPV, Monte Carlo Simulation and risk analysis	Decision support system Tariff-at-risk Economic stability Weighted average score Win-win-win scenario Go or no go decision	Malini (1999) Shen et al. (2002) Ye and Tiong (2003) Shen and Wu (2005) Lianyu and Tiong (2005) Ng et al. (2007) Ng and Xie (2007) Zhang (2009) Ng et al. (2010) Bagui and Ghosh (2011) Wu et al. (2012) Yu and Lam (2013) Carbonara et al. (2014)	Concession period design and determination Tariff design in BOT water supply projects Concession period and tariff structure Compound tariff Risk allocation and analysis Toll/tariff regime design and determination Proposal and Scenario Analysis Incentive scheme Net asset value A win-win model for a fair risk sharing
Fuzzy Simulation and Multi-objective decision model optimization	Win-win-win solution that satisfies the various stakeholders	Ng et al. (2007) Khanzadi et al. (2010) Nasirzadeh et al. (2014)	Concession price and period determination Bi-objective problem Toll, capacity and concession period optimization Fuzzy-Delphi technique
Multi-linear regression model and simulation	Equitable risk sharing Quantitative risk allocation Win-win situation Regression model	Ngee et al. (1997) Liou and Huang (2008) Xu et al. (2012) Marco et al. (2012)	Concession pricing Concession price adjustment mechanism Concession period determination Risk factors influencing concession pricing Multiple regression model and analysis

Genetic algorithm and Simulation	Pareto frontier Time-cost trade-off	Subprasom and Chen (2007) Liou et al. (2011) Li et al. (2011)	Concession price determination Determination of decision space of financial and concessional terms
Bargaining-game theory	Concession period boundaries	Shen et al. (2007) Hanaoka and Palapus (2012)	Concession period determination
Real option approach	Incentive mechanism	Huang and Chou (2006)	Minimum revenue guarantee
Fuzzy randomness hybrid simulation	Weighted Fuzzy Delphi method	Attarzadeh (2014) (this dissertation)	Fuzzy multi objective function Fuzzy representation of NCIs IND-at-risk and uncertainty

Study on establishing NCIs is important and crucial to the success of a PPP project. Niu and Zhang (2013) studied the characterization of the optimal BOT contract. To design a BOT contract, they considered three critical parameters as NCIs: the length of the concession period, the infrastructure's capacity and the toll/tariff.

One of the most important and crucial concession items is *concession period* which has received more attention compared to other concession items. According to Zhang and Kumaraswamy (2001b) establishing an appropriate concession period is important to the success of a BOT project. The main reason is because capital investment of the private partner is recovered through the operational revenue over the concession period. The concession period is a measure for deciding when the project ownership will be transferred from the concessionaire back to the government concerned. It also delimits the benefits, authorities, and responsibilities between the government and private investors. Generally, a longer concession period is more beneficial to the private investor, but granting an excessively lengthy concession period may result in loss to the government. On the other hand, if the concession period is too short, the investor will either refuse the contract offer or be forced to increase the service fees in the operation of the project in order to recover the

investment costs and to make a certain level of return and profit. Consequently, the risk burden as a result of the short concession period will be transferred to the end users who use the facilities. Logically, increasing the service fees is obviously not desirable from the end users' standpoint and is not in their interest (Shen et al., 2002). Concession period is one of the most important decision variables (NCIs) in arranging a BOT-type contract, and there are few methodologies available for helping to determine the value of this variable under uncertainties (Ye and Tiong, 2003; Shen et al., 2007).

Tiong and Alum (1997) examined both the government and promoter by adopting 13 financial and contractual elements as criteria. According to their results, the government and promoter prioritized the three most important elements during negotiations as the initial level of tariff, future tariff increases, and financial commitments by bankers of the promoters. Moreover, the government and promoters prioritize tariff as the most important element during final negotiations of financial and contractual concerns.

The initial level of tariff/toll and also tariff/toll adjustment scheme are key issues in the development of privately financed infrastructure projects. The design of tariff/toll is an important financial and contractual negotiation parameter. It involves the determination of tariff/toll magnitude, the choice of tariff/toll structure, and the design of adjustment mechanisms. Tariff/toll structures can be an all-in tariff or a compound tariff/toll. Tariff/toll adjustment mechanisms can be used to address different risk factors such as inflation, exchange rate, demand, and fuel prices. An appropriate combination of tariff/toll structure and adjustment mechanism can be effective to manage key risks of privately financed infrastructure projects. Simulation results show

that a well-designed tariff/toll can create a “win-win” solution for both project concessionaire and the host government. In some cases, concessionaire was requested to renegotiate the tariff/toll, since the tariff/toll become a heavy burden to the end users and affect social stability (Ye and Tiong, 2003; Lianyu and Tiong, 2005; Ng and Xie, 2008).

Therefore, concession period and the design of tariff/toll should (1) pursue end users/public objectives, (2) provide incentives to avoid the loss of performance efficiency, (3) reduce the risk exposure of both the concessionaire and the government to satisfactory level, (4) limit the cost/burden of regulation to an adequate level, and (5) avoid drawbacks in implementation (Ye and Tiong, 2003). Determining negotiable concession items as decision variables have correlation to each other. For instance, PPP-BOT projects with a shorter concession period could result in a higher toll/tariff regime. Consequently, the risk burden due to the short concession period will be transferred to the end users (Shen et al., 2002).

Deciding and determining reasonable and feasible NCIs which meet and ensure all parties' interests always was, and still is a big concern in PPP-BOT negotiations especially in the development phase. Since negotiation in PPP-BOT projects is so important, researchers have studied it from different perspectives of theory analysis and supporting tools. For instance, some researchers focus more on determining the concession period, one of the most essential and effective NCIs. Conversely, some researchers focus more on determining the initial level of tariff/toll and tariff/toll adjustment scheme (tariff/toll increases regime). Some researchers attempt to address both

simultaneously and their trade-off analysis. There are also a few studies on royalty.

Some research has been conducted on how to determine the length of the concession period. Zhang and AbouRizk (2006) proposed a methodology, using the conventional MCS, to determine appropriate length of the concession based on a “win-win” principle for parties involved and exercises simulation techniques in measuring and evaluating construction and economic uncertainties and risks. Moreover, the proposed methodology, mathematical model, and simulation-based approach would facilitate the public sector in the determination of a suitable concession period for a particular infrastructure project, and the private sector in determining whether to bid for a concession solicited by public agency. It would also facilitate the private sector to develop unsolicited concession proposals for potential infrastructure projects and the public sector to evaluate such unsolicited proposals. Other studies also focus on developing models for determining the concession period for BOT projects. Khanzadi et al. (2012) presented an integrated fuzzy-system dynamics (SD) approach for determination of concession period. The complex inter-related structure of different factors affecting a BOT project is modelled using the system dynamics approach. Owing to the imprecise and uncertain nature of different factors affecting the concession period, fuzzy logic is integrated into the system dynamics modelling structure. The values of different factors affecting the concession period are determined by fuzzy numbers based on the opinions of different experts involved in the project. The application of Zadeh’s extension principle and interval arithmetic is proposed for the system

dynamics to enable the system outcomes to be presented considering uncertainties in the input variables.

The investment return, tariff regime and concession period are the most important items that influence the success of a concession-based PPP project. Some researchers carried out their research on optimizing concession items. For instance, Ng et al. (2007) proposed a fuzzy simulation model which aims to assist the public partner to determine an optimal concession period for a PPP scheme based on the expected investment and tariff regime. The requirements for establishing different scenarios to represent the risks and uncertainties involved are presented, and a fuzzy multi-objective decision model is introduced to trade-off the associated three concession items. The combined features of the simulation and fuzzy multi-objective decision models enable the scenario most likely to result in a “win-win-win” concession scheme to be identified. The results of simulation show that the risks and uncertainties, such as a change in inflation rate, traffic flow, and operation cost, could influence the decision on the concession period. Subprasom et al. (2003) developed a simulation-based genetic algorithm to determine the optimal selection of capacity and toll in a BOT toll road project under multiple uncertainties. The consideration of multiple uncertainties is important when evaluating the feasibility of a BOT project.

The process of promoting PPP-BOT projects to the host government is a time-consuming and expensive business. The negotiations and renegotiations are extensive and the financial risk of losing the tender is high. Some researchers carried out their research to simulate the negotiation of PPP-BOT projects and obtain optimized negotiation parameters.

For instance, in order to facilitate the contractual negotiation, Ngee et al. (1997) proposed an automated mechanism that allows the government and sponsor to reach a consensus on the combination of concession period, tariff structure, and rate of return of a BOT project. The proposed approach is using multiple regression models to formulate prediction equations using toll rates, concession period, and rate of return variables. This approach deals with the negotiation of financial and contractual parameters associated with a BOT project in development phase before it is awarded to the promoter. It describes the development of an automated mechanism as an alternative approach in expediting the negotiation over a suitable pricing structure for the BOT project. The mechanism was developed by incorporating spreadsheet data into multiple linear regression models to formulate the prediction equations using the tariff, concession period, and rate of return as the variables.

Such mechanism is useful to reduce the bulk of urgent re-computations of the project cash flows during the final negotiation and renegotiation that would otherwise entail the use of considerable resources. The mechanisms could therefore be used as enhanced tools for dynamic negotiation between the government and promoter for an acceptable level of tariff structure; concession period and rate of return on the promoter's investments; and for balancing the risk/return profiles of both parties. There are some shortcomings with Ngee et al. (1997) mechanism. Their model developed on the basis of incremental (manual) data inputs, is not intended to assess the risk of the BOT project in the negotiation model. Later on Liou and Huang (2008) extended the automated mechanism to address the shortcomings.

Alternatively, Shen et al. (2002) developed a quantitative BOT concession model (BOTCcM) for determining a proper concession period that can protect the interests of both the government concerned and concessionaire. However, there are still some limitations and shortcomings on this model. Firstly, it ignored risk impact on the model. Later on Shen and Wu (2005) extend the BOTCcM model and considered the risk impact to this model and presented an additional risk concession model by incorporating conventional Monte Carlo Simulation. Secondly, a typical weakness in using BOTCcM is that the model cannot recommend a specific time span for concessionary. BOTCcM does not present possible combinations between concession period and other financial variables. Shen et al. (2007) extended the BOTCcM model to a new method called BOT bargaining concession model to identify a specific concession period by using bargaining-game theory, which takes into account the bargaining behaviour of the two parties engaged into a BOT contract.

Liou and Huang (2008) incorporated risk attributes of the BOT project into the formulation of a contractual-negotiation model. The proposed model allows the government and the sponsor to reach a consensus on the terms of financial returns as well as the risk of the project is determined. The pro forma cash flow of a BOT project is developed and used to generate the probability distribution of NPV from the owner's viewpoint by using Monte Carlo simulation. High and low risk scenarios are obtained to determine whether the contractual negotiation models vary in accordance with risk levels. Results show that, given the expected NPV, the sponsor should be offered more favourable concessional terms for projects with high risk than with low risk. They also suggested that the

government and industry practitioners embody the risk attributes of the project in the automated contractual-negotiation model.

In PPP-BOT infrastructure development projects, government usually preset and predetermined the concession period to a fixed length before private sector is invited to bid on other concession items such as price (tariff/toll) and royalty. The concession period (CP) consists of the construction duration (CD) and the concession operation period (OP). Different construction duration results in different profits for the concessionaire. According to the time-cost trade off principle, shortening the CD increase the construction cost; shortening the CD also prolongs the OP, which could increase the total benefit of BOT projects. This practice has potential economic, financial, and social problems. To overcome this limitation on concession period, Zhang (2009) proposed a win-win concession period determination methodology, wherein PPP is addressed as a principal-agent maximization problem. The proposed simulation-based approach combines the critical path method and Monte Carlo simulation technique in an effort to quantify construction and market risks for decision making. Both deterministic and simulation-based methods are provided to determine the concession period using conventional MCS. Further, Li et al. (2011) proposed a methodological framework including optimization, sensitivity analysis, and genetic algorithms for BOT projects. Through this framework, the reasonable construction duration of a BOT project can be obtained.

Lianyu and Tiong (2005) carried out their research on minimum feasible tariff model for a real BOT water supply project. This model provides a mechanism to quantitatively examine the effectiveness of risk allocation

arrangements. Through a case study, risk analysis is performed to demonstrate the application of the simulation model on the key factors and critical risks such as inflation, exchange rate and demand risk. Their analysis shows that for inflation risk, a pre-set tariff adjustment formula is useful in lowering minimum feasible tariff. For exchange rate risk, the reference rate should be set lower than the best estimate. Lowering of minimum feasible tariff can also be achieved if the tariff for additional demand is lower than the tariff for guaranteed demand.

The tariff and concession period of a BOT project are the most important variables at the negotiation stage of a BOT project. While the initial version of contractual terms is normally based on pro forma financial statements conducted during the feasibility study or the appraisal stage, a change in terms will most likely alter the financial parameters.

A number of capital investment decision methods can take risks into account, but each of them focuses on different factors and has its limitations. Therefore, a more robust method is needed. Through Monte Carlo simulation, Ye and Tiong (2000a) provided a method called the NPV-at-risk by combining the weighted average cost of capital (WACC) and dual risk return methods. It incorporates the time value of money into the mean-variance method using NPV concept and takes financing methods into account using WACC as the discount rate. The results show that this combination can overcome some problems inherent in other methods, and the method can be used in decision making for privately finance infrastructure projects. Moreover, Risk-return trade-off was studied to make sure a sufficiently long concession period for generating financial returns that can compensate the risks. Their method shows that NPV-at-risk as a more

dynamic method can provide a better decision for risk evaluation of investment in privately financed infrastructure projects (Ye and Tiong, 2000a).

Ye and Tiong (2003) provided a method for evaluating the mean and variance of NPV, and NPV-at-risk of different concession period structures. So both government and concessionaire can understand their risk exposure and rewards. Then they analyse the influence of project characteristics on concession period design to evaluate the feasibility of the design. It is concluded that a well-designed concession period structure can create a “win-win” solution for both concessionaire and host government.

Malini (1999) used the conventional Monte Carlo simulation model to analyse the risk of BOT bridge projects and concluded that the simulation model accurately estimates the financial risk of BOT projects. Variables used as simulators consist of tariff structure, tariff revision schedule, extent of the grant, and duration of the concession period.

Islam and Mohamed (2007) developed an intelligent algorithm using a combination of GA and the fuzzy set theory to optimize conflicting financial interests in deriving the right mix of three key decision variables: equity ratio, concession length and base price; as concession items which are called NCIs in this research. Later on Islam and Mohamed (2009) developed a concession-investment optimization model to optimize the winning potential of a concession-bid from the prospective promoter's viewpoints by taking into account imprecise investment parameters. A financial performance measure has been developed to quantify bid-winning potential. The developed model yields global near-optimal solution of bid-winning potential with contributing values of concessionary items: concession length, base price, and quality level

under uncertain investment environment. A clear research gap in this study is perceived in simultaneous evaluation of profitability and bid-winning potential from the promoter's perspective.

As can be seen, concession period, tariff/toll design and royalty are the main NCIs and are decided in the negotiations within the development phase before the contract award. The concession period, as one of the most important decision variable and concession items in arranging a BOT-type contract, should be determined by considering the existing risks and uncertainties. The construction duration (CD) and operation period (OP) form the concession period (CP) in a BOT contract. Basic toll/tariff rate (toll/tariff rate prescribed) is determined based on consideration of affordability, benefits derived from the project and end user willingness to pay analysis. The basic toll/tariff structure is fed as input to the model, and hence, the model can accommodate any desired combination of toll rates for the various modes. As PPP-BOT projects are generally characterized by long concession period, it is necessary to revise the toll structure periodically to partially compensate for inflation. Thus, the periodicity of toll/tariff increase and the rate of increase are fed to the model as inputs to compute the toll/tariff rate for each mode for every year of the operating period (Malini, 1999). The problem of determining optimal NCIs is a multi-objective multi-party decision making problem. Thus to find optimal solution of this problem, considering multi-objective multi-party using Pareto efficiency is helpful.

Research on simulation and concession items optimization techniques has been motivated in the recent years. Consequently, a number of simulation based models with specific aims are developed for PPP-BOT project. The

results of such developed models point out the important and significant role in decision making. Among the sampling techniques, Monte Carlo simulation (MCS) has been applied more. One of the major advantages of this technique is that through the MCS the impact of risk has been taken into account. However, there remain some shortcomings and limitations in this technique. Such shortcomings and limitations are particularly critical when dealing with complex and long term infrastructure projects that involve high risks and uncertainties about concession items and decision parameters.

Firstly, in addition to associated risks in the PPP-BOT projects, complexity and long term estimation impose strong uncertainty associated to concession items and decision parameters of the PPP-BOT projects. Most of the existing models lack the capability to manage uncertainty modelling and to incorporate and combine uncertainty and risk modelling in associated decision making under risk and uncertainty. This drawback neglects the usefulness of available models under uncertain circumstances. Secondly, almost all proposed models have focused merely on one party's perspective. Neglecting other parties' perspective during the development phase, may leads to impracticable decisions. Thirdly, in a real decision making situation, it is recognized that human judgment on qualitative criteria is always subjective and imprecise and it combines with data from experiences and past projects. The existing models cannot manage this issue well and this is a research gap.

2.6 Research on Real Options Valuation and Analysis

This section presents a review of Real Options Valuation and Analysis application in PPP-BOT projects. The use of Real Options in infrastructure

development decision makings has gained popularity although it is still in its infancy. Rose (1998) evaluated the concession period and deferral of the concession fee options. Ford et al. (2002) proposed a binomial option pricing model using strategic flexibility to capture project values hidden in dynamic uncertainties and represent alterations in design. Ho and Liu (2002) developed a real option pricing model, incorporated project net cash flow and construction cost, to evaluate the impact of the government debt guarantee and the developer negotiation option on the financial viability of the privatized infrastructure projects. Yao and Jaafari (2003) presented a combining decision tree with Real Options Valuation model. They demonstrated that the Real Options approach can be used as a clear and simple method to integrate appropriate project evaluation with optimal project management strategy in a bid to avert or reduce project risks from the perspective of a real project. Garvin and Cheah (2004) discussed methods for valuing private investments in public infrastructure and evaluated deferment option. Wibowo (2004) studied valuing the government guarantees and their financial impact on BOT toll roads from the government and sponsor's perspective. Huang and Chou (2006) developed a compound option pricing model. The combination of minimum revenue guarantee (MRG) and the option to abandon in the pre-construction phase are studied as a series of European style call options. Vassallo and Solino (2006) described the applied model and results of the MRG mechanism implementation in Chile. Cheah and Liu (2006) applied Monte Carlo simulation to evaluate government guarantees and subsidies as Real Options. Mattar and Cheah (2006) introduced a new category of risks, which is called private risk. Methods for pricing private risks are evaluated

and the effects of private risks in real option analysis are studied. The difference in real option values can be considered as a form of private risk premium. Chiara et al. (2007) presented least-squares Monte Carlo method for quantifying the value of a minimum revenue guarantee (MRG) as Bermudan (American) options in a BOT project. This approach is presented and illustrated to determine the fair value of real option. Liu and Cheah (2009) illustrated the analysis of two types of options: the incentive scheme, guarantee, and repayment feature, the placement of a cap on the tariff/toll rates. They demonstrated that a negotiation band incorporating these option values can be constructed which would enlarge the feasible bargaining range for both parties to prevent a total negotiation breakdown. Huang and Pi (2009) applied a sequential compound option approach for valuing multi-stage BOT projects, in the presence of dedicated assets. Shan et al. (2010) presented collar option, which is a combination of a put and call option, as a technique to manage revenue risks. Furthermore, its potential features are derived from an exploration of existing risk management practices in real toll projects. Galera and Solina (2010) developed a real option-based methodology to value minimum traffic guarantee of highway concessions. Qiu and Wang (2011) developed a model to examine the incentives, efficiency and regulation in BOT contracts. Ashuri et al. (2012) applied the Real Options Theory to price MRG and traffic revenue cap (TRC) options as compound options in BOT projects and determined their effects on the concessionaire's economic risk profile.

In PPP projects, it is often necessary for host governments to provide guarantees to investors due to the large scale of investments involved, long

tenure of the project, and hence greater risks. Although PPP has become a matured topic in construction management, research on evaluation of restrictive competition in PPP projects remains surprisingly scarce. With real option theory, Liu et al. (2014) analysed government's guarantee of restrictive competition in PPP projects, and constructs an evaluation model for restrictive competition. The results illustrate the significance of the valuation to both host government and investors, and provide them with a clear reference when negotiating on the level of restrictive competition.

PPPs are adopted throughout the world for delivering public infrastructure. Despite the attractiveness of the PPP structure, its implementation has not been without trouble due to multiple uncertainties embedded with PPP projects. Private investors often require some mitigation of these risks through government support. One of the most common forms of government support is minimum revenue guarantee (MRG). Carbonara et al. (2014) developed a real option-based model that uses a new mechanism for setting the revenue guarantee level secured by the government, which balances the private sector's profitability needs and the public sector's fiscal management interests and uses the concept of fairness for structuring MRGs. The model uses Monte Carlo simulation to take into account the uncertainty. The model is applied to the projected 1 kilometre long 'Camionale di Bari' toll road that will link the port of Bari (located in Puglia, Southern Italy) with the existing road network without affecting the urban traffic. It was found that government support is often needed to make the project attractive to private investors and that the developed model can be, for both public and private sectors, a valid tool for

defining the fair value of the minimum amount of revenue secured by the government.

As can be seen, options which arise from certain clauses of the contract are more valuable in risky projects. The correct evaluation of the concession in a bidding process is essential for government and bidders. There are two main aspects as research gaps. Firstly there is need for a means for valuing of early fund generation option. Secondly there is need for a procedure to calculate equitable bound for guaranteed rate of return for project sponsor under uncertainties and risks.

2.7 Concluding Remarks, Research Gaps: Motivation for Required Studies

As the reader has seen so far, a comprehensive literature review was conducted as part of this research to examine the current state of knowledge regarding long term infrastructure projects, PPP-BOT projects and risk management in this kind of projects. Over 100 journal articles and other publications pertaining to PPP-BOT projects were collected and reviewed.

According to this comprehensive literature review, it can be inferred some useful and reasonable results that led to the current research titled *“Negotiation-based risk management of PPP-BOT infrastructure projects”* under uncertainty and risk - using fuzzy game theory, simulation and Real Options Analysis. The broad gaps identified frame the direction of this dissertation. We discuss these results that led us to this research in more detail.

- 1. *Negotiation-based risk management:*** according to research records about failure and success in PPP-BOT projects, interview with the

experts and PPP-BOT project managers and also the author's experiences in some PPP-BOT projects (author was involved in some PPP-BOT projects in his home country), the crucial and essential part of the these long term projects is *negotiation* and in a better word *negotiation series management* that lead the project to success or failure. So risk management of these projects must be done from a negotiation perspective.

2. ***Negotiable Concession items:*** when the idea to manage risks and uncertainties of these projects is through the negotiation, determination of *negotiable concession items* under the combination of uncertainty and risk is very crucial. This will lead to answer the commonly asked question of how to pursue a win-win-win scenario among the public sector (government), the private sector (concessionaire), and ultimate general public users (end users).
3. ***Dynamic environment:*** Methods, models and tools are needed to move on to dynamic situations properly to evaluate financial viability mechanisms for PPP-BOT project in order to manage the financial vulnerability which is crucial in PPP-BOT projects as long term infrastructure projects especially under catastrophic risks.

CHAPTER 3 TOWARD A PARETO FRONTIER NEGOTIATION POSITION USING FUZZY GAME THEORY IN PPP-BOT PROJECTS

3.1 Introduction

The use of game theory (GT) in analysing realistic problems of competitive situations in PPP projects has proved fruitful. Game theory is used in order to simulate the negotiation behaviour aimed to analyse, characterize and forecast parties' behaviour in the negotiations and observe players' tendency and characteristic of behaviour. It also aims to determine the equilibrium solution and negotiation positions in such a way as to manage conflicts of parties' interests.

In most of the literature using game theory application in PPP-BOT procurement process, particularly for negotiations, the solution of the Game is obtained based on the Nash equilibrium. The solution of the *cooperation game* obtained via the Pareto optimum is superior in payoffs when compared to the *competition game* solution obtained via the Nash equilibrium. This is proved mathematically and is illustrated through a real case study. With the project procurement as the Game, it is assumed that all parties involved, as players, have complete information about the game. This is a simplified and unrealistic assumption.

This chapter studies negotiations between public and private sectors based on the game theory perspective under uncertainties and risks. The two main aspects that this study contributes in the use of game theory when applied to PPP-BOT are finding the superior negotiation positions based on Pareto

optimality and considering the PPP negotiations as a game under uncertainty and risk by utilizing fuzzy game theory. The scope of this research is negotiations in the development phase of PPP-BOT projects. Recognizing and understanding the use of game theory when applied to PPP enables decision makers to realize negotiation behaviour of parties involved in the development phase under uncertainties which results in choosing an optimal strategy that leads to reduction in costs and potential losses and mitigate the risks of the conflicts involved in a project.

This chapter is organized as follows: first classifications and types of games are reviewed. Furthermore it is shown how game theory is used as a decision making tool in solving Multi-objective Optimization Problem (MOP) in various negotiations in development phase. The application of the game theory in PPP-BOT projects is discussed in order to overcome to aforementioned problems in the development phase by using Pareto optimality concepts. A mathematical model aimed to enhance the Nash equilibrium solution using Pareto optimality concept is presented. The concepts of cooperative and non-cooperative game theory and fuzzy set theory are then combined to bring in a new optimization method that takes into account the uncertainty involved which is referred to herein as fuzzy game theory. The concept of the proposed game model is also validated through an illustrative case study in this chapter and has been examined in a real case study in chapter 7 in detail.

3.2 Public Private Partnership (PPP)

In Public Private Partnership (PPP) projects the responsibility for the delivery of public facilities is shifted from a public institution to a private sector firm for a particular period of time. The motivation and role of PPP is to attract private sector capital, resources, assets, management skills, experiences and innovation for the provision of public sector infrastructures and services (Mustafa 1999, Forshaw 1999, Allen et al. 2002). PPP also has two other important characteristics: an emphasis on provision of service/product, as well as investment, by the private sector; and significant risk transferred from the public sector to the private sector. This delivery is in such a manner that the service delivery objectives of government are fulfilled along with the profit objectives of the private partner. Figure 3-1 shows the three-phase PPP-BOT project life-cycle: development, concession (CP), and post-concession (PCP) with key time points. It also demonstrates the procedure steps together with the effective and closing dates.

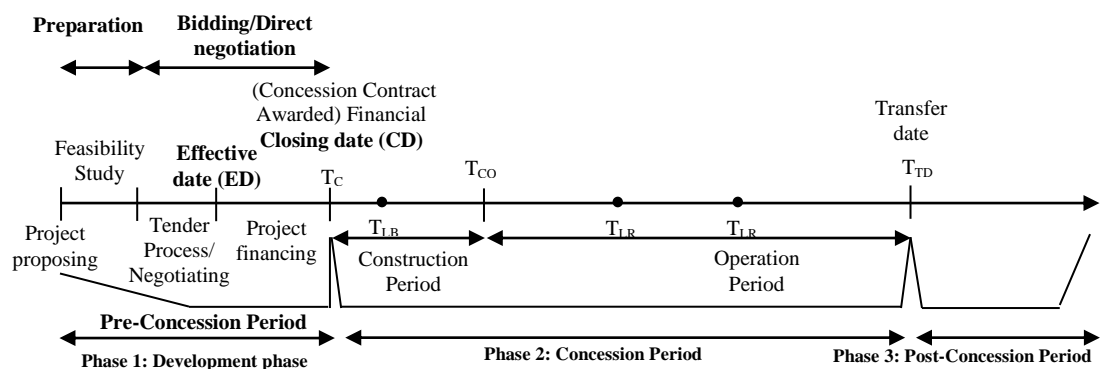


Figure 3-1 Life-cycle of PPP-BOT project, procedures steps and key time points

Not all PPP projects have been implemented successfully because of problems due to inappropriate administration policies during the negotiations and re-negotiations. Most problems are found during the pre-contract

negotiations, while a few are found in post-contract negotiations (Zhang 2005, Tiong et al. 1992). *Negotiation failure* has been identified as the principal cause of unsuccessful implementation of PPP projects. This is due to firstly, disagreements between public and private parties on the negotiable contractual parameters and consequently unbalanced allocation of project risks and returns. Secondly, an “unfair” closing of the pre-contract award negotiations that post-contract award renegotiations were unable to recompense. In fact, it is often advocated that the main problems associated with PPP, as long-term contracts, are uncertainty, informational asymmetries, and renegotiation (Chiara, 2009). The average tendering period is 33-34 months (NAO, 2007). The primary obstacle to PPP success was found to be “*lengthy delays in negotiation*” (Chan et al. 2010).

The application of game theory in the field of construction management is a recent approach, in particular, for PPP-BOT negotiations (Ho and Liu, 2004; Ho, 2005). The main reason why game theory is appropriate in these circumstances is because it is an exploratory study of decision making process where several players must make decisions that potentially affect the interest of the other players. Furthermore, game theory is used to simulate negotiations between two main parties involved in PPP-BOT project: “*government agency*” as public sector and “*concessioner*” as private sector consortium. It has been shown that GT is one of the best tools to simulate these types of negotiations. By using this method, the equilibrium solutions which are strategically stable respective positions in the sense that no player would have an incentive to deviate from its action given the actions of the other players (Nash equilibrium), can be found.

Game theory could be applied to PPP-BOT projects in two main areas, (1) Bid competition model and policy, (2) Renegotiation model and policy-bargaining, e.g., *Financial Renegotiation* to negotiate a subsidy in order to rescue a distressed project, *Renegotiate* on extension of concession period, debt guarantee, and more tax exemption for a certain number of years, and *Renegotiate* on extra loan or equity investment, *refinancing* issue.

Many common decision problems in PPP projects can be thought of as a game. For instance in the development phase, before the effective date milestone, both parties (concessionaire and government) meet each other around the negotiation table, maybe on several occasions, in order to make decision to promote the project and allocate responsibilities, risks and benefits to each party. This game has been called *bargaining-game* (Nash, 1950). This bargaining-game can be categorised by types of objectives and decision variables. The most common bargaining process is negotiations over negotiable concession items (NCIs): *concession period*, *tariff/toll* and *royalty* which are the most important concession items. A less common bargaining process is negotiations over subsidy and claim.

Research shows that game theory principles have been applied in PPP procurement, particularly during negotiations that immediately precede the concession agreement: pre-contract negotiations. Ho (2005 and 2006) applied game theory to analyse the information asymmetry problem during the procurement of a BOT project (bid compensation model) and its implication in project financing and government policy (financial renegotiation model). Ho and Liu (2004) developed a game theoretic model for analysing the behavioural dynamics of builders and owners in construction claims. In PPP-

BOT projects, conflicts and strategic interactions between public and private parties are common, and thus game theory can be a natural tool to analyse the problems of interest. Shen et al. (2007) utilized game theory to find the equilibrium solution for negotiation over the concession period, one of the most important NCIs.

A majority of the papers from the literature review, particularly those dealing with the application of game theory in PPP-BOT, made simplified and unrealistic assumptions. Firstly they assume that each player's payoff, objective and utility function and strategies is common knowledge with certainty for all players involved in PPP-BOT project. The game is then considered as a game of "complete information". Secondly researchers have found equilibrium solutions of the game based on the Nash equilibrium. (Dhingra and Rao, 1995; Ho and Liu, 2004; Ho, 2005, 2007; Wu and Parlar, 2011). The solution of the *cooperation game* obtained via the Pareto optimum is superior in payoffs when compared to the *competition game* solution obtained via the Nash equilibrium. However, these assumptions were barriers to successful implementation of game theoretic ideas. For instance, in a PPP-BOT sealed-bid process, the bidders do not know each other's valuations. There are a small number of studies that deal with games played under uncertainty, incomplete information. Furthermore, the existing game solution does not reflect the maximum possible gain/payoff for players. These are research gaps and this study contributes to the literature by proposing methods to overcome these limitations and problems.

In order to fill these gaps, firstly this study proposes to combine concepts of game theory and uncertainty modelling such as fuzzy logic to investigate

and analyse negotiation processes under uncertainty, with incomplete information. Secondly it proposes to incorporate Pareto efficiency/Pareto optimality concept to enhance the game solution. The scope of this chapter is bid competition negotiations in the development phase of PPP-BOT projects.

3.3 Game Theory

Game theory (GT) is a mathematical tool used in the study of the resolution of conflicting claims for multi-party decision making (Myerson, 1991). A game may be viewed as a multi-objective optimization problem (MOP) where each player equates to an objective function. Each player seeks to improve his overall position subject to constraints. In a MOP, it is rarely possible to find a single solution that would optimize all the objectives. Some objective vectors may be better than others. When this occurs the improvement in one objective vector leads to a degrading of one or more of the other objective vectors.

Nash (1950) demonstrated that finite games always have an equilibrium point at which each player chooses the best response to each other players' strategies. Thus, each player's predicted strategy must be that player's best response to the predicted strategies of the other players. Such prediction, which is called Nash equilibrium (NE), is *strategically stable*, because no single player wants to deviate from his/her predicted strategy. Moreover, in GT, each player attempts to maximize his/her utility/payoff. The preferences of each player are expressed by a utility function/ payoff function. Therefore, GT assumes rational players based on the desire of utility/payoff maximization. Each player is assumed to know the preference patterns of the other players.

GT can be described formally at various levels of detail. Within the scope of this research, three levels of GT classifications are described, namely approach, movement and information. Under the approach classification in traditional game theory, there are two main types: the competitive (non-cooperative) game, and the cooperative game. In the competitive game, players consider only their own strategic objectives and they try to maximize their own benefits. Competitive games require players to form strategies that directly oppose the other players in the game, i.e. the goals of the players are opposed.

In contrast, a cooperative game models a situation where two or more players have interests that are “neither completely opposed nor completely coincident” (Nash, 2002). In other words, a cooperative game is a game where groups of players (coalitions) may enforce cooperative behaviour, hence the game is a competition between coalitions of players, rather than between individual players. In the cooperative game, players cooperate to acquire the maximum benefits and at the same time try to allocate gains on an equitable basis. Although opportunities exist for players to be able to work together to achieve a win-win solution, a cooperative game does not always guarantee that cooperating players will benefit equally or even benefit at all. An example is a coordination game, when players choose the strategies by a consensus decision-making process. The classic cooperative game is the iterative version of the prisoner’s dilemma (Dawkins, 1989).

A third category of games also exists under the approach classification, namely collaborative game. In a collaborative game, all the participants work together as a team, sharing the payoffs and outcomes; if the team wins or

loses, everyone wins or loses. Collaboration as a team differs from cooperation among individuals in that cooperative players may have different goals and payoffs where collaborative players have only one goal and share the rewards or penalties of their decisions. The challenge for players in a collaborative game is working together to maximize the team's utility. Collaborative games necessitate collaboration.

There are two kinds of games in terms of the phasing of decision making based on the movement: *static games* and *dynamic games*. In a static game, the players act simultaneously, in the sense that each player makes his decision without knowing the decisions made by others. The bid compensation decision process model (Ho, 2005) is demonstrated as a non-cooperative static game. This model aims to study the impacts of bid compensation and to develop appropriate bid compensation strategies. The strategic form is used for illustration of this game. This form is represented in Table 3-1. On the other hand, in a dynamic game, the players act sequentially. The financial renegotiation model (Ho, 2006) and construction claims (Ho and Liu, 2004) are non-cooperative dynamic game, where private parties and government take turns in making decisions after observing the other party's action. Extensive form (game tree) is used for illustration of this game. The structural components of game tree involve nodes (initial, decision and end), branches (alternative) and payoffs for each player.

There are two categories of games based on information and is used to describe what the players know during the game course, *complete information* and *incomplete information*. In a game of complete information, the players know not only the structure of the game (strategies) and their own payoff

functions but also the payoff functions of the other players. In other words, they know the available strategies and preferences of all of the players. Otherwise, the game is incomplete information. A game has perfect information when at any point in time only one player makes a move, and knows exactly all the actions that have been made until then. Otherwise, it is imperfect information game. Perfect information is often confused with complete information, which may appear to be a similar concept. Complete and perfect information are importantly different.

3.4 Pareto Optimality vs. Nash Equilibrium, Illustrative Example

Generally two theories and models have been used to abstract the conflicting interest's situation between the players; the non-cooperative model based on the concept of Nash equilibrium, and the cooperative model based on the concept of a Pareto efficiency or Pareto optimality solution (Dhingra and Rao, 1995).

In a non-cooperative game, each player is unconcerned how his choice will affect the payoffs of other players. With this outlook each player selects a suitable strategy for himself. The parties as game players then engage in bargaining on contractual parameters and exchange risks and the benefits until equilibrium is reached. The resulting solution, referred to as Nash equilibrium, is the basic solution of the game and is the best strategy a player can choose based on the other players' strategies. It is a solution where players have no incentive by changing their strategy and no player can improve his payoff by altering and choosing another strategy, and attaining different amount of risks and benefits (Nash, 1950; Dhingra and Rao, 1995; Gibbons, 1992).

In contrast, a cooperative game proceeds with the intent to ensure an appropriate balance of risk and return allocation such that all players are in the best position as possible, which would not be worse than the Nash solution, and an improvement in the payoff for one player does not result in loss for another player. The bargaining scheme postulated by the concept of Pareto optimality yields a unique and optimal distribution of risk and return such that the arbitrated outcome is Pareto optimal (Dhingra and Rao, 1995). The Prisoner's Dilemma is considered as an illustrative example and demonstrated in Table 3-1 (Osborne, 2004).

Table 3-1 Prisoner's Dilemma (values: payoff, maximum is in favourite.)

		Player 2	
		Confess	Not Confess
Player1	Confess	(2, 2) \Rightarrow	(0, 3)
	Not Confess	(<u>3</u> , 0) \Rightarrow	(1, <u>1</u>)

“Not Confess, Not Confess” is pure-strategy Nash Equilibrium as denoted by underline in payoff table. The arrows in the game table denote the flow to Nash Equilibrium position. “Confess, Confess” is Pareto optimal solution. These solutions are shown in Figure 3-2. As can be seen, the dash curve constitutes the Pareto optimal frontier which represents the best payoffs both players can hope for. As can be observed, by cooperation game players could gain more and move to better position i.e. from Nash equilibrium solution to Pareto optimal solution. This movement is demonstrated in Figure 3-2 by arrow.

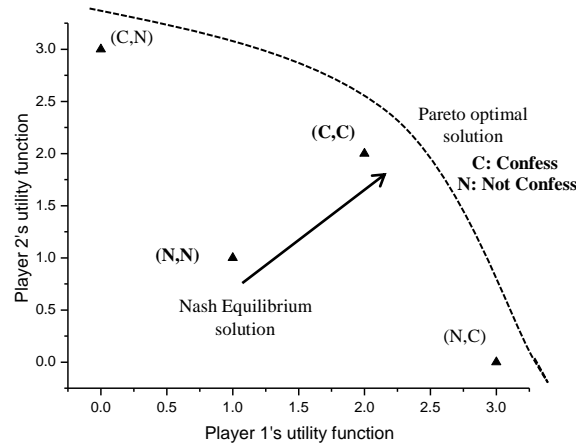


Figure 3-2 Pareto optimal frontier of payoff for Prisoner's Dilemma game

3.5 Framework of the Study in the Development Phase

As various parties engaged in PPP project, such as government, project sponsors, investors, lenders, construction companies, operators, insurers, etc. where they have different and conflicting objectives and aims, the cooperation of parties is needed instead of competition to achieve best payoff for them at win-win solution. This cooperation could be considered as multistage games. The focus of this chapter is negotiation in the bid competition at development phase, particularly between the government and the private sector (SPV).

The framework of PPP-BOT negotiations in development phase is demonstrated in detail in Figure 3-3. Development phase is divided into two stages, *Bid preparation and tendering* and *Final Negotiations*. The negotiation risk management planning steps are shown as well. It starts by risk identification, evaluation and analysis. Risk allocation table is established based on the agreeable concession items. The risk allocation procedure is closed to achieve financial closure of the project. Following this risk monitoring and control process will be started.

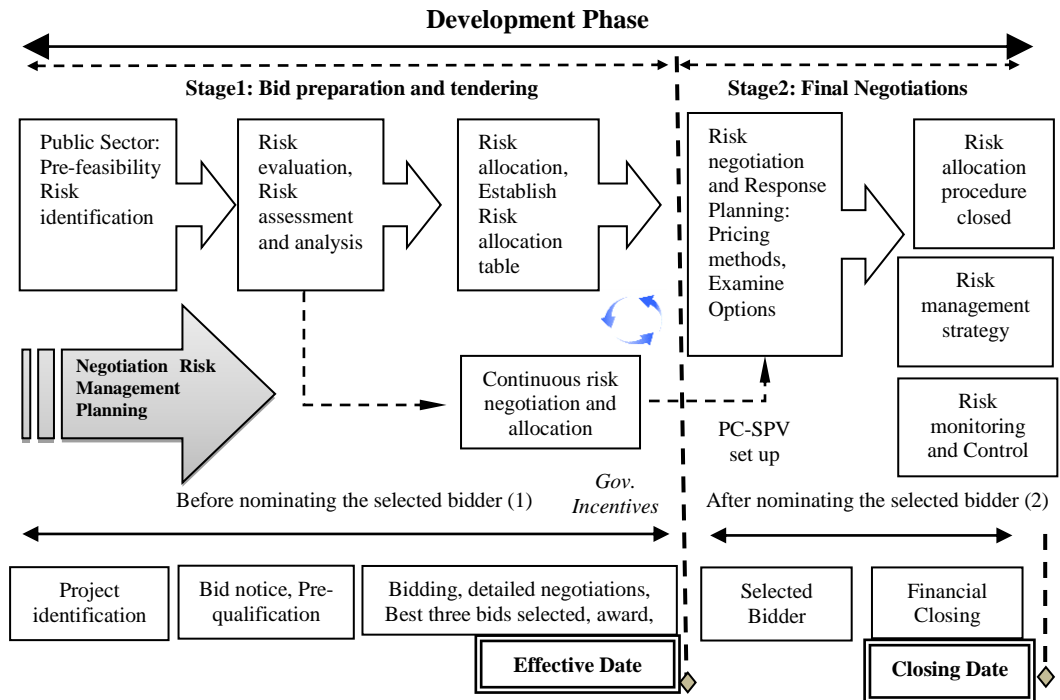
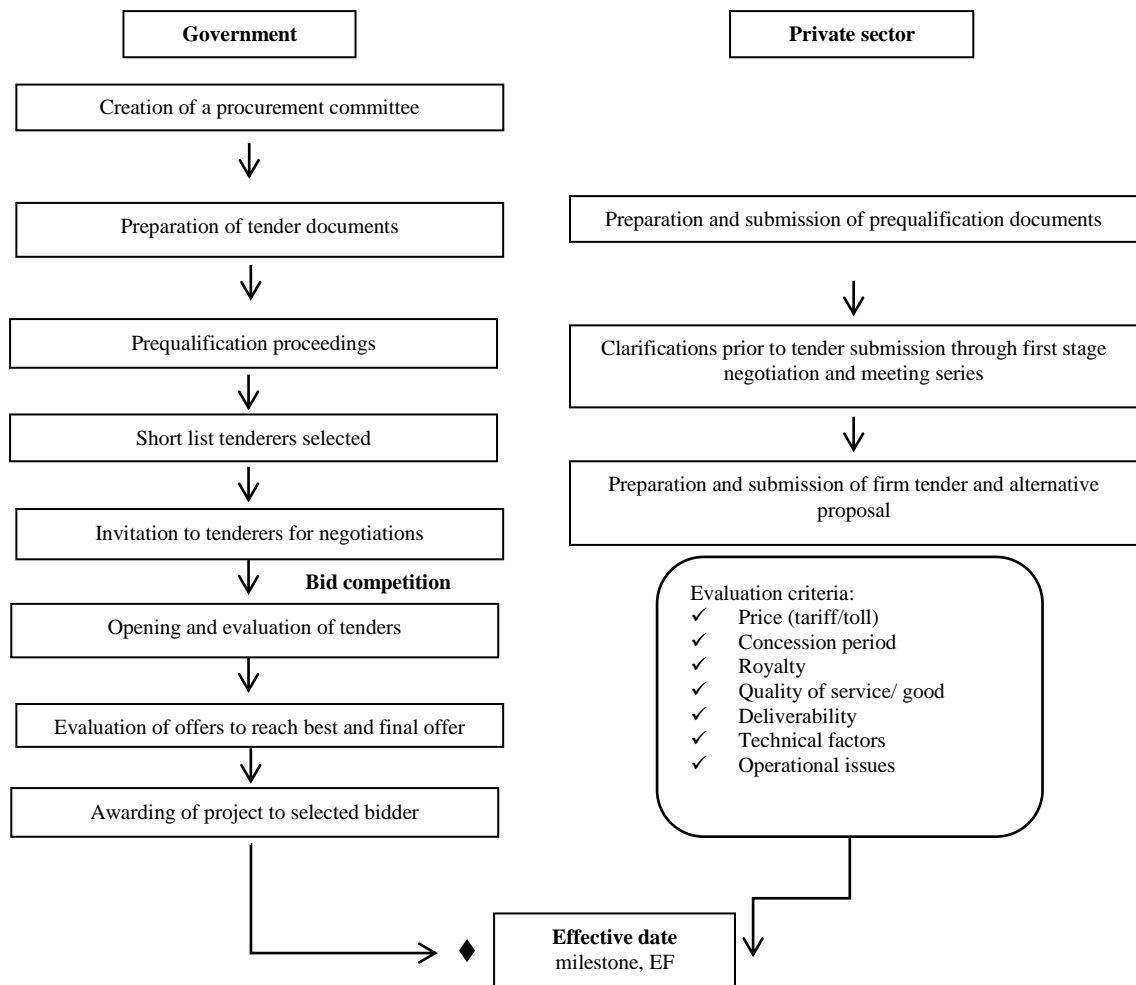


Figure 3-3 Framework of PPP-BOT negotiations in development phase - risk analysis and management perspective

The stages of the development phase and corresponding actions by each party are shown in Figure 3-4. At the first stage shortlist tenderers are selected by the government via the prequalification procedure. Then the project is awarded to the selected bidder by considering the evaluation criteria such as price (tariff/toll), concession period and royalty are considered. At the second stage risk negotiation, pricing and allocation procedure is carried on by the government and the selected bidder till reach financial closure. Game theory in PPP-BOT projects is concerned with how parties make decisions. Either static or dynamic games are utilized to represent the decisions made.

Stage1: Bid preparation and tendering



Stage2: Final Negotiations

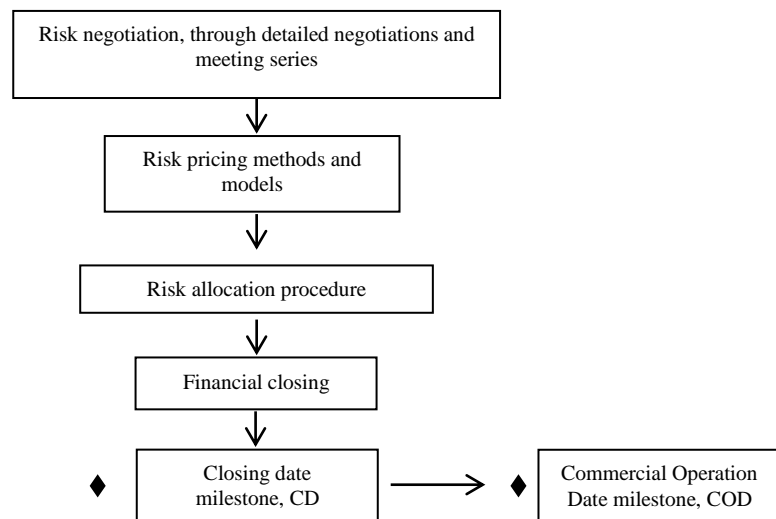


Figure 3-4 Stages in development phase of PPP-BOT procurement procedure

In practice, two methods are adopted to grant concession and nominate concessionaire in PPP-BOT projects by public sectors: *bid competition* and *direct negotiation*. Bid competition which is more common and accepted by concerned governments, is the focus of this chapter. Direct negotiation is used when information of similar projects including the contractual parameters such as price are available to public sector. So in direct negotiation method, the new project is granted based on the experience of previous projects. Direct negotiation bargaining process (Shen et al., 2007), financial renegotiation model (Ho, 2006) and construction claims model (Ho and Liu, 2004) are direct negotiation game model.

3.6 The Proposed Game Model

Divergence of interests and motivations cannot be prevented in a PPP-BOT project. Different types of negotiations with diverse objectives are realized between main parties involved in PPP-BOT in the development phase. Of course, each party is going to increase its proportion of the payoff (in the payoff matrix). On the contrary it can be seen simultaneously that each party is going to decrease and cut its proportion of the risks. Therefore, the decision making criteria of PPP-BOT model should be to satisfy all stakeholders. Interest and motivation of main parties involved in PPP project are represented in Table 3-2. The private sector aims for profit maximization and the Private sector interest is financial returns. Return on equity (EIRR) and NPV of equity cash flow are taken as the indicator for SPV (Expression: Max ROE). In contrast, the public sector aims for the accomplishment of service delivery, risk transfer and value for money (VFM) by means of PPP-

BOT approach. Although two parties have different objectives, they are able to adopt a win-win approach eventually.

Table 3-2 Interest and motivation of main parties involved in PPP project

<i>Party involved in PPP project</i>	<i>Interests/ motivations</i>	<i>Expression</i>
Private sector	Financial returns/profit maximization	Max ROE/EIRR/NPV of equity cash flow
Public sector	Economic and social performance/ Infrastructure development	Max VFM-SLR/NPV
Lenders-Banks	Timely Return on principal and interest with repayment security	DSCR/LLCR Not less than specific amount
The public/end users	Reasonable quality and cheaper goods/facility	Min Tariff/Toll (Levelized)

We make the assumptions that both parties observe rational behaviour and have different information for the model building. All parties contribute to the project financial plan by injecting capital into the project in different forms such as fund, loan and guarantee. The objective function of each party and also project could be represented mathematically as follows.

Private sector (concessionaire) objective function:

$$\Pi_p = NPV_{\alpha}^{\mu} = \sum_{t=1}^{CP} NPV_{t\alpha}^{\mu} = \sum_{t=1}^{CD} -\frac{I_{t\alpha}^{\mu}}{(1+r_{\alpha}^{\mu})^t} + \sum_{t=CD+1}^{CP} \frac{Rev_{t\alpha}^{\mu} - C_{t\alpha}^{\mu}}{(1+r_{\alpha}^{\mu})^t} - I_0 \quad 3.1$$

Public sector (government) objective function:

$$\Pi_g = VFM_{\alpha}^{\mu} + \Phi_{\alpha}^{CP\mu} + \Psi_{\alpha}^{PCP\mu} \quad 3.2$$

Project Objective function:

$$Max \Pi_p \quad 3.3$$

$$Max \Pi_g \quad 3.4$$

Subject to:

$$I_{\alpha}^{C^{\mu}} R \leq \Pi_p \leq I_{\alpha}^{C^{\mu}} V \quad 3.5$$

$$SLR_{\alpha}^{\mu} \geq 1 \quad 3.6$$

$$VFM_{\alpha}^{\mu} \geq 0 \quad 3.7$$

$$\Psi_{\alpha}^{PCP^{\mu}} \geq 0 \quad 3.8$$

$$DSCR_{t\alpha}^{\mu} \geq \rho \quad 3.9$$

$$LLCR_{k\alpha}^{\mu} \geq \rho \quad 3.10$$

Where:

$$\Phi_{\alpha}^{CP^{\mu}} = \sum_{t=1}^{CP} \frac{RY_{t\alpha}^{\mu}}{(1+r_{\alpha}^{\mu})^t}, \Psi_{\alpha}^{PCP^{\mu}} = \sum_{t=CP+1}^{t_e} NPV_{t\alpha}^{\mu} = \sum_{t=CP+1}^{t_e} \frac{(\text{Rev}_{t\alpha}^{\mu} - C_{t\alpha}^{\mu})}{(1+r_{\alpha}^{\mu})^t}$$

$$EBIT_{t\alpha}^{\mu} = \text{Rev}_{t\alpha}^{\mu} - \text{O\&M}_{t\alpha}^{\mu} - \text{DEP}_{t\alpha}^{\mu},$$

$$C_{t\alpha}^{\mu} = \text{O\&M}_{t\alpha}^{\mu} + \text{Tax}_t$$

$$VFM_{\alpha}^{\mu} = \nabla NPV^{PSC-PPP} = NPV^{PSC} - NPV^{PPP}, SLR_{\alpha}^{\mu} = \frac{NPV_{R\alpha}^{\mu}}{NPV_{C\alpha}^{\mu}}$$

$$DSCR_{t\alpha}^{\mu} = \frac{EBIT_{t\alpha}^{\mu} + \text{DEP}_{t\alpha}^{\mu} - \text{Tax}_t}{D}$$

$$LLCR_{k\alpha}^{\mu} = \frac{\sum_{t=k}^N \left(\frac{EBIT_{t\alpha}^{\mu} + \text{DEP}_{t\alpha}^{\mu} - \text{Tax}_t}{(1+r_{\alpha}^{\mu})^{(t-k+1)}} \right)}{\sum_{i=k}^N \left(\frac{D_{t\alpha}^{\mu}}{(1+r_{\alpha}^{\mu})^{(t-k+1)}} \right)}$$

The decision variables, known as independent variables, in the multi-objective model shown by Equations (3.1) - (3.10) are negotiable concession items (NCIs). Most important items are tariff/toll, concession period and royalty. These are the components of other parameters like revenue (apart

from decision variables like toll, in some cases, the parameters like capacity, are also decision variables).

The conceptual feasible negotiation space (negotiation yield) of the project based on the defined project objective functions is demonstrated in Figure 3-5. The x-axis is private sector payoff (Π_p) which is between the payoffs at the hurdle rate (minimum internal rate of return, MIRR) and maximum return acceptable by the public sector. The y-axis is public sector payoff (Π_g) which is between the payoffs at VFM_{min} and VFM_{max} ($\Phi_{\alpha}^{CP\mu}$ and $\Psi_{\alpha}^{PCP\mu}$ are assumed to be same for all bid submissions by tenderers). So the feasible negotiation space is the shaded area which is limited to the maximum and minimum value of public and private sectors' payoffs. This area is also restricted by $DSCR_{min}$ and $LLCR_{min}$ to meet the lenders requirements (they are assumed to be linear functions of Π_p and Π_g). The Nash equilibrium solution would be located at the bottom area near to the intersection point. The Pareto optimal solution is located at the top area near to Pareto frontier curve. Within these two areas indifference curves could be defined based on the players' utility functions.

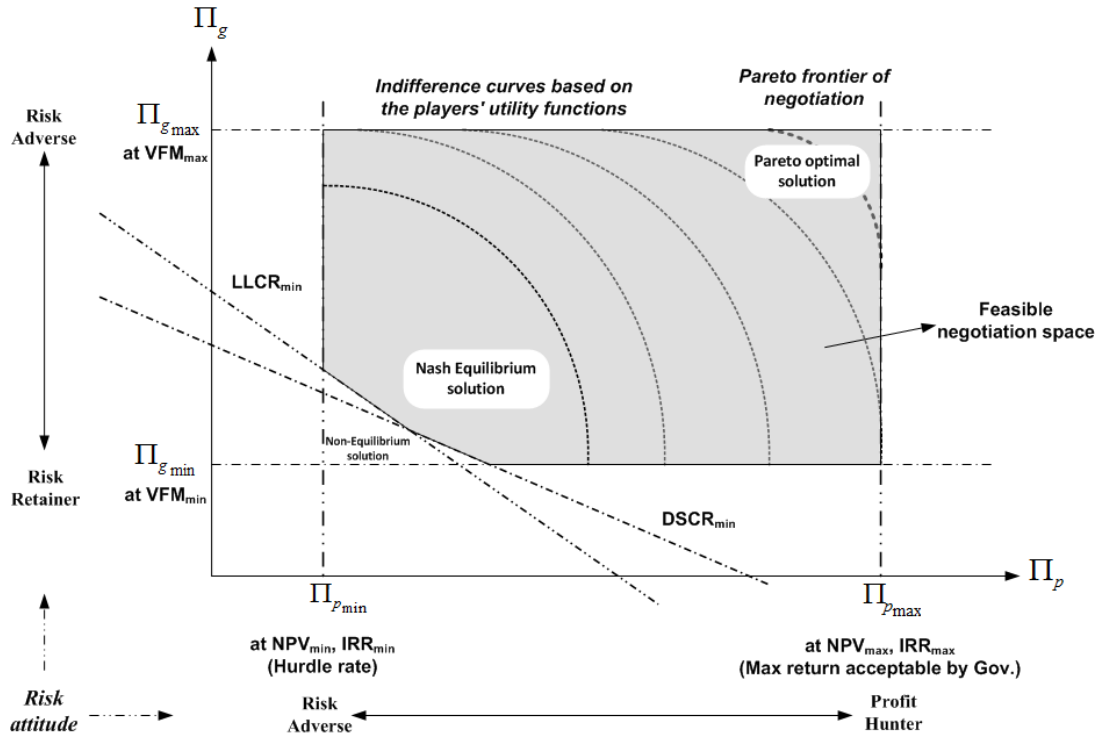


Figure 3-5 Conceptual feasible negotiation yield (negotiation space) for a PPP-BOT project during development phase

3.6.1 The Conceptual Negotiating Model for PPP-BOT Projects

Consider a game theory problem with two players, government and concessionaire, at development phase of a PPP-BOT project. Assume $U_i(x)$ is the utility function (payoff) associated with each player i ($i=1, 2$) such that if strategy X ($X \in S$, S is the possible negotiation space) is selected, player i 's payoff will be $U_i(x)$ ($i=1, 2$). These two players are involved in negotiating and wish a deal such that their payoff functions are maximized. There also exists a status quo point $X_w \in S$ that is called Nash equilibrium position such that if both players decide not to cooperate (bid preparation and tendering stage), their payoffs will be $u^* = U_1(X_w)$ and $v^* = U_2(X_w)$ respectively. Status quo is a Latin term meaning the current or existing state of affairs. To maximize their payoffs and utilities, player 1 wishes a deal denoted by a point as far to the right as possible in S , while player 2 desires a point as high in S as

possible. Using the diagram of S, it can be seen that the Polygon Pareto optimal frontier of Payoffs (Polygon Ω) represents the best payoffs both players can hope for (see Figure 3-6). The negotiating model developed in this study is an extension and modification of the model presented by Dhingra and Rao (1995).

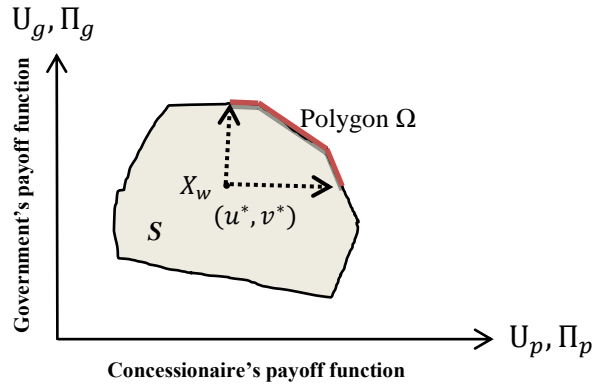


Figure 3-6 Pareto optimal frontier

Assume set of options S is a convex bounded and closed area and a special point $X_w \in S$ corresponding to point of initial agreement between the players called Nash equilibrium position, and a set of payoff functions $U_i(x)$, $i=1,2$, associated with each player: $U_1(x) = U_p$, $U_2(x) = U_g$.

To determine a fair solution, a plausible negotiating function is defined as:

$$B(x) = \prod_{i=1}^2 [U_i(x) - U_i(X_w)] = [U_p(x) - U_p(X_w)][U_g(x) - U_g(X_w)] \quad 3.11$$

$$\text{For all } X_w \in S^*, S^* = [X | X \in S, U_i(x) - U_i(x_w) \geq 0] \quad 3.12$$

An optimum compromise solution X^{opt} is then given as

$$B(X^{opt}) = \max B(x), X_w \in S^*. \quad 3.13$$

This negotiating scheme returns an option X^{opt} which maximizes the product of each player's distance from the Nash equilibrium position. Consider now an MOP problem with 2 objective functions, Π_p and Π_g . A game theory formulation for this problem consists of 2 players where each player

corresponds to an objective function. The bargaining function $B(x)$ for this MOP problem is given as:

$$B(x) = \prod_{i=1}^2 [\Pi_i(X) - \Pi_i(X_w)] = [\Pi_p(X) - \Pi_p(X_w)] [\Pi_g(X) - \Pi_g(X_w)] \quad 3.14$$

Here objective functions $\Pi_i(X)$ and the utility functions $U_i(X)$ have to be maximized. In equation (3.14) $\Pi_i(X_w)$ is the worst value (status quo) of objective function Π_i that player i is willing to accept. Implicit in the negotiating function given is the assumption that all objective functions are equally important. If we associate differing degrees of importance with objective functions, the plausible negotiating function $B(x)$ is generalized as:

$$B(x) = \prod_{i=1}^2 ([\Pi_i(X) - \Pi_i(X_w)] * w_i) \quad 3.15$$

where w_i 's are relative degrees of importance of objective function Π_i . The weights w_i can be determined using the Saaty's method of paired comparisons (Saaty, 1997). Thus game theory formulation for an MOP problem bring in:

$$Max B(x) = \prod_{i=1}^2 ([\Pi_i(X) - \Pi_i(X_w)] * w_i) \quad 3.16$$

Subject to $X \in S^*$ and $\sum_{i=1}^2 w_i = 1$

The game theory formulation for an MOP problem yields an optimum solution that is Pareto optimal and insures that at the final solution all objective functions attain acceptable values. This computational procedure helps each player analyse the maximum benefit that can be obtained while negotiating with other players in different stages. The conceptual negotiating model given in equation 3.16 permits a trade-off between various goals; whereby players are willing to compromise their own payoffs to improve the position overall.

3.6.2 Fuzzy Game Theory: Dealing With Uncertainty and Risk

To be realistic, by considering PPP projects as a game, it is necessary to take into account that it is a game played with imperfect and incomplete information. This means that players involved in the negotiations maximize their bargaining power and consequently their payoff by expanding their access to information.

Zadeh (1965) introduced the concept of fuzzy set theory. Based on the extension principle, the arithmetic of fuzzy numbers can be derived. Generally a fuzzy interval is represented by two *fuzzy numbers* and membership functions, such as *triangular and trapezoid fuzzy numbers* (*T.F.N* and *Tr.F.N*). An α -cut operation can be applied to the fuzzy numbers. If we denote an α -cut interval for fuzzy number $TrFN = \tilde{A} = (a_1, a_2, a_3, a_4)$ as \tilde{A}_α , the obtained interval \tilde{A}_α is defined as $\tilde{A}_\alpha = [a_2^\alpha, a_3^\alpha]$. Table 3-3 demonstrates public-private general game of PPP decision model under risk and uncertainty. The expected utility of each party associated with each strategy is also established. The payoff functions may be obtained as fuzzy numbers using fuzzy Delphi method: $\tilde{A}_i = (a_{i1} \ a_{i2} \ a_{i3} \ a_{i4})$ and $\tilde{B}_i = (b_{i1} \ b_{i2} \ b_{i3} \ b_{i4})$. i is ordered pair index in payoff table. Then by applying fuzzy operational laws the expected payoff of each player is computed. ($a_{i1} < a_{i2} < a_{i3} < a_{i4}$ and $b_{i1} < b_{i2} < b_{i3} < b_{i4}$)

Table 3-3 Two-parties general fuzzy game of PPP Decision Model				
			Public Sector (Player2)	
	Probability		q	$1-q$
		Strategy	F_1	F_2
Private investor (Player1)	p	S_1	$(\tilde{A}_1, \tilde{B}_1)$	$(\tilde{A}_2, \tilde{B}_2)$
	$1-p$	S_2	$(\tilde{A}_3, \tilde{B}_3)$	$(\tilde{A}_4, \tilde{B}_4)$

$$\begin{aligned}\tilde{A}_1 &= (a_{11}, a_{12}, a_{13}, a_{14}), \tilde{A}_2 = (a_{21}, a_{22}, a_{23}, a_{24}), \tilde{A}_3 = (a_{31}, a_{32}, a_{33}, a_{34}), \tilde{A}_4 = \\ &= (a_{41}, a_{42}, a_{43}, a_{44}), \quad \tilde{B}_1 = (b_{11}, b_{12}, b_{13}, b_{14}), \quad \tilde{B}_2 = (b_{21}, b_{22}, b_{23}, b_{24}), \quad \tilde{B}_3 = \\ &= (b_{31}, b_{32}, b_{33}, b_{34}), \quad \tilde{B}_4 = (b_{41}, b_{42}, b_{43}, b_{44})\end{aligned}$$

Fuzzy operational laws (Zadeh, 1965, 1975) are as follows. Assuming:

Fuzzy addition: $\tilde{A}_1 + \tilde{A}_2 = (a_{11} + a_{21}, a_{12} + a_{22}, a_{13} + a_{23}, a_{14} + a_{24})$, Fuzzy

subtraction: $\tilde{A}_1 - \tilde{A}_2 = (a_{11} - a_{24}, a_{12} - a_{23}, a_{13} - a_{22}, a_{14} - a_{21})$, Fuzzy

multiplication: $\tilde{A}_1 * \tilde{A}_2 = (a_{11} * a_{21}, a_{12} * a_{22}, a_{13} * a_{23}, a_{14} * a_{24})$, Fuzzy

division: $\tilde{A}_1 / \tilde{A}_2 = \left(\frac{a_{11}}{a_{24}}, \frac{a_{12}}{a_{23}}, \frac{a_{13}}{a_{22}}, \frac{a_{14}}{a_{21}} \right)$

Scalar multiplication: $k * \tilde{A}_1 = (k * a_{11}, k * a_{12}, k * a_{13}, k * a_{14})$ if $k > 0$,

(k: scalar) $k * \tilde{A}_1 = (k * a_{14}, k * a_{13}, k * a_{12}, k * a_{11})$ if $k < 0$

Since the expected payoff of player 1 is:

$$E[U(Y_1)] = q[\tilde{A}_1 * p + \tilde{A}_3 * (1-p)] + (1-q)[\tilde{A}_2 * p + \tilde{A}_4 * (1-p)], \text{ So:}$$

$$E[U(Y_1)] = q[(a_{11}, a_{12}, a_{13}, a_{14})p + (a_{31}, a_{32}, a_{33}, a_{34})(1-p)] +$$

$$(1-q)[(a_{21}, a_{22}, a_{23}, a_{24})p + (a_{41}, a_{42}, a_{43}, a_{44})(1-p)] =$$

$$\begin{pmatrix} q[pa_{11} + (1-p)a_{31}] + (1-q)[pa_{21} + (1-p)a_{41}], \\ q[pa_{12} + (1-p)a_{32}] + (1-q)[pa_{22} + (1-p)a_{42}], \\ q[pa_{13} + (1-p)a_{33}] + (1-q)[pa_{23} + (1-p)a_{43}], \\ q[pa_{14} + (1-p)a_{34}] + (1-q)[pa_{24} + (1-p)a_{44}] \end{pmatrix}$$

In conclusion: $E[U(Y_1)] = (y_{11}^*, y_{12}^*, y_{13}^*, y_{14}^*)$ where:

$$y_{11}^* = q[pa_{11} + (1-p)a_{31}] + (1-q)[pa_{21} + (1-p)a_{41}],$$

$$y_{12}^* = q[pa_{12} + (1-p)a_{32}] + (1-q)[pa_{22} + (1-p)a_{42}],$$

$$y_{13}^* = q[pa_{13} + (1-p)a_{33}] + (1-q)[pa_{23} + (1-p)a_{43}],$$

$$y_{14}^* = q[pa_{14} + (1-p)a_{34}] + (1-q)[pa_{24} + (1-p)a_{44}]. \quad 3.17$$

Similarly, the expected payoff of player 2 $E[U(Y_2)] = (y_{21}^*, y_{22}^*, y_{23}^*, y_{24}^*)$

where:

$$y_{21}^* = q[pb_{11} + (1-p)b_{31}] + (1-q)[pb_{21} + (1-p)b_{41}],$$

$$\begin{aligned}
y_{22}^* &= q[pb_{12} + (1-p)b_{32}] + (1-q)[pb_{22} + (1-p)b_{42}], \\
y_{23}^* &= q[pb_{13} + (1-p)b_{33}] + (1-q)[pb_{23} + (1-p)b_{43}], \\
y_{24}^* &= q[pb_{14} + (1-p)b_{34}] + (1-q)[pb_{24} + (1-p)b_{44}].
\end{aligned}
\tag{3.18}$$

3.6.3 Crisp Games: No Uncertainty and Risk

Table 3-4 demonstrates public-private general game of PPP decision model under deterministic assumption of payoffs or the case of crisp games. The expected utility of each party can be established.

In classical set theory, the membership of elements in relation to a set is assessed in binary terms according to a bivalent condition. An element either belongs or does not belong to the set, the boundary condition of the set is crisp.

Table 3-4 Two-parties general game of PPP Decision Model				
			Public Sector (Player2)	
	Probability	Strategy	q	$1-q$
			F_1	F_2
Private investor (Player1)	p	S_1	(a_1, b_1)	(a_2, b_2)
	$1-p$	S_2	(a_3, b_3)	(a_4, b_4)

Pure strategies selected by player2(Y_2)		Expected payoff for player1(Y_1)
F₁ (w.pr.: q)		$a_1p + a_3(1-p)$
F₂ (w.pr.: 1-q)		$a_2p + a_4(1-p)$
$\Rightarrow E[U(Y_1)] = q[a_1p + a_3(1-p)] + (1-q)[a_2p + a_4(1-p)]$		
Pure strategies selected by player1(Y_1)		Expected payoff for player2(Y_2)
S₁ (w.pr.: p)		$b_1q + b_2(1-q)$
S₂ (w.pr.: 1-p)		$b_3q + b_4(1-q)$
$\Rightarrow E[U(Y_2)] = p[b_1q + b_2(1-q)] + (1-p)[b_3q + b_4(1-q)]$		

3.6.4 Bid Competition Game Model

The bid competition includes two types of games, *game with the government* and *game with competitors*. The pure strategy NE solution of the game with competitors is examined by Ho (2005). The mixed strategy NE solution of this game as well as the game with the government is studied and developed in this present chapter. Fuzzy game is implemented by applying the equations that were developed in section 3.6.2, fuzzy game theory.

Game with the Government

The first type of game in bid competition is the game with government. This game is studied in the present chapter. The strategies and corresponding payoff functions are illustrated in Table 3-5. Private investor's strategies are contract fulfilment (keep the project at contracted quality and price at the agreed level) and profit maximization (deviate from contract by lowering quality or increasing prices from agreed level). The government's set of strategies consists of regulate the contract/bid (i.e. enforcement of contract specificity, quality standards and marginal cost pricing (tariff/toll cap)) and not regulate the contract/bid. Under strategy profit maximization, the private investor is subject to pay its cost. Under strategy regulate the contract/bid; the government is subject to pay the cost of regulation and also to pay royalty to the private investor.

Table 3-5 Public-Private game of Bid competition Decision Model			
		Government	
Concessionaire	Strategy	Not regulate the contract/bid	Regulate the contract/bid
	Contract fulfilment	$(\Pi_{p_{min}}, \Pi_g)$	$(\Pi_{p_{min}} + R, \Pi_g - R - C_r)$
	Profit maximization	$(\Pi_{p_{max}}, \Pi_g + C_p)$	$(\Pi_{p_{max}} + R, \Pi_g - R - C_r + C_p)$

The normalized payoff functions of the above game are as follows.

<i>Strategy</i>	<i>Not regulate the contract/bid</i>	<i>Regulate the contract/bid</i>
<i>Contract fulfillment</i>	$(-R, R + C_r)$	$(0, 0)$
<i>Profit maximization</i>	$(\Pi_{p_\Delta} - R, C_p + C_r + R)$	(Π_{p_Δ}, C_p)

Where $\Pi_{p_\Delta} = NPV_{\Delta} : NPV_{max} - NPV_{max}$

So (Profit maximization, Not regulate the contract/bid) strategy is the pure strategy Nash Equilibrium solution.

Game with Competitors

The second type of game in bid competition is the game with competitors. The pure strategy NE solution of this game is examined by Ho (2005). In the present chapter, by introducing the probability distribution over the strategies, the mixed strategy NE solution is studied. Table 3-6 illustrates this game. The *optimal mixed strategy* for bidder 1 is considered. The expected payoff for player1 is illustrated as follows. These expected payoffs are plotted on a graph to implement Minimax theorem. By drawing L1 & L2 and using minimax (or maximin) criterion, optimal mixed strategy for player 1 could be found (Figure 3-7). For example, in the case that players choose strategies (H, H) and (A, A), since both have same level of efforts the compensation and profit are divided equally.

Table 3-6 Two-bidder game of Bid competition/compensation Decision Model				
			Bidder 2	
Bidder 1	probability	Strategy	q	$1 - q$
			H	A
	p	H	$(\frac{S}{2} + \frac{T}{2} - E, \frac{S}{2} + \frac{T}{2} - E)$	$(T - E, S)$
	$1 - p$	A	$(S, T - E)$	$(\frac{S}{2} + \frac{T}{2}, \frac{S}{2} + \frac{T}{2})$

Explanations and Notations:

1. *Level of efforts as strategies:* High (denote by H-with extra cost “E” to improve the quality of the proposal) and Average (denote by A-without extra cost)

2. Fixed amount of bid compensation, “S”: the fixed amount can be expressed by a certain percentage of the average profit, denoted as “T”.
3. Probability of choosing each strategy H&A (H,A) for bidders 1 & 2: $(p, 1 - p)_{Y_1}, (q, 1 - q)_{Y_2}$

Pure strategies selected by player2(Y_2)	Expected payoff for player1(Y_1)
H (w. pr.: q)	$\left(\frac{S}{2} + \frac{T}{2} - E\right)p + (S)(1 - p)$
A (w. pr.: $1 - q$)	$(T - E)p + \left(\frac{S}{2} + \frac{T}{2}\right)(1 - p)$

Pure strategies selected by player1(Y_1)	Expected payoff for player1(Y_1)
H (w. pr.: p)	$\left(\frac{S}{2} + \frac{T}{2} - E\right)q + (T - E)(1 - q)$
A (w. pr.: $1 - p$)	$(S)q + \left(\frac{S}{2} + \frac{T}{2}\right)(1 - p)$

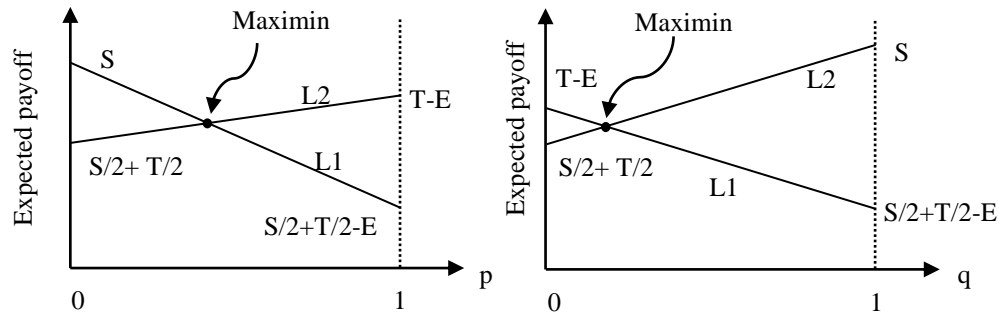


Figure 3-7 Graphical procedures for solving Game

In other words, player1 expected payoff is:

$$\begin{aligned}
 E[Y_1] = & q \left[p \left(\frac{S}{2} + \frac{T}{2} - E \right) + (1 - p)(S) \right] \\
 & + (1 - q) \left[p(T - E) + (1 - p) \left(\frac{S}{2} + \frac{T}{2} \right) \right]
 \end{aligned}$$

Player 2 aims to minimize this expected payoff for player1. Given p , player 2 can minimize this expected payoff by choosing the pure strategy that corresponds to the “bottom” line for that p in Figure 3-7. According to the minimax (or maximin) criterion, player1 wants to maximize this minimum expected payoff. Consequently, player 1 should select the value of p where the bottom line peaks, i.e., where the L_1 and L_2 lines intersect, which yields an expected payoff of:

$$L_1 = p \left(\frac{S}{2} + \frac{T}{2} - E \right) + (1 - p)(S), \quad L_2 = p(T - E) + (1 - p) \left(\frac{S}{2} + \frac{T}{2} \right) \quad 3.19$$

On the other hand:

$$\text{Expected payoff for player1 by choosing H} = q \left(\frac{S}{2} + \frac{T}{2} - E \right) + (1 - q)(T - E)$$

$$\text{Expected payoff for player1 by choosing A} = q(S) + (1 - q) \left(\frac{S}{2} + \frac{T}{2} \right)$$

Expected payoff for player1:

$$E[Y_1] = p \left[q \left(\frac{S}{2} + \frac{T}{2} - E \right) + (1 - q)(T - E) \right] + (1 - p) \left[q(S) + (1 - q) \left(\frac{S}{2} + \frac{T}{2} \right) \right] \quad 3.20$$

To calculate mixed strategy Nash Equilibrium the following equation must satisfy:

$$q \left(\frac{S}{2} + \frac{T}{2} - E \right) + (1 - q)(T - E) = q(S) + (1 - q) \left(\frac{S}{2} + \frac{T}{2} \right), \quad 3.21$$

$$\text{So: } q = \frac{S/2 - T/2 + E}{2T - 2E}$$

To solve algebraically for this optimal value of p at the intersection of the two lines L_1 and L_2 , the following equation is set:

$$p \left(\frac{S}{2} + \frac{T}{2} - E \right) + (1 - p)(S) = p(T - E) + (1 - p) \left(\frac{S}{2} + \frac{T}{2} \right), \quad 3.22$$

$$\text{So: } p = \frac{S/2 - T/2}{2E}$$

3.6.5 Application of Game Theory before Nominating the Selected Bidder

In the course of the prolonged and costly development phase, the aim of each bidder is to be nominated as selected bidder (the first best bidder: concessioner). It is common for failed negotiations to conduct on contemplation of the reserved bidder. So bidders try to carry out better than their competitors. Thus the game type in this stage is non-cooperative game. Each consortium's bid is treated as a game. It is a “*Simultaneous Move Game*” where players make their strategy choices simultaneously, without knowing thoroughly the strategies that have been chosen by other players. The games at this period are played on the basis of *incomplete information*, as

players may not know some/complete information about the other players, e.g. strategies, payoffs and priorities.

So, the games at the first part of development phase, bid preparation and tendering stage, are non-cooperative non-zero incomplete information simultaneous static games. Each bidder principally is inclined to play a *two-person game* with the government agency. Thus the government agency will play several games simultaneously with the respective bidders. Furthermore, the public sector has a tendency to play pure strategies before the a bidder is nominated, while the private sector consortia “*concessionaire*” tends to play by means of mixed strategies.

At this stage lengthy, costly and complex negotiations are held between the two main parties, i.e. public sector “*government agency*” and private sectors “*concessionaire*” as PPP project investors. All necessary issues are highlighted and negotiated. They bargain on *NCIs* such as length of concession “*concession period*”, *tariff/toll* and *royalty*. For the sake of simplicity of decision making in the bid, normally government agency is willing to provide complete and standard bid documents and employ it in the bid. In this kind of bid documents every component of contract, including all contractual parameters such as technical, financial, and etc. aspects of the project are set and predetermined clearly. Only one contractual parameter such as *tariff/toll* is remained as decision variable for bid participants to propose and the government agency will decide and nominate the best bidder as concessionaire based on this remaining contractual parameter.

3.6.6 Application of Game Theory after Nominating the Selected Bidder

At this stage, lengthy, costly and complex negotiations are held with third parties such as insurers and EPC contractors. The results of these negotiations may affect main negotiations between two main parties, i.e. the public sector “government agency” and the private sector consortium “concessioner”. As a major result, two main parties will revisit and verify the *risk allocation* and *re-assess* the risk profile of the project. Benefits and risks could be shared while negotiating. These issues lead negotiating parties to finalize the terms of concession agreement. A life-cycle financial model is often used to evaluate the financial outcome of the project in long-term perspective. The concessioner and government agency’s attitude at this stage is changed to co-operative type of game, with the objective of achieving a win-win result. The “*extensive form*” can be used to represent the games at this stage. Information is agreed to flow easily between two players. The open book approach is adopted here, as it is beneficial to the two parties to do so. This is applicable in direct negotiation method.

Here the two parties negotiate several issues i.e. *NCIs*, especially the project risks and their consequences for payoffs. Some of the risks may be shared between the two parties. Where the private sector feels it is being asked to bear an unusual risk, it will propose to either refuse or charge a high premium for it. The government agency would then respond. By means of “*Alternating Offers Bargaining*” the two parties would negotiate such an issue until it is resolved to their satisfaction. Briefly, the games at final negotiations stage are cooperative non-zero complete and perfect information dynamic

games. The solution of the game at this stage is proposed to achieve based on the “*Pareto efficiency or Pareto optimality*” concept.

3.7 Illustrative Hypothetical Example

Chapter 7 covers a real case study with full detail. Here, a hypothetical simple example on bid competition, game with competitors, is used to illustrate the basic concepts and the applicability of the proposed game model and its analysis. Bid competition, game with competitors, was studied in section 3.6.4. Following assumptions are adopted in this hypothetical simple example. The profit is assumed as uncertain variable and is estimated as triangular fuzzy number (T.F.N). $T=\langle 0.85,1,1.1 \rangle$ M\$. $S=0.07T$, $E=0.05T$. The game is illustrated in Table 3-7.

Table 3-7 Hypothetical example on bid competition, game with competitors				
			Bidder 2	
	probability	Strategy	0.4	0.6
			<i>H</i>	<i>A</i>
Bidder 1	0.6	<i>H</i>	$(0.485T, 0.485T)$	$(0.95T, 0.07T)$
	0.4	<i>A</i>	$(0.07T, 0.95T)$	$(0.535T, 0.535T)$

By using equations 3.17 and 3.18, the expected payoff of players 1 and 2 are computed:

$$E[U(Y_1)]=\langle 0.585,0.689,0.758 \rangle \text{ and } E[U(Y_2)] = \langle 0.496,0.583,0.642 \rangle.$$

As can be seen the expected payoffs are fuzzy numbers.

3.8 Conclusion Remarks

Game theory is a tool which enables decision makers to understand players’ behaviour and model games, foreseeing outcomes based on the rules and determine the negotiation position. This chapter has presented the game theory model for determining negotiation positions. The aim of this chapter

was to ensure each player the highest possible expected payoff under uncertainties and risks. The game theory was applied in development phase of PPP-BOT project. Based on these results, the development phase of PPP-BOT project is divided into two stages. The proposed mathematical model reveals that by increasing the cooperation between public and private sectors, the game type of negotiation is changed from incomplete static game to complete and perfect dynamic game. By this movement the payoff of both players are increased from Nash equilibrium position to Pareto optimality position. One advantage of game theory is that it can capture and anticipate behaviours in complex projects with multiple players and multiple diverse and inconsistent objectives.

This chapter proposes appropriate type of game to solve the problems and difficulties involved. This capability facilitates the generation of alternative negotiation outcomes for both public and private sectors which are strategically stable during the development phase of PPP-BOT projects. In addition, game theory provides a method and module for achieving win-win solutions.

Currently, the payoff of game theory is deterministic and this is a major drawback of game theory application. Thus, current research has focused on the integration of game theory and possibility theory (fuzzy logic) to manage the uncertainties involved in the game. This limitation has been omitted by extending to fuzzy game theory.

By using this chapter's approaches both parties gain more in PPP-BOT projects in compare to conventional approaches. The expected earnings can be calculated properly based on the fuzzy game theory approach for the strategy

outlined for each player. Thus, if players cooperate together (cooperation case), they will go for Pareto optimal, which the position is more efficient than Nash equilibrium.

CHAPTER 4 FUZZY RANDOMNESS SIMULATION OF LONG TERM INFRASTRUCTURE PROJECTS

4.1 Introduction

Conventional simulation model in prediction of long term infrastructure development systems such as PPP-BOT projects assumes single probabilistic values for all of the input variables. Traditionally, all the input risks and uncertainties in the Monte Carlo Simulation (MCS) are modelled based on the probability theory and then the simulation is performed. Its output result is also presented by a probability distribution function (PDF) and a cumulative distribution function (CDF) and is utilized for analysis decision making. However, in reality, some of the variables are estimated based on the experts' judgment and some are derived from historical data (previous projects). Also, the parameters' data of probability distribution for the simulation model input are subject to change and are difficult to predict. Therefore, a simulation model which is capable of handling both types of fuzzy and probabilistic input variables is needed and vital. Recently fuzzy randomness, which is the extension of classical probability theory, provides additional features and improvements for combining fuzzy and probabilistic data to overcome aforementioned shortcomings.

Fuzzy Randomness Monte Carlo Simulation (FR-MCS) technique is a hybrid simulation approach for risk and uncertainty evaluation. The proposed approach permits any type of risk and uncertainty in the input values to be explicitly defined prior to the decision analysis being undertaken. It extends the practical use of the conventional MCS by providing the capability of

choosing between fuzzy sets and probability distributions. This is done to quantify the input risks and uncertainties in a simulation. A new algorithm for generating fuzzy random variables is developed as part of the proposed FR-MCS technique based on the α -cut. FR-MCS output results are represented by fuzzy probability and the decision variables are modelled by fuzzy CDF. The FR-MCS technique is demonstrated in a PPP-BOT case study. The FR-MCS results are compared with those obtained from the conventional MCS. It is shown that FR-MCS technique facilitates decision making for both the public and private sectors' decision makers involved in PPP-BOT project by determining a negotiation bound for negotiable concession items instead of crisp value as posed to do in conventional MCS's output result. This approach prevents prolonged and costly negotiations in development phase of PPP-BOT projects by providing more flexibility for decision makers. Both parties could take benefit of this technique at negotiation table.

This chapter proposes a new technique, FR-MCS, for uncertainty and risk modelling and their propagation in the simulation model. The proposed technique generalizes the conventional MCS. FR-MCS can be utilized in risk assessment as an alternative to the conventional MCS. In this chapter a comparison of the two approaches relative to their computational requirements, data requirements and availability is provided. Understanding negotiation bound and maximizing gains within the bound are the main benefit and advantage of this approach.

This chapter is organized as follows: firstly, after a discussion on decision making under uncertainty and risk, the related works in the literature are reviewed. Secondly, conventional MCS and value at risk are considered.

Thirdly, FR-MCS technique is proposed and studied in detail. A new algorithm is proposed to generate fuzzy random variables. Finally, FR-MCS is applied for decision making under uncertainty and risk in a real case of PPP-BOT project.

4.2 Decision Making Under Uncertainty and Risk

A majority of decision making in real projects takes place in an environment in which the objective functions, the constraints and the consequences of possible actions are not precisely known. Moreover, the historical data for long term infrastructure development systems are not normally available and therefore are not directly determinable. Even the available data from previous projects cannot be used since in general each project is unique. Difficulties arise if the available information is limited and is of a fuzzy rather than of a stochastic nature. To use historical data expert knowledge must be applied. Expert knowledge is especially useful in the development phase when insufficient data are available for negotiations.

In order to achieve an appropriate simulation modelling in accordance with the nature of the underlying input data, it is common to use non-deterministic methods. Typically, there are two types of uncertainties: *Randomness* due to inherent variability and *fuzziness* due to imprecision and lack of knowledge and information. The former type of uncertainty is often referred to as objective, aleatory and stochastic whereas the latter is often referred to as subjective, imprecise and being a major source of imprecision in many decision processes. Our argument is that there is a need for differentiation between the two types of imprecision modelling. The distinction between aleatory and imprecise uncertainty plays a particularly important role in the

quantitative risk assessment framework (e.g., MCS) that is applied to complex and long term infrastructure development systems.

Risk (randomness characteristic) that refers to probabilistic features is expressed by stochastic models (probability theory and statistical methods) and uncertainty (fuzziness characteristic) that refers to non-probabilistic, also called possibilistic, features is represented by fuzzy sets (theory of possibility). In this research for simplicity, the former is called *stochastic* and the latter is called *fuzzy*.

A fuzzy set (Zadeh, 1965) is a non-probabilistic method and model used in subjective modelling which overcomes the short comings of the probabilistic methods. Briefly, fuzzy approach is used due to unique aspects of a project, lack of data and subjectivity. In these circumstances subjective judgment and linguistically information obtained from the practitioners of a PPP-BOT project, is often necessary and leads to non-probabilistic uncertainty modelling, or fuzziness.

The distinction between risk (stochastic) and uncertainty (fuzzy) helps to avoid inappropriate modelling of the non-deterministic input data, especially when both probabilistic and non-probabilistic components appear. Because practical situations of risk computation often involve both types of vagueness, methods are needed to combine these two modes of ambiguity representation in the propagation step of simulation. Also, a more vigorous investment decision method that incorporates both risk and uncertainty in simulation and financial modelling and evaluation is needed.

In the current risk assessment practice, both types of uncertainties are represented by means of probability distributions. In other words, to deal

quantitatively with imprecision, traditionally the concepts and techniques of probability theory have been employed. This approach has some shortcomings to overcome uncertainties in decision makings. The conventional simulation approach presented in the literature review is incapable of fuzzy modelling. Hence, the estimation and simulation of the project data and decision variables is unreliable. Therefore, other theories and computational methods that propagate uncertainty and variability in exposure and risk assessment are needed.

This chapter presents an adequate hybrid simulation model and its procedure regarding risk analysis process and uncertainty propagation in PPP-BOT projects using non-deterministic approaches. The focus of this chapter is non-probabilistic features of the simulation input data and the representation of the uncertainty by fuzzy numbers. This approach leads to better decisions in negotiations for main parties involved in long term infrastructure projects. In the proposed fuzzy randomness simulation model, random variables and random processes are utilized to cater for the objective input variables and their assessment. Furthermore, fuzzy variables and fuzzy inference system (FIS) are utilized to cater for the subjective input variables and their assessment. Fuzzy probability approach is used to combine these two variables in the simulation process. Having a simulation approach that can deal with stochastic and fuzzy process is fundamental and crucial in risk analysis process of PPP-BOT projects. Then probabilistic and possibilistic risk and uncertainty assessment technique is carried out instead of the conventional probabilistic risk assessment (PRA). This approach introduces a new concept and uncertain characterization method that is called uncertainty modelling.

The negotiation simulation problem including parameters with undeclared and vague probabilities is solved by a combination of stochastic simulation and fuzzy analysis. The simulation output is then captured in terms of fuzzy probability which denotes success/failure in project objectives based on the predetermined criteria. In this context fuzzy probability approach provides a powerful tool to combine the observed data and judgmental information. Fuzzy randomness simultaneously describes objective and subjective information as a fuzzy set of possible probabilistic models over some range of imprecision. This generalized uncertainty and risk model contains fuzziness and randomness as special cases.

The output of a risk analysis based on the conventional MCS is therefore a probability distribution (PDF, CDF) of all probable expected returns, offering the prospective investors an incomplete return profile which is called risk profile of the project showing all the probable outcomes that could result from the investment decision. Conversely, the output of a risk and uncertainty analysis based on the FR-MCS is a set (range) of probability distribution (PDF, CDF) of all probable and possible expected returns, offering the prospective investors a complete return profile which is called risk and uncertainty profile of the project showing all the probable and possible outcomes that could result from the investment decision.

If sufficient information to generate PDFs and CDFs of the parameters as random variables are not available, but expert knowledge or scarce data exists to represent the PDF and CDF of the parameters as fuzzy numbers with appropriate membership function, then fuzzy set theory can be utilized to treat the uncertainties in these parameters. In the subjective probabilities approach,

there are two cases for possibility risk assessment. In the first case, instead of describing the parameters of PDFs and CDFs as crisp value, e.g. mean (μ) and standard deviation (σ) for normal distribution, they can be described as fuzzy numbers. This case is called Alternative 1, fuzzy randomness. Alternatively, in the context of PPP-BOT projects, fuzzy parameters and numbers are directly used to address lack of data or subjective issues. This case is called Alternative 2, pure fuzzy.

As can be seen in literature review, section 2.3, varieties of mathematical models are developed to address risk and uncertainty modelling. In this chapter, fuzzy randomness (Moller and Beer, 2004) is used as an appropriate approach. The proposed fuzzy randomness simulation of long term infrastructure projects is a modification of Moller and Beer (2004). Uncertainty of the simulation input data can be modelled appropriately with the aid of non-probabilistic methods under possibility theory. Fuzzy set is common non-probabilistic model for uncertainty modelling. Furthermore, fuzzy probability which is the focus of this chapter is applied properly when risk and uncertainty appear simultaneously.

The possibility theory is utilized directly to reflect uncertainties based on the experts judgments. Fuzzy set theory is used in combination with probabilistic methods to generate hybrid approaches for risk and uncertainty assessment studies. Vague probabilistic models for the uncertain variables and parameters are determined with the aid of fuzzy numbers. However, the proposed algorithm for generating fuzzy random variable and FR-MCS is simpler to implement because it is an interval analysis based on the α -level

sets (α -cuts) of the input fuzzy sets. FR-MCS is carried out for finding the inferior and superior values of the output α -cuts intervals.

4.3 Monte Carlo Simulation Technique

The MCS is a method for analysing risk propagation, where the goal is to study outcome variability of a system (Wittwer, 2004). The MCS is currently regarded as a powerful technique for cash flow analysis and analysing its problems especially for long term infrastructure projects. To do this the conventional PRA technique is carried out. (Reilly, 2005; Dey and Ogunlana, 2004; Stock and Watson, 2005). Full statistical analysis of outcomes using the MCS, incorporating sensitivity analysis and scenario analysis (worst/best cases), gives more realistic risk analysis and representation in terms of range (confidence intervals) of probable outcomes, and provides the most detailed comparisons. Sensitivity Analysis measures the impact on project outcomes of changing one or more key input values about which there is uncertainty. (Akintoye et al., 2001a, b, c; Grimsey and Lewis, 2005; Stock and Watson, 2005). Since the MCS can only treat input parameters as random variables by using probabilistic (stochastic) models, its main problem is observed when some of the input parameters are stochastic and some are fuzzy.

The MCS is unable to address this general situation. Mathematically, random variable X is represented by: $X_{R.V.} = \mu + z * SD$ where μ is mean, SD is standard deviation; z is the number of SD . A key task in the application of MCS is the generation of the appropriate values of the random variables in accordance with the respective prescribed probability distributions. This can be accomplished systematically for each variable by first generating a uniformly distributed random number between 0 and 1, and

through an appropriate transformation the corresponding random number with the specified probability distribution is then obtained (Ang and Tang, 1984).

4.3.1 Value-at-Risk

Value-at-risk (VaR) is related to the percentiles of probability distributions and measures the predicted maximum portfolio loss at a specified probability level over a certain period. Mathematically, VaR at a probability level $100(1 - \theta)\%$ is defined as the value γ such that the probability that the negative of the investment return will exceed γ is not more than θ :

$$VaR_{1-\theta}(\tilde{r}) = \min\{\gamma | P(-\tilde{r} > \gamma) \leq \theta\}$$

where \tilde{r} denotes the random variable representing the investment return, and $-\tilde{r}$ is associated with the portfolio loss. (e.g., $\theta = 0.05$, then $100(1 - \theta)\% = 95\%$ means that decision maker is interested in the 95% VaR which is the level of the investment losses that will not be exceeded with probability of more than 5%).

VaR is the difference of the mean value and a multiple of standard deviation. It can be expressed as deviations from the mean VaR in units of the standard deviation. Every percentile can be expressed as a sum of the mean of the distribution and the standard deviation scaled by a multiplier as confidence coefficient indicating the degree of confidence for an individual risk level (number of standard deviations) with general form: $VaR_{(1-\theta)} = -\mu + \beta\sigma$ and in the case of the normal distribution: $VaR_{(1-\theta)} = -\mu + Z_{1-\theta}\sigma$, where μ is the mean and σ is the standard deviation of the underlying data distribution, respectively. The number $Z_{1-\theta}$ is the $100(1 - \theta)^{th}$ percentile of a standard normal distribution (e.g.: $Z_{0.95}$ corresponding to the 95th percentile is 1.64).

VaR could be generated for a PPP-BOT project from different perspective at a specific confidence level. VaR in the PPP-BOT projects context, is defined as the minimum expected value at a given confidence level. Figure 4-1 presents the cumulative probability for the VaR of a PPP-BOT project with low risks. In the context of PPP-BOT projects, a project manager as a decision maker is typically interested in two important statistics issue aim to final decision making: (1) an arbitrary and subjective quantile, and (2) the probability of exceeding (or not exceeding) a specific threshold. In most cases, project managers are concerned in finding the probability that a project will exceed a certain value (a specific threshold) of interest (meet the target on cost or time). At the given confidence level, $(1 - \theta)\%$, the value-at-risk (VaR_θ) is shown in Figure 4-2. VaR^* is defined as acceptable threshold value from party's perspective based on its objective. It represents the worth of Value-at-Risk at confidence level of $1 - \theta^*$. θ^* represents the confidence level at the point of VaR^* (See Figure 4-1). In this case VaR_θ is more than VaR^* . Value-at-risk at a given confidence level, $1 - \theta$, is computed by making the integration between $-\infty$ and VaR_θ equal to θ , and the confidence level at the point of VaR^* is obtained by integration between $-\infty$ and VaR^* (See Figure 4-2).

Literature review of the current simulation and financial risk evaluation methods shows that VaR system provides decision criteria with a confidence level. Ye and Tiong (2000) defined the NPV-at-risk based on the VaR system as a particular NPV generated for a project at some specific confidence level. Their definition of NPV-at-risk can be used to derive the decision rule: the project is acceptable with a confidence level of $1 - \theta$ if the NPV-at-risk at given confidence is greater than zero. According to the requirements of

decision rules, there are two approaches to investment decision making: the calculation of NPV at a given confidence level and the calculation of a confidence level at the point of zero NPV. NPV-at-risk at a given confidence θ and the confidence level at the point of zero NPV can be obtained using percentile analysis on the cumulative distribution function (CDF). The NPV-at-risk method takes into account all probable returns resulting from various risks associated with PPP-BOT projects.

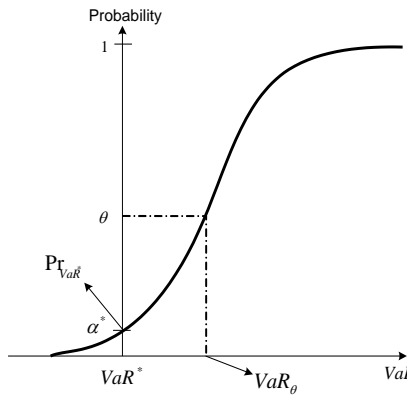


Figure 4-1 Cumulative distribution function of VaR

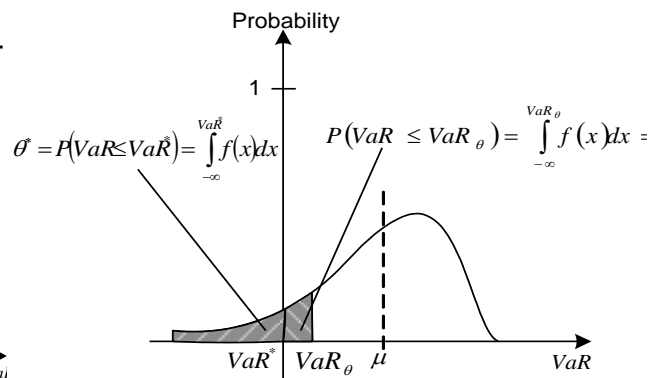


Figure 4-2 Probability distribution function of VaR

The decision rule emerging from the use of this criterion indicates that a PPP-BOT project investment should be selected for implementation if its indicator at risk (IND-at-risk) as VaR expected shortfall exceeds an investor defined limit. As can be seen, although VaR analysis has been successfully performed in previous research projects, it could only take randomness into account and cannot deal with fuzziness involved. Following sections will address this essential gap.

4.4 Fuzzy Variables/Numbers

Fuzzy set theory introduced by Zadeh (1965) permits the gradual assessment of the membership of the elements in relation to a set. It provides a suitable basis for relaxing the need for precise values or bounds. It allows the

specification of a smooth transition for elements from belonging to a set to not belonging to a set. This is described with the aid of a membership function. Membership values are assigned to the estimation results by subjective assessment. A fuzzy set \tilde{A} is defined as follows. $\tilde{A} = \{(x, \mu_A(x)), x \in X, 0 \leq \mu_A(x) \leq 1\}$. Membership function, $\mu_A(x)$, associates each $x \in \tilde{A}$ to a real number in the interval $[0,1]$. $\mu_A(x)$ represents the membership degree of x in set \tilde{A} . The fuzzy set \tilde{A} is referred to fuzzy variable \tilde{x} (Moller and Beer, 2004). A fuzzy number is said to be normal if there is an $x \in A$ such that $\mu_A(x) = 1$ and it is a convex fuzzy subset of the real line if $\mu_A(\lambda x_1 + (1 - \lambda)x_2) \geq \min(\mu_A(x_1), \mu_A(x_2))$, for $\lambda \in [0,1]$. The definition of fuzzy random variables (FRVs) is due to Kwakernaak (1978, 1979); “fuzzy random variables (FRVs) are random variables whose values are not real, but fuzzy numbers”.

Fuzzy numbers are a generalization and refinement of intervals for representing imprecise parameters. This modelling corresponds to the theory of fuzzy random variables and to fuzzy probability theory (Kratschmer, 2001; Beer, 2010).

4.4.1 α -level set (α -cut)

α -level set (α -cut) is one of the important features of fuzzy set \tilde{A} and is useful in processing fuzzy variables through engineering computation. For the fuzzy set \tilde{A} , the crisp sets $A_{\alpha_k} = \{x \in X, \mu_A(x) \geq \alpha_k\}$ can be extracted for real numbers $\alpha_k \in (0,1]$. These crisp sets are called α -level sets. All α -level sets A_{α_k} are crisp subsets of the support $S(\tilde{A})$. The support $S(\tilde{A})$ is defined as follow: $S(\tilde{A}) = \{x \in \mathbb{R}, \mu_A(x) > 0\}$. For a convex fuzzy set, its α -level sets

are intervals $A_{\alpha_k} = [x_{\alpha_k}^L, x_{\alpha_k}^R]$, see Figure 4-3. This aids the illustration of the fuzzy set \tilde{A} using its α -level sets as follow:

$$\tilde{A} = \left\{ \left(A_{\alpha_k}, \mu(A_{\alpha_k}) \right), \mu(A_{\alpha_k}) = \alpha_k \forall \alpha_k \in (0,1] \right\},$$

$$A_{\alpha_k} \subseteq A_{\alpha_i} \forall \alpha_i, \alpha_k \in (0,1], \alpha_i \leq \alpha_k$$

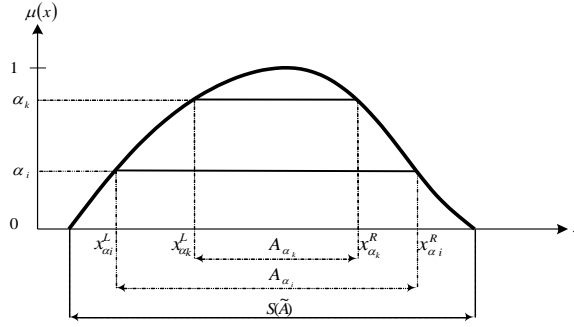


Figure 4-3 α -level set (α -cut) of a fuzzy variable

If the fuzzy set \tilde{A} is convex, each α -level set A_{α_k} is a connected interval $[x_{\alpha_k}^L, x_{\alpha_k}^R]$ in which:

$$x_{\alpha_k}^L = \min[x \in X, \mu_A(x) > \alpha_k], x_{\alpha_k}^R = \max[x \in X, \mu_A(x) > \alpha_k].$$

In the other word, the α -cut of a continuous convex possibility distribution, \tilde{A} , could be understood as the inequality as follows:

$$\tilde{A}_{\alpha_k} = \{x | p(x \in [x_{\alpha_k}^L, x_{\alpha_k}^R]) \geq 1 - \alpha_k\}$$

The α -level set of each fuzzy input parameter represents a set of values within an interval with max-min values which is called superior-inferior values corresponding to specific α -level set. Fuzzy alpha-cut (FAC) technique uses fuzzy set theory to represent uncertainty or imprecision in the concerned parameters at different level of uncertainties (α -levels). Uncertain parameters are considered to be fuzzy numbers with some assumed membership functions. There are many types of functional formulations for the membership functions. Two common used membership functions are triangular and trapezoidal functional formulations and corresponding fuzzy

numbers/variables can be represented by the following notations. Triangular fuzzy number “T.F.N” $\tilde{x}_{Tri}: \langle a_1, a_2, a_3 \rangle$, Trapezoidal fuzzy number “Tr.F.N” $\tilde{x}_{Trap}: \langle a_1, a_2, a_3, a_4 \rangle$. Figure 4-4 and Figure 4-5 show parameter x represented as a triangular and trapezoid fuzzy number with support of A_0 . The wider the support of the membership function, the higher the uncertainty. The fuzzy set that contains all elements with a membership of $\alpha \in [0,1]$ and above is called the α -cut of the membership function. At a resolution level of α , it will have support of A_α and the higher the value of α , the higher the confidence in the parameter.

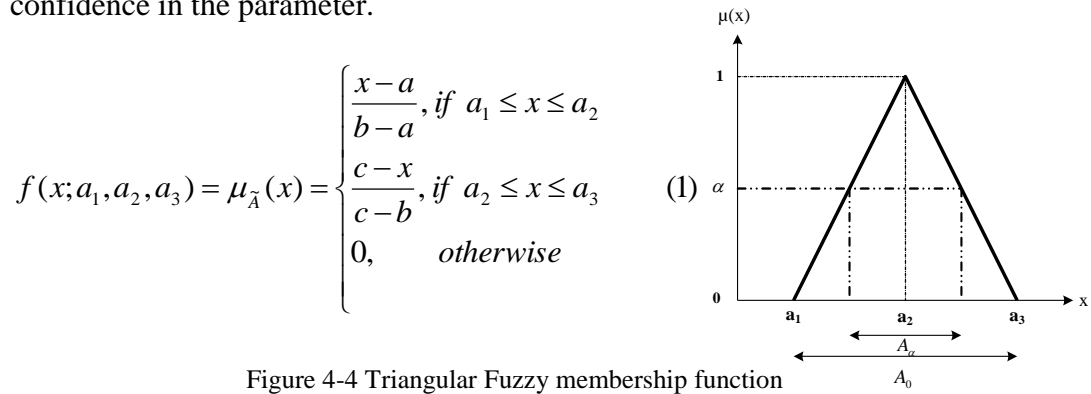


Figure 4-4 Triangular Fuzzy membership function

Defining the α -cut, the interval of confidence at level α , T.F.N is characterized as follows: $\forall \alpha \in (0,1], a_1 \leq a_2 \leq a_3$

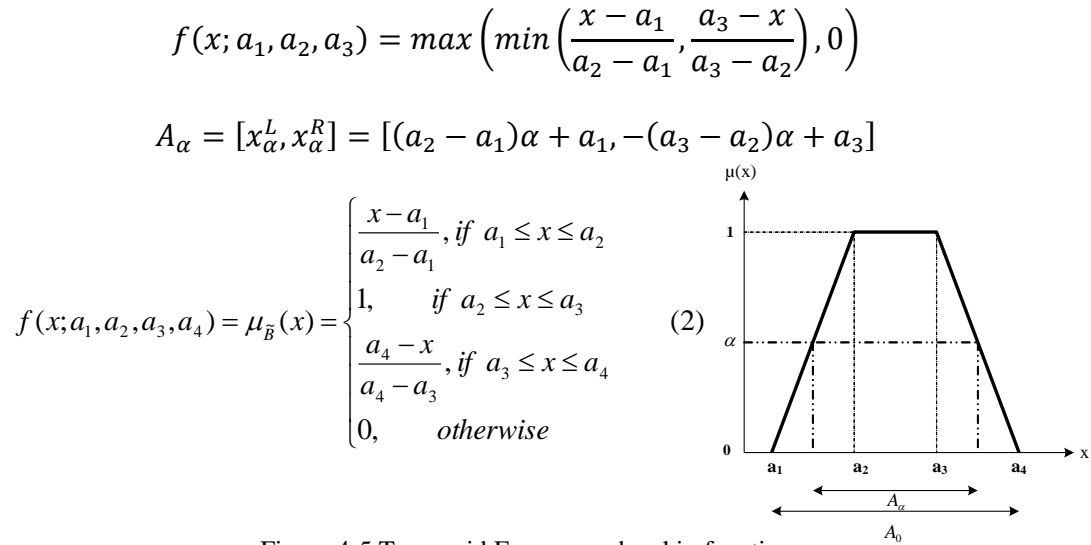


Figure 4-5 Trapezoid Fuzzy membership function

Defining the α -cut, the interval of confidence at level α , Tr.F.N is characterized as follows: $\forall \alpha \in (0,1], a_1 \leq a_2 \leq a_3 \leq a_4$

$$f(x; a_1, a_2, a_3, a_4) = \max \left(\min \left(\frac{x - a_1}{a_2 - a_1}, 1, \frac{a_4 - x}{a_4 - a_3} \right), 0 \right)$$

$$A_\alpha = [x_\alpha^L, x_\alpha^R] = [(a_2 - a_1)\alpha + a_1, -(a_4 - a_3)\alpha + a_4]$$

The proposed FAC method is based on the fuzzy extension principle (Zadeh, 1975), which implies that functional relationships can be extended to involve fuzzy arguments and can be used to map the dependent variable as a fuzzy set. In simple arithmetic operations, this principle can be used analytically. However, in most practical modelling applications where relationships involve partial differential equations and other complex structures, the analytical application of this principle is difficult. Therefore, interval arithmetic is used to carry out the analysis.

4.5 Fuzzy Randomness-Monte Carlo Simulation (FR-MCS) Technique

To address aforementioned shortcomings, this chapter proposes a new simulation technique which is called ***Fuzzy Randomness-Monte Carlo simulation (FR-MCS) technique***. The structure of FR-MCS technique is demonstrated in Figure 4-6. Numerical processing of fuzzy probabilities can be realized with a combination of stochastic and fuzzy analysis. Whilst probabilistic model is analysed with a traditional stochastic approach, the imprecision of the probabilistic model is transferred to the results via fuzzy analysis. The purpose of proposing FR-MCS is to provide an alternative approach to conventional MCS for treating uncertainties in the simulation input including the parameters of the PDFs using fuzzy set theory. This technique can model uncertainties involved in simulation input efficiency,

accompanied with random variables and deterministic input parameters. For instance $y = f(x_1, \dots, x_m, \tilde{x}_1, \dots, \tilde{x}_{n-m})$ is a function of n variables includes of both types of non-deterministic variables: risky and uncertain variables. Risky (randomness) variables group: x_1, \dots, x_m , uncertain (fuzziness) variables group: $\tilde{x}_1, \dots, \tilde{x}_{n-m}$.

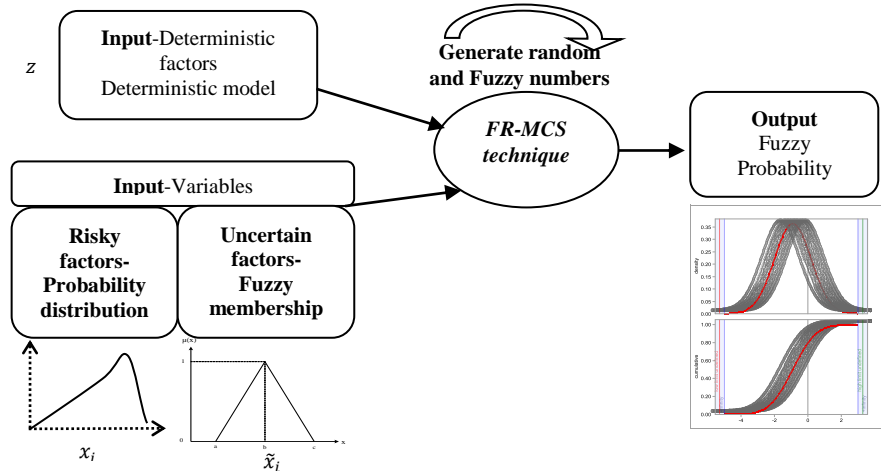


Figure 4-6 Fuzzy randomness Monte Carlo Simulation technique structure

FR-MCS, which is used to combine multiple PDFs and CDFs in a risk calculation, is a means of quantifying uncertainty or variability in a hybrid fuzzy-probabilistic framework using simulation. The simulation output, based on the conventional MCS, will be exactly a CDF. On the other hand, FR-MCS is proposed as a general form of MCS technique. The output of a FR-MCS analysis is a collection of CDFs for each simulation and it results in a bound of CDFs (CDF series).

FR-MCS combines MCS (Random Sampling) with the extension principle of fuzzy set theory (Zadeh, 1975; Gerla and Scarpati, 1998; Moller and Beer 2004, 2008). FR-MCS utilizes a combination of probability and possibility theories to include probabilistic and possibilistic information in the risk analysis model. Fuzzy approach provides all the possible risks and likelihood of occurrence of each risk value. The risk value corresponding to a

membership value of 1.0 is the most possible/likely risk. Higher uncertainty and variability involved can be seen from the supports of the membership functions of fuzzy risks generated for various percentiles. The resulting fuzzy risk has a larger range of possibilities (i.e., the support of the membership function is larger). Fuzzy calculations take into consideration all possible combinations of parameter values rather than random sampling. Similar to conventional MCS, the variability in the random variables of the risk equation (i.e., exposure frequency/probability and consequence) is treated using normal PDFs and the uncertainty associated with them is treated by using fuzzy numbers for the parameters of these random variables. That is, the means and the standard deviations of these PDFs are modelled as fuzzy numbers. Similar to MCS, the independence of the input parameters has been assumed in generating fuzzy random variables and producing fuzzy randomness; the output may be overestimated when using fuzzy randomness for a function with dependent input parameters. Algorithms are required to generate random variables and fuzzy random variables to implement FR-MCS. In the following section an algorithm is proposed for generating fuzzy random variables.

FR-MCS technique results in multiple CDF of function y which is called $F(y)$ series. It considers the spread of CDFs membership functions. Based on the resulted $F(y)$ series, lower bound, $\underline{F}(y)$, as inferior value and upper bound, $\overline{F}(y)$, as superior value of CDFs are determined. The appropriate membership degree, μ , corresponding to each CDF is then determined. This procedure is demonstrated in Figure 4-7.

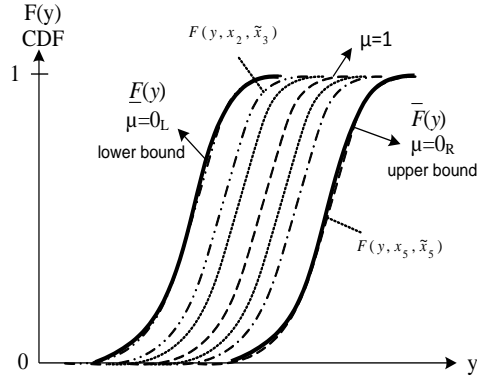


Figure 4-7 Fuzzy CDF and membership degree (μ) corresponding to each CDF

The FR-MCS produces two CDFs (i.e., one for upper and one for lower bound) for each alpha-cut level except for alpha-cut 1.0 since the lower and the upper bound at alpha-cut 1.0 is the same. For each specific value of y e.g.: y' , based on the lower and upper bounds, fuzzy probability of y' can be calculated and drawn. Also for each membership degree, lower and upper bound of CDFs are determined. Consequently, a corresponding fuzzy probability is established which is represented as a confidence level interval $[CL_L^\alpha, CL_R^\alpha]$ as demonstrated in Figure 4-8. For each specific value of $F(y)$ as a confidence level e.g.: θ , based on the lower and upper bounds, fuzzy probability of y' can be calculated and drawn. Also for each membership degree, lower and upper bound of CDFs are determined. Consequently, a corresponding fuzzy probability is established which is represented as negotiation interval $(y_L^{\alpha, \theta}, y_R^{\alpha, \theta})$ as demonstrated in Figure 4-9.

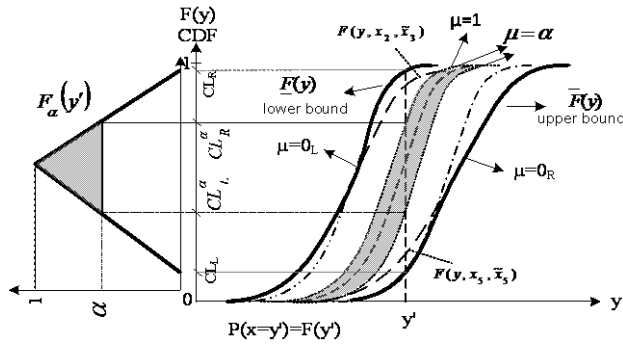


Figure 4-8 Analysis of fuzzy distribution function $\tilde{F}(x)$ of a fuzzy function y and its membership function on a specific value y' to determine confidence interval (confidence level bound)

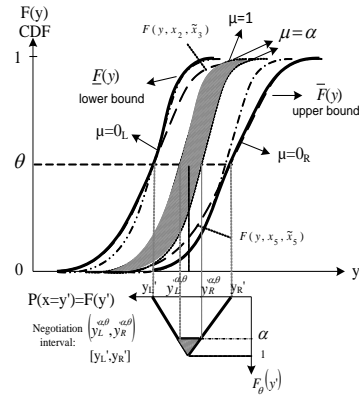


Figure 4-9 Analysis of fuzzy distribution function $\tilde{F}(x)$ of a fuzzy function y and its membership function on a specific probability θ to determine negotiation interval

Compatible decisions that are made using conventional MCS can be made based on the FR-MCS technique only for the case of pure random variables of simulation input (no fuzziness). In the case of pure probabilistic (absence of fuzziness) in the input of FR-MCS technique the result of simulation will be exactly a CDF. As the number of fuzzy variables in the simulation input is increased, the CDF function in the simulation output has more fuzziness (i.e. more uncertainties are involved). Consequently CDF bound is wider. In the case of pure fuzzy random variables of simulation input (no randomness), the results are similar with the fuzzy set theory analysis. In this case the CDF bound is widest. The fuzzy inference mechanism is an applicable technique for this case. Mamdani and Sugeno are two types of fuzzy inference mechanism (Sivanandam et al., 2007). The Mamdani style is the most famous types of fuzzy controllers. α -cut levels signify uncertain level and represent the amount of uncertainty involved. On the contrary, α -confidence levels signify risky level and represent the amount of risk involved. Thus if the decision maker is optimistic and assumes high precision ($\mu = 1$), (s)he works with the cores of the fuzzy intervals, but, if is cautious, (s)he may choose $\mu = 0$ and use

corresponding supports. In the case of in between, a corresponding value within $\mu = [0, 1]$ is chosen by decision maker.

The method of decision making using fuzzy sets is based on the confidence level between 0 and 1 to get a range of values for the simulation final output. This range is calculated by finding the α -cut at the value of 1 minus the confidence level. In this manner, the decision maker can choose from a range of values (interval) instead of a crisp output which is the result of conventional MCS. An arbitrary quantile can also be determined using the inverse of the fuzzy CDF. Fuzzy CDF has the unique feature of representing both fuzzy and probabilistic (uncertainty and risk) in a single diagram.

4.5.1 Algorithm for Generating Fuzzy Random Variable

The procedure of generating fuzzy random variable is not the same as that for generating random variable described earlier, in section 4.3 Monte Carlo Simulation technique. Current literature provides some knowledge on specific procedure for generating fuzzy random variable. Moller and Beer (2004, 2008) proposed a procedure which could be summarized as follows. They argue that fuzzy variables need to be treated separately. The fuzzy variables (let's say n fuzzy variables), for each alpha-level (alpha cut), form an n -dimensional hypercube. For each point (vector) out of this hypercube Monte Carlo can be performed with the random variables and a CDF obtained for the result, e.g. a failure probability or some other probability of interest. Now it is needed to select another point out of the hypercube and repeat the Monte Carlo to get another result. When repeating this analysis, the aim is to find those points in the hypercube, which lead to the max and min final results (e.g. the failure probability). This is called global optimization (Moller and Beer, 2004, 2008).

When some knowledge about simulation function is available, this analysis may be significantly simplified. For example, when the simulation function is *monotonic* in every direction, then the extreme points are the corners of a hypercube. Only these points need to be checked for optimization.

In this chapter, a modified and simplified procedure is developed. Generating fuzzy random variable procedure is explained in detail for two main types of fuzzy numbers and variables: triangular fuzzy number T.F.N, $\tilde{x}_{Tri}: \langle a_1, a_2, a_3 \rangle$, trapezoidal fuzzy number Tr.F.N, $\tilde{x}_{Trap}: \langle a_1, a_2, a_3, a_4 \rangle$ in 4 operative steps for a hybrid function of both randomness and fuzziness type of variables: $y = f(x_1, \dots, x_m, \tilde{x}_1, \dots, \tilde{x}_{n-m})$. Randomness (probabilistic) variables group: x_1, \dots, x_m , which is characterized by probability distributions, and fuzziness (possibilistic) variables group: $\tilde{x}_1, \dots, \tilde{x}_{n-m}$ which is represented in terms of possibility distributions (membership function) measuring the degree of possibility that the linguistic variables are.

Step 1: The membership function is cut horizontally at a finite number of α -levels between 0 and 1, $\alpha = \{\alpha^1, \alpha^2, \dots, \alpha^i, \alpha^j, \dots, \alpha^N\}$. Consequently, for each α -level, an interval (a boundary) of concerned fuzzy values is achieved. For each α -level of the parameter, the model is run to determine the minimum and maximum possible values of the concerned output. This information is then directly used to construct the corresponding membership function (fuzziness) of the output which is used as a measure of uncertainty. If the output function is *monotonic* with respect to the dependent fuzzy variables, the process is rather simple since only two simulations will be enough for each α -level (one for each boundary in left and right). Otherwise, optimization routines have to be carried out to determine the minimum and maximum values of the output

for each α -level. This approach is used to model the interested output subject to imprecise boundary conditions and properties.

The α -cut can be repeated for a number of iteration, N. Apply α -level set (α -cut) for a set of α to a fuzzy number, T.F.N or Tr.F.N (Figure 4-10). The resulted intervals are varied, when the membership function is characterized by convex and concave shape instead of common linear shape.

Step 2: The boundary and resulted interval corresponding to α -level is demonstrated as follows: $A_\alpha = [x_\alpha^L, x_\alpha^R]$, The resulted intervals for T.F.N are characterized as follows:

$$A_\alpha = [x_\alpha^L, x_\alpha^R] = [(a_2 - a_1)\alpha + a_1, -(a_3 - a_2)\alpha + a_3], \forall \alpha \in (0,1].$$

The resulted intervals for Tr.F.N are characterized as follows:

$$A_\alpha = [x_\alpha^L, x_\alpha^R] = [(a_2 - a_1)\alpha + a_1, -(a_4 - a_3)\alpha + a_4], \forall \alpha \in (0,1].$$

Step 3: Generate random variables from resulted intervals: $A_\alpha = [x_\alpha^L, x_\alpha^R]$, corresponding to each set of α - level (α -cut) e.g.: $x_\alpha^r = x_\alpha^L + RAND() * (x_\alpha^R - x_\alpha^L)$, (This procedure is demonstrated in Figure 4-10). $RAND()$ is a function to generate random numbers in the interval (0,1), by assuming a uniform distribution function. These random numbers multiply by the range of resulted intervals. Having more information, other type of distribution function may apply.

Step 4: Take the resulted values in steps 1, 2 and 3, including the boundary values in left and right and random variables generated for each α -level, as a set of fuzzy random variables: $FRV = \{x_\alpha^L, x_\alpha^r, x_\alpha^R\}$.

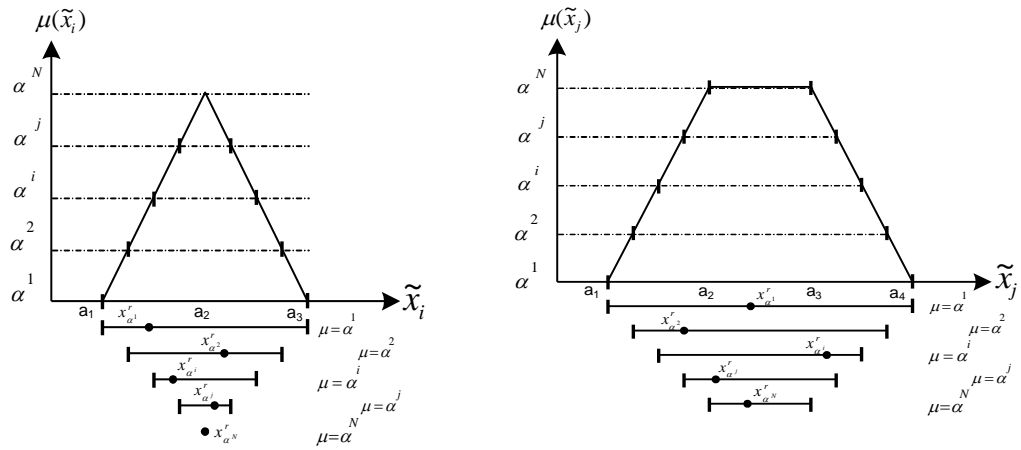


Figure 4-10 Algorithm for generating fuzzy random variable

4.6 Fuzzy Probability Distribution

Fuzzy probability provides a suitable framework for a realistic modelling of risk and uncertainty to ensure that both risky and uncertain input data type is appropriately reflected in computation results. In the framework of fuzzy probability, both the probabilistic and the non-probabilistic data can be considered simultaneously and transferred and reflected combinedly and jointly to the results (Moller and Beer, 2004; Baudrit et al., 2006).

The processing of fuzzy randomness simulation can be realized with a combination of stochastic simulation and fuzzy analysis in a nested form. Fuzzy numbers with appropriate membership function as uncertain variables are input parameters for a fuzzy analysis. With each set of crisp values and random variables for the simulation input parameters, a traditional stochastic analysis is performed. The extreme results from the various conventional stochastic computations and also incorporating the uncertain variables subsequently define the bounds on probability or fuzzy probabilities respectively. This issue is important for the loss caused by catastrophic risks, project bankruptcy and negotiation failure. Negotiation failure and bankruptcy

probability are obtained as fuzzy variables. Their range of possible values reflects the non-probabilistic feature of uncertain variables from the specification of the probabilistic model for the input variables. The reader may also refer to Moller and Beer (2004) for more discussion on the same topic.

For the propagation of probabilistic and possibilistic uncertainty information, the conventional MCS technique (Kalos & Whitlock, 1986) can be combined with the extension principle of fuzzy set theory (Zadeh, 1965, 1975) by means of the following 3 main steps:

- I. Repeat Monte Carlo sampling of the probabilistic variables to process their risk (generating random variable).
- II. Apply fuzzy interval analysis to process the uncertainty connected with the possibilistic variables.
- III. Employ fuzzy probability procedure for joint propagation of probabilistic and possibilistic uncertainty.

A possibility value α as uncertain level is selected. The generic k^{th} random values for i^{th} iteration, x_k^i , $k = 1, \dots, m$, are sampled by Monte Carlo from the probabilistic distributions. A fuzzy set π_l^f , estimate of possibility distribution for l^{th} possibilistic variables \tilde{x}_l^i of $y = f(X)$, $l = 1, \dots, n - m$, is constructed by fuzzy interval analysis according to the assumed α -level. After m repeated samplings of the probabilistic variables, x_k^i , the fuzzy set estimates π_l^f , $l = 1, 2, \dots, n - m$, are combined with those of random values to give an estimate of $y = f(X)$ as a fuzzy random variable (or random possibility distribution) according to the rules of evidence theory (Shafer, 1976). This is repeated for a number of iteration ($i=1, \dots, N$).

The steps of the fuzzy probability distribution procedure are as follows:
(Baraldi and Zio, 2008; Guyonnet et al., 2003)

Step 1: Select a possibility value α and the corresponding cut of the possibility distributions $(\pi_1^f, \dots, \pi_{n-m}^f)$ as intervals of possible values $A_\alpha = [x_\alpha^L, x_\alpha^R]$ of the possibilistic variables $\tilde{x}_l^i (\tilde{x}_1^i, \dots, \tilde{x}_{n-m}^i)$.

Step 2: Sample the i^{th} realization of the probabilistic variables $x_k^i (x_1^i, \dots, x_m^i)$.
(Generating random variable for i^{th} iteration)

Step 3: Interval calculation, compute the supremum and infimum (largest and smallest) values of $y^i = f(x_1^i, \dots, x_m^i, \tilde{x}_1^i, \dots, \tilde{x}_{n-m}^i)$, denoted by \underline{f}_α^i and \bar{f}_α^i , respectively.

Step 4: Return to Step 2 to generate a new realization of the random variables.
The above procedure is repeated for $i = 1, 2, \dots, N$; at the end of the procedure an ensemble of realizations of fuzzy intervals is obtained, that is, $(\pi_1^F, \dots, \pi_N^F)$.

Step 5: Return to step 1, choose another α -cut and repeat the process for new α -cut; after having repeated steps 2 to 4 for all the α -cuts of interest, the fuzzy random realization (fuzzy interval) π_i^F of $y = f(X)$ is obtained as the collection of the values \underline{f}_α^i and \bar{f}_α^i . Then, take the extreme values of \underline{f}_α^i and \bar{f}_α^i , found in this step, as lower and upper limits of α -cuts of $y = f(x_1, \dots, x_m, \tilde{x}_1, \dots, \tilde{x}_{n-m})$ and denote them by \underline{F}_α^i and \bar{F}_α^i . In other words, π_i^F is defined by all its α -cut intervals $[\underline{F}_\alpha^i, \bar{F}_\alpha^i]$ (Refer to Figure 4-12).

Hence, a fuzzy probability distribution function $\tilde{F}(x)$ can be formulated as a fuzzy set of traditional probability distribution function $F(x)$ of random variable X , which is given by:

$$\tilde{F}(x) = \left\{ \left(F(x), \mu(F(x)) \right) \mid X \in \tilde{X}, \mu(F(x)) = \mu(X) \right\}$$

The functional values of $\tilde{F}(x)$ are fuzzy variables and possess membership functions. Interval probabilities $F_\alpha(x) = [\underline{F}_{\alpha l}(x), \bar{F}_{\alpha r}(x)]$ weighted by the membership degree $\mu(F_\alpha(x))$ that can be obtained for each α -level. This interval probability contains the probability of all possible states describing the occurrence of $X \in \tilde{X}$. Thus, a fuzzy probability function can be described as a fuzzy set of interval probabilities. For introducing the $\tilde{F}(x)$ in numerical procedures the α -discretization is applied. This leads to fuzzy functional value for each specified x .

$$\tilde{F}(x) = \left\{ \left(F_\alpha(x), \mu(F_\alpha(x)) \right) \mid F_\alpha(x) = [\underline{F}_{\alpha l}(x), \bar{F}_{\alpha r}(x)], \right. \\ \left. \mu(F_\alpha(x)) = \alpha \forall \alpha \in (0,1] \right\}$$

$$\bar{F}_{\alpha r}(x) = \max \tilde{F}(x), \underline{F}_{\alpha l}(x) = \min \tilde{F}(x)$$

The fuzzy probability distribution function $\tilde{F}(x)$ of \tilde{X} may thus be interpreted as being the set of the probability distribution functions $F(x)$ of all originals X of \tilde{X} with the membership values $\mu(F(x))$. This representation is suitable for numerical processing of fuzzy probabilistic variables. The description of fuzzy probability distribution functions can be realized with the aid of fuzzy variables for parameters in the probability functions. For instance, if the underlying uncertain random variable X is assumed to be normal distribution $N(\tilde{m}, \tilde{\sigma})$ with fuzzy expected value $\tilde{m}_x = \langle 5.5, 6.0, 6.8 \rangle$ and fuzzy standard deviation $\tilde{\sigma}_x = \langle 0.8, 1.0, 1.1 \rangle$, then fuzzy PDF and fuzzy CDF can be specified as,

$$\tilde{f}(x) = \frac{1}{\tilde{\sigma}\sqrt{2\pi}} e^{-0.5\left[\frac{(x-\tilde{m}_x)}{\tilde{\sigma}_x}\right]^2}, \tilde{F}(x) = \frac{1}{\tilde{\sigma}\sqrt{2\pi}} \int_{-\infty}^x e^{-0.5\left[\frac{(t-\tilde{m}_x)}{\tilde{\sigma}_x}\right]^2} dt$$

and are shown in Figure 4-11. The functional value of $\tilde{F}(x)$ at a specified value x is a fuzzy variable. For instance, $\tilde{F}(6) = \langle 0.15, 0.5, 0.75 \rangle$. All PDFs and CDFs used to describe the variability in a fuzzy probability model have a certain degree of uncertainty (μ : membership function).

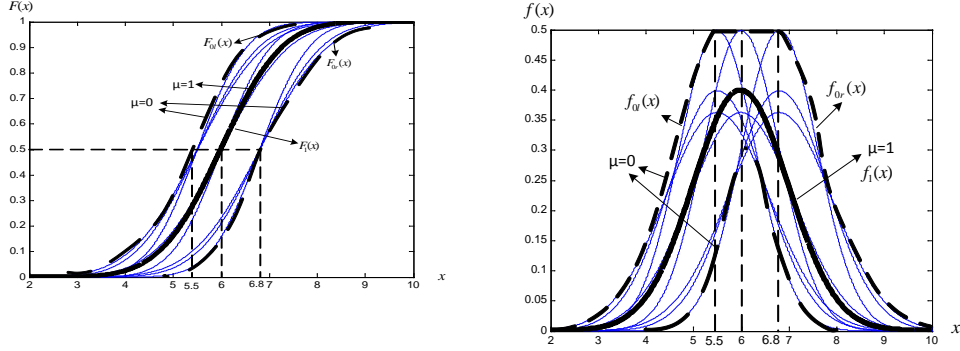


Figure 4-11 Fuzzy CDF and fuzzy PDF of a fuzzy normal distribution

4.7 Reliability Modelling and Evaluation with Fuzzy Data

Fuzzy probability can be generalized as is represented in Figure 4-12. Two ways to fuzzify the series curves $\tilde{F}(x)$ are shown. $\bar{F}(x)$ and $\underline{F}(x)$ are upper and lower CDF bounds. $F_1(x)$ is the expected CDF. As a rule, minimization and maximization algorithm can be used for finding *Inf* and *Sup* values of a general model. However, when the simulation model is a simple *monotonic* function, as in our study, the *Inf* and *Sup* values are identified directly without using minimization or maximization algorithms.

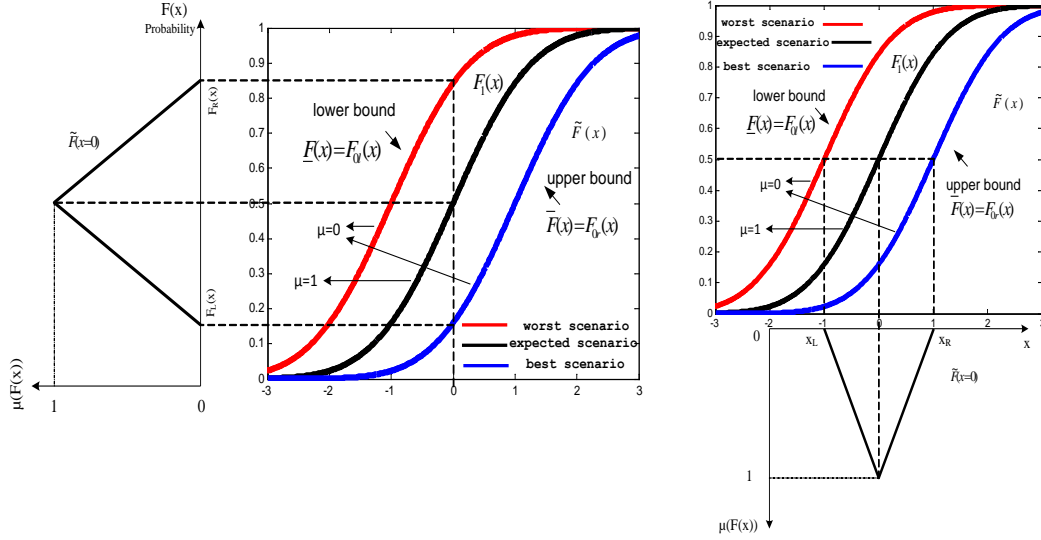


Figure 4-12 Fuzzy distribution function $\tilde{F}(x)$ of a fuzzy random variable \tilde{X} and its membership function on a specific value (Left-hand), on a specific probability (Right-hand)

When it is known which combination of parameters from the alpha-level sets of fuzzy variables in simulation input leads to the boundary/extremes curves in simulation output, any software can be utilized to plot output fuzzy probability curves and gray out the area in between. When it is unknown which combination of parameters leads to the extremes, the best way to get a figure is to perform FR-MCS over the parameter space and plot curve by curve for the result. Now we consider the membership function of the series curves $\tilde{F}(x)$ as follows.

$$\mu(F(x)) = 0, \text{ if } F(x) \leq \underline{F}(x), \mu(F(x)) = 0, \text{ if } F(x) \geq \bar{F}(x)$$

$$\mu(F(x)) = \frac{F(x) - \underline{F}(x)}{F_1(x) - \underline{F}(x)}, \text{ if } \underline{F}(x) \leq F(x) \leq F_1(x),$$

$$\mu(F(x)) = \frac{\bar{F}(x) - F(x)}{\bar{F}(x) - F_1(x)}, \text{ if } F_1(x) \leq F(x) \leq \bar{F}(x)$$

and using the α -cuts:

$$\tilde{F}_\alpha(x) = [\underline{F}(x) + (F_1(x) - \underline{F}(x))\alpha, \bar{F}(x) - (\bar{F}(x) - F_1(x))\alpha]$$

In this section it is shown that when an uncertainty is associated with the estimates, the simulation output function and other related concepts can be modelled using the intervals of confidence, and fuzzy numbers instead of the probabilistic characterization. The extension principle, which is one of the most important concepts of fuzzy set theory, is used to conduct arithmetic operations on interval of confidence and fuzzy numbers. As can be seen the simulation and financial evaluation method based on the Value-at-risk and uncertainty (VaRaU) approach, which incorporates both risk and uncertainty analysis using confidence and uncertain levels and discount rate concept give more equitable results for all parties involved in the PPP-BOT project. Therefore by these simulation results, negotiations objectives will be promptly obtained.

4.8 Illustrative Case Study- MCS vs. FR-MCS

Typically case studies assume deterministic assumption. FR-MCS has been employed to estimate volatility of parties' objectives like volatility of investment project value and the impact of uncertainties on the project cost estimation, contract decision variables/indicators and the optimal outcomes. This is to simulate cash flows of a PPP-BOT investment project with appropriate risk and uncertainty models and further to describe fuzzy probability distribution of cost estimation and returns by iterating large number of simulations. The application of the FR-MCS model for the evaluation of uncertainties including demand uncertainty for a BOT toll road and bridge project is demonstrated with a realistic case study. To do this, a special program has been developed by MATLAB (The MathWorks, Inc., Natick, Massachusetts). In this study our focus is on the representation of the

uncertainties by fuzzy numbers. Basic input data of the project comprises deterministic, uncertain and risky parameters. Uncertain and risky parameters consist of three components i.e. *macroeconomic indicators and indexes*, *fuzzy-stochastic variables (FSV)* and *negotiable concession items (NCIs)*. Main project data including expected value of parameters and their distribution or membership function is tabulated in Table 4-1.

Table 4-1 Basic input data of the case study

Input data	Expected Value	Distribution/Membership function
Macroeconomic indicators and indexes		
Project Economic life, project life cycle (yrs)	40	Deterministic
Costs regime during construction	-	<0.1,0.3,0.5,0.1>
Escalation rate during construction/inflation rate during operation period (%)	4	Log Normal distribution, LnN(4,1)
Amortization period (yrs)	20	Deterministic
Tax rate (%)	30	Deterministic
Gov. discount rate (%)	8.16	Deterministic
Cost of debt (%)	5.25	Deterministic
Cost of equity (hurdle rate) (%)	14	Deterministic
Loan Interest rate (%)	7.5	Deterministic
Loan repayment period/debt maturity (yrs)	10	Deterministic
Annual growth rate of unit price (%)	5	Normal distribution, N(5,1)
Annual growth rate of quantity of demand (%)	5	Normal distribution, N(5,1)
Cost of finance coefficient for Pre concession period costs calculation	0.05	Deterministic
Cost of tender coefficient for Pre concession period costs calculation	0.05	Deterministic
Annual revenue coefficient for O&M calculation	0.07	Deterministic
Increasing rate of annual growth rate of unit price (%)	10	Normal distribution, N(10,1)
Expected Base Cost coefficient for Asset value calculation at transfer date	0.1	Normal distribution, N(0.1,0.01)
Fuzzy-Stochastic Variables (FSV)		
Total project costs (M\$)	170	Normal distribution, N(170,25)
Operation and maintenance costs (M\$/year)	1.8907	Normal distribution, N(1.8907,0.25)
Annual growth rate of O&M costs (%)	5	Normal distribution, N(5,1)
Initial daily traffic (vehicles/day)	20,000	Fuzzy variable: Tr.F.N, {19,178, 20,000, 20,000, 20,822}
Quantity of demand (vehicle per year)	7,300,000	Fuzzy variable: Tr.F.N, {7,000,000, 7,300,000, 7,300,000, 7,600,000}
Operating revenue (M\$/year)	27.01	Fuzzy variable: Tr.F.N, {25.9, 27.01, 27.01, 28.12}
Pre concession period (yrs)	2	Log Normal distribution, LnN(2,0.5)
Negotiable concession items (NCIs)		
Construction period (yrs)	4	
Operation period (yrs)	21	
Concession period (yrs)	25	
Unit price of services (service in first year of operation) (\$)	3.7	
Debt, Equity (%)	40%,30%	
Government subsidy/contribution, grant fraction, Royalty	30%	

The expected value of parameters is taken from *The Toolkit for Public-Private Partnerships in Roads and Highways* provided by the World Bank-PPIAF (V1.1, 2009). The distribution or membership function of parameters is taken based on the expert knowledge through interview. The fuzzy approach has been used as a measurement of uncertainty, e.g., demand uncertainty (See Figure 4-13). The level of uncertainty is represented and considered by membership value between 0 and 1. The membership function of operating revenue by considering demand uncertainty is represented in Figure 4-14.

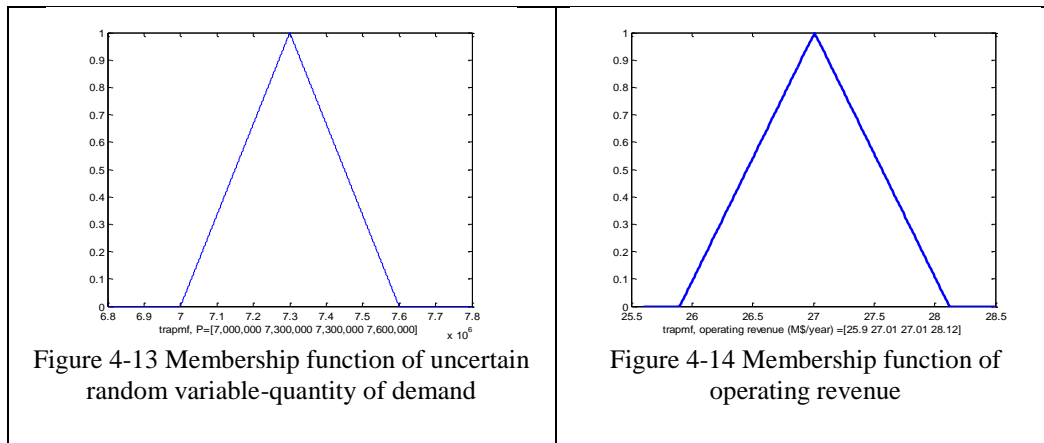


Figure 4-15 and Figure 4-16 represent PDF and CDF of total project costs for the same case resulted from conventional MCS by considering no uncertainties. The result is just a PDF/CDF that does not take into account any uncertainty. Consequently by taking a value for probability (θ) in CDF, just a deterministic value will be intersected. Based on this result, as engineering implication, decision maker will come to negotiation table with a deterministic value for decision variables.

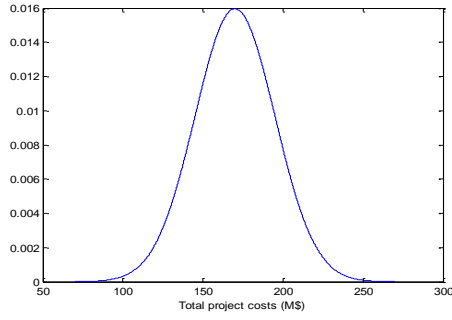


Figure 4-15 PDF of total project costs by MCS

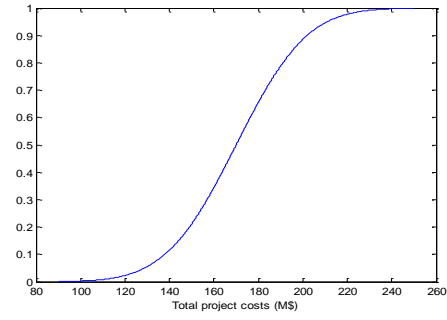


Figure 4-16 CDF of total project costs by MCS

In this case a total of 1000 iterations are performed to carry out FR-MCS and generate fuzzy CDFs. Figure 4-17 illustrates three dimensional view of fuzzy CDF for total project costs (TPC) resulting from the FR-MCS that are generated by MATLAB. Figure 4-18 and Figure 4-19 represent the x-y and x-z views of fuzzy CDF resulted in Figure 4-17 respectively.

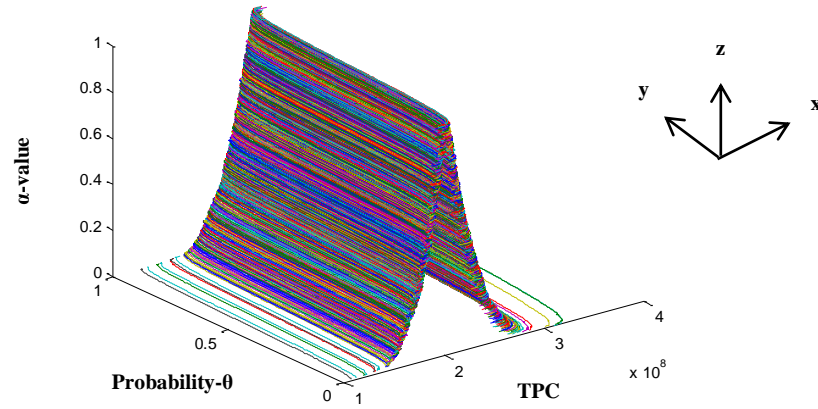


Figure 4-17 three dimensional view of fuzzy CDF for total project costs resulting from the output of FR-MCS, x-axis: TPC, y-axis: probability, z-axis: α -value

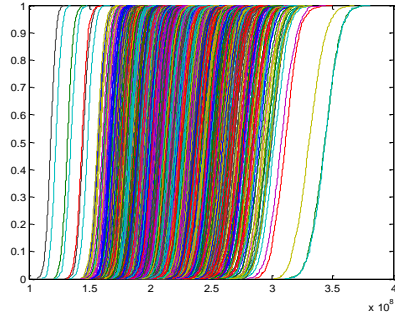


Figure 4-18 x-y view of fuzzy CDF resulted in Figure 4-17

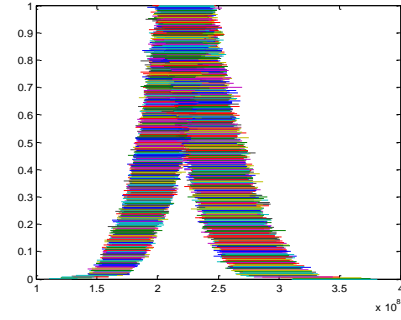


Figure 4-19 x-z view of fuzzy CDF resulted in Figure 4-17

As for decision variables the procedure is the same. Figure 4-20 shows the three dimensional view of fuzzy CDF for the debt service cover ratio (DSCR) resulting from the FR-MCS. Figure 4-21 and Figure 4-22 represent the x-y and x-z views of fuzzy CDF resulted in Figure 4-20 respectively.

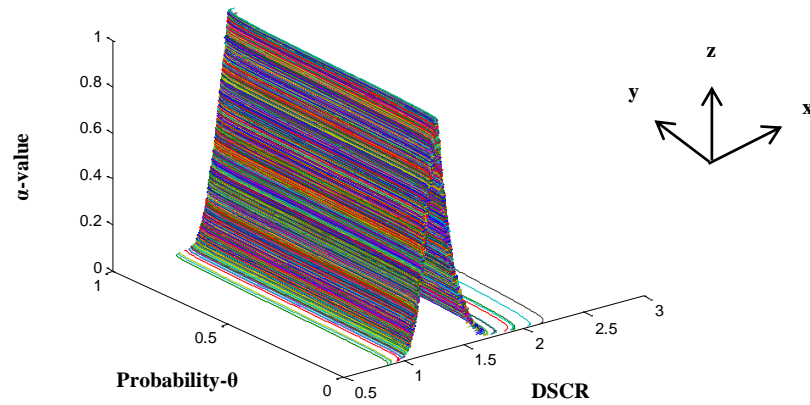


Figure 4-20 three dimensional view of fuzzy CDF for debt service cover ratio (DSCR) resulting from the output of FR-MCS, x-axis: TPC, y-axis: probability, z-axis: α -value

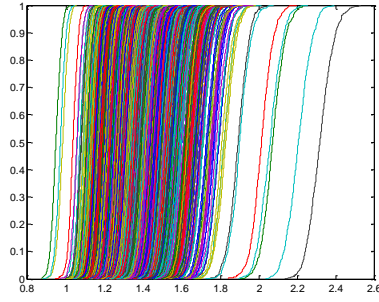


Figure 4-21 x-y view of fuzzy CDF resulted in Figure 4-20

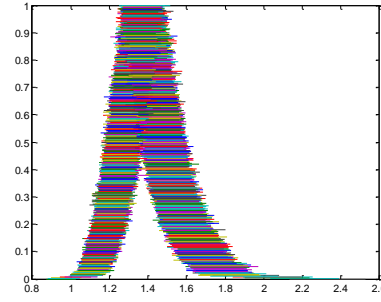


Figure 4-22 x-z view of fuzzy CDF resulted in Figure 4-20

As can be seen, the result of conventional MCS is a CDF which no uncertainty is taken into account while the result of FR-MCS is fuzzy CDFs and has taken uncertainties into account i.e. means to take into account the possibility that uncertainty may increase or reduce. As a result, by taking a specific value of the confidence level in fuzzy CDF, an interval for the decision variable will be obtained. On the contrary, by the same approach for CDF resulted from MCS, just a deterministic value will be achieved. Decision makers are more comfortable with interval on the negotiation table.

4.8.1 Sensitivity Analysis of FR-MCS Technique

The outputs of FR-MCS are sensitive to fuzziness of input variables. In the absence of fuzziness (pure probability in inputs) the result of FR-MCS is exactly equal to a CDF which is the same with the results of conventional MCS. In the absence of randomness (pure fuzziness in inputs) the result of FR-MCS is represented by CDF bound. It can be shown that the fuzziness of the output expands when the number of fuzzy random variables increases. Reasonably, for smaller number of fuzzy random variables, the CDF function has less fuzziness, and the CDF bound is narrower. More detailed discussion was illustrated in Figure 4-8 and Figure 4-9.

4.8.2 Decision Making Based on the Generated Fuzzy Probability Distributions

Similar to the CDF function concluding from conventional MCS (refer to value-at-risk section), a decision maker can use the fuzzy CDF of the decision variable/indicator in the simulation output to do decision making on not just probability but also possibility of acquired desirable output (i.e. probability and possibility that the decision variable/indicator will be more/less than a specific amount) and probability and possibility of success. Furthermore, it can be used to find an appropriate contingency value (arbitrary quantile) of project decision variable/indicator.

Figure 4-23 represents intersecting of x-y view of fuzzy CDF of return on equity (EIRR) resulted from FR-MCS with hurdle rate. It indicates the probability that the rate of return on equity will not be less than hurdle rate, 14%. This probability is in the form of a fuzzy set, as shown in Figure 4-23. The Level Rank defuzzification method (Moller and Beer, 2004) is used to convert the output fuzzy variable into a crisp value. By defuzzifying the output in Figure 4-23, it can be stated the probability that the rate of return on equity will not be less than hurdle rate, 14%, is around 79.5% (=1-20.5%).

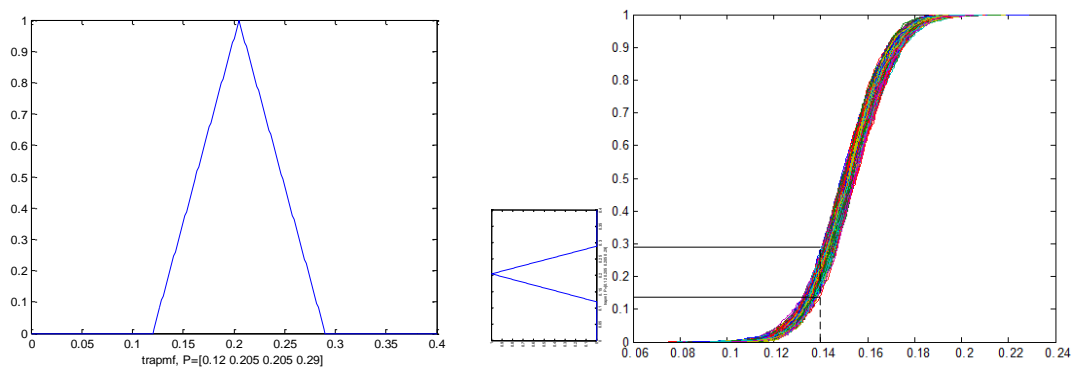


Figure 4-23 Intersecting of x-y view of fuzzy CDF of return on equity (*EIRR*) resulted from FR-MCS with specific amount to find the probability of interest (right), fuzzy set of probability of acquired desirable output (left)

The arbitrary quantile in a Fuzzy CDF is represented as a fuzzy set. Figure 4-24 illustrates intersecting of x-y view of fuzzy CDF of return on equity (EIRR) resulted from FR-MCS with specific confidence levels, 0.10 and 0.50, to find the appropriate contingency values (arbitrary quantile). It represents the 10th and 50th quantile of return on equity (EIRR). By defuzzifying the outputs in Figure 4-24, it can be stated that with 10% and 50% probability the rate of return on equity are around 17.10% and 15.20% respectively which are much greater than hurdle rate, 14%.

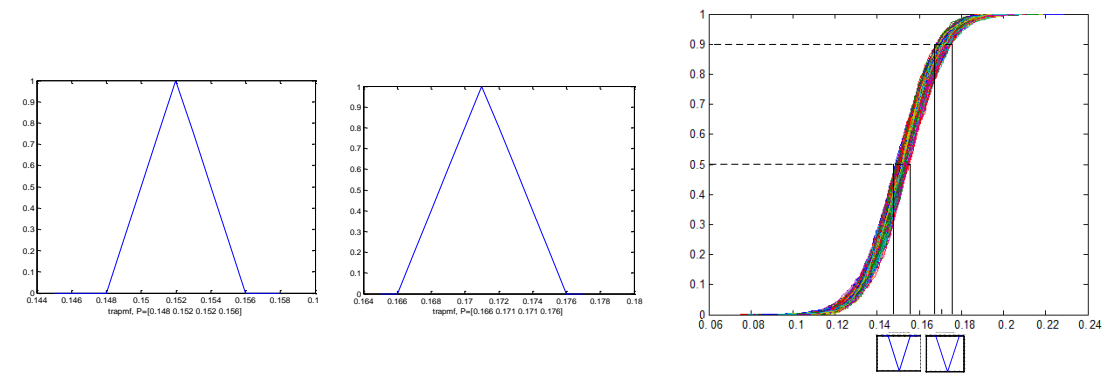


Figure 4-24 Intersecting of x-y view of fuzzy CDF of return on equity (*EIRR*) resulted from FR-MCS with 10% and 50% confidence levels to find the appropriate contingency values (arbitrary quantile) (right), fuzzy set of the appropriate contingency values (arbitrary quantile) with 10% confidence level (middle) and with 50% confidence level (left)

As can be seen, the FR-MCS technique and obtained fuzzy CDF have improved decision making based on the conventional MCS by incorporating the uncertainties involved in the project. FR-MCS helps and facilitates decision makers to come up with negotiation interval for negotiable concession items (NCIs) that takes players' characteristics into account.

4.9 Concluding Remarks

Probability theory has been successfully used in modelling random variables; however, this is insufficient for modelling imprecise information. Currently, the most popular method to carry out the PRA is MCS and its

analysis. Typically the data required to conduct the conventional MCS is not readily available or it is too costly to collect the required data. However, available data can be utilized through other mathematical tools such as fuzzy set theory. Thus, it is risk analysts responsibility to investigate, gather and efficiently include all the existing information using the most appropriate methods and mathematical tools.

This chapter introduced a new approach to simulation techniques under risk and uncertainty, which is called FR-MCS technique. The aim of this development is for generalization the conventional MCS to make decision based on the hybrid simulation approach of randomness and fuzziness of input parameters. The basic requirement of FR-MCS is to be able to randomly produce random/fuzzy/crisp number in simulation procedure. Consequently, determine inferior and superior of output values of simulation function by using fuzzy probability (fuzzy CDF). The proposed methodology has been introduced to integrate fuzzy set theory into PRA studies. α -cut method is used to perform algorithm for generating fuzzy random variable and to implement FR-MCS. Practically, given enough iterations of FR-MCS technique, it will produce a sufficiently small error.

The main idea proposed here is to utilize subjective probabilities, i.e. available information to represent the uncertain variable as a fuzzy number, and produce outputs which reflect all variable and uncertain information (i.e., uncertainty due to randomness, imprecision or due to both). In this approach, random variables parameters are treated as fuzzy numbers (Alternative 1). Alternatively, by using subjective approach, random variables are treated as pure fuzzy numbers (Alternative 2).

For cases where the necessity of conventional MCS and its analysis is justified but necessary information to conduct this analysis does not exist, the new approach proposed in this research can be conducted as an alternative to conventional MCS. The proposed FR-MCS technique allows fuzzy and probabilistic uncertainty to be considered simultaneously for the risk analysis of PPP-BOT projects. Depending on the project host country, the decision maker can adjust the conservative nature of FR-MCS using lower percentiles of risk and uncertainties. As for FR-MCS, the decision making will be based on the intervals while in MCS the decision making is based on the deterministic values. This advantage facilitates decision making.

The proposed technique is applied to a case whose data requirements are comparatively less or easier to obtain. The membership functions of the parameters of the fuzzy random variables can be formed using imprecise, vague information or expert judgment. Thus, application of the FR-MCS approach to risk assessment problems instead of conventional MCS approaches may be more realistic for many PPP-BOT cases and may provide decision makers with sufficient information for decision making. The results of conventional MCS and its analysis cannot easily be compared with fuzzy results of FR-MCS. It is not straightforward. Extensions of possibilistic concepts to various situations of reliability evaluation expand these results in the PPP-BOT context.

CHAPTER 5 DEVELOPING A HYBRID SIMULATION-BASED INTEGRATED SYSTEM FOR DETERMINING NEGOTIABLE CONCESSION ITEMS FOR PPP-BOT PROJECTS UNDER RISKS AND UNCERTAINTIES

5.1. Introduction

Determination of negotiation and concession items such as concession period and tariff which are called negotiable concession items (NCIs), directly affects the financial return and risks of both the government and concessionaire in long term infrastructure development projects.

According to the literature review, current methods for determining NCIs have some shortcomings and limitations. Firstly, the problem of how to simultaneously deal with fuzziness and randomness in determining NCIs is not studied. They do not map well the uncertainties in the simulation input to the simulation output, i.e. concession items determination taken as a deterministic value is unreasonable.

Secondly, they do not meet and guarantee all parties' interest. They generally focus on single party's objective e.g. private sector. As a PPP-BOT project cannot be successful without all main parties' agreement and involvement, considering the individual perspective is fruitless. So the obtained solutions are not equilibrium solutions and are not consensus solutions for all main parties. Thirdly, current methods do not provide a framework to prioritize NCIs for parties based on their goals. Finally, they do not address subjective information based on the experts' judgment and experience in the process of NCIs determination.

This chapter proposes a mechanism for determination of financial and contractual negotiation parameters (NCIs) under life cycle risks and uncertainties that could meet all parties' objectives. On the other hand, the proposed technique is tried to find the most satisfying agreement on NCIs as negotiation parameters under risks and uncertainties that meet all main parties' interest.

FR-MCS technique, which was introduced in chapter 4, has been used to overcome aforementioned problem by determining concession items (NCIs) as a bound (interval) via its fuzzy CDF instead of deterministic value from each party's perspective. In the last step of the proposed method, NCIs are considered by utilizing multi fuzzy numbers based on the multi party's objectives involved in the project. Subsequently, consensus on NCIs is represented by a fuzzy number based on the fuzzy operation. Finally, agreed NCIs are derived as a crisp value for final decision makings by using defuzzification methods at specific α -cut/ θ -confidence level.

By applying the proposed method, both parties' decision makers are able to see a clear picture of risk and uncertainty involved in PPP-BOT project and make better decisions on NCIs. It also guarantees multiparty interests and it can meet all players' objectives under risk and uncertainty. Furthermore, it prevents prolonged and costly negotiations in the development phase of PPP-BOT projects by providing more flexibility for decision makers.

The next sections present the proposed technique and its application to facilitate negotiations for determining agreeable NCIs. The proposed method is examined in a real case study.

5.2. Determining NCIs under Risks and Uncertainties

PPP-BOT projects' investment is through project finance rather than corporate finance. This induces other active parties moreover to private sector (first party) such as public sector (second party). Thus PPP-BOT negotiation model become bilateral, trilateral or even quadripartite negotiation games with complicated interactions and complete/incomplete information instead of a simple unilateral decision making process. PPP-BOT could offer a course of achieving project objectives by attaining a win-win-win solution among the public sector (government), private sector (concessionaire) and end user (public). A delicate balance has to exist among the private sector capacities and benefits, government regulatory function, and public and end user satisfaction simultaneously.

Negotiation is an important collaborative decision making and coordination behaviour in PPP-BOT projects, which can take place at any stage and phase of project to fulfil the parties' objectives such as the terms of the concession agreement. Success or failure of whole project is tied to success or failure of negotiations especially in the development phase. Concessionaire and public sector have several negotiations in the development phase to bargain on essential negotiation parameters which are called *negotiable concession items (NCIs)* in this research. Through this approach, the amount of risk can be rightly apportioned during the negotiations in the development phase by choosing reasonable, effective and efficient NCIs. This basic work and the process of updating the risk assessment and the process of risk mitigation and control—often summarized under the term risk

management– are supported and organized by the especial and proper process (Attarzadeh, 2007).

The negotiable terms of a PPP-BOT concession agreement, mainly including *concession period*, *tariff/toll design*, and *royalty*, are often discussed intensively during negotiations in the development phase. While the preliminary version of contractual terms is normally grounded on pro forma financial statements conducted during the feasibility study or the appraisal stage of the BOT project, change in any one of the terms will most likely alter the cash flow and deviate from the expected project return for all parties involved in the project (Liou and Huang, 2008).

Decision variables are defined based on the objectives of active and passive parties involved in the negotiations. NCIs are policy parameters that active parties negotiate on them at the negotiation table. Passive parties' interest should also be taken into account in determining NCIs. Negotiation pattern in a PPP-BOT project is demonstrated in Figure 5-1.

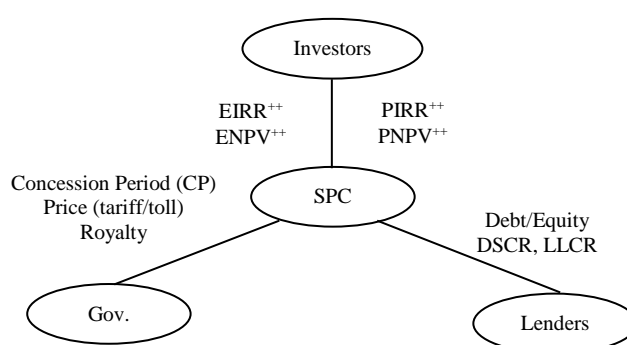


Figure 5-1 Negotiation pattern in PPP-BOT projects

In the course of analysing risks and uncertainties, five techniques are employed: probability analysis, possibility analysis, sensitivity analysis, variance analysis and scenario analysis. Probability analysis requires the random variables in input of simulation (or financial) model (risks) expressed

as probability distribution with a predefined spread (risky variable follows a specific probability distribution). Possibility analysis entails the uncertain variables in input of simulation (or financial) model (uncertainties) expressed as membership function using fuzzy logic (uncertain variable follows a specific membership function). Sensitivity analysis, variance analysis and scenario analysis are techniques as supplements evaluation methods to aid decision makings under risks and uncertainties in the course of risks and uncertainties management. Sensitivity analysis considers the effect on the project's decision variables of changes in the value of each input variable which poses potential serious risk to the project. On the other hand, variance analysis indicates how much the risk and uncertainty in a variable affects the goal and objective's variation. Scenario analysis examines a number of different likely scenarios (pessimistic, expected and optimistic scenarios) involving a simultaneous change of values for a number of key project variables.

Fuzzy sets are used for decision making based on incomplete or insufficient data, and probabilistic models are used as a decision making based on complete information about the probability distribution. Due to the difficulties in estimating the long-term uncertainties and wider-risk profiles at the tendering stage, this research suggests using a hybrid simulation approach of uncertainty modelling methods and probabilistic and stochastic risk analysis techniques (such as fuzzy sets, probability and possibility models and Monte Carlo simulation). This is called fuzzy randomness Monte Carlo simulation (FR-MCS) technique. Readers are recommended to refer to the chapter 4 for the details of definitions and procedures.

The advantage of hybrid probabilistic and fuzzy approach (fuzzy randomness) lies in the fact that by using values lying within a bound (interval) and model those by a defined distribution density or a membership function, the reality can be modelled better than by using deterministic and probabilistic figures solely. Actually, FR-MCS is performed to generate a distribution of decision variables of parties involved under risks and uncertainties over the project's economic life, practically NCIs. Based on the generated distribution, a range of NCIs for PPP-BOT players is obtained to negotiate.

5.3. Proposed Technique and Methodology

The step-by-step process of system structure of the proposed technique, aimed to determine consensus of NCIs, are represented in the following flowchart. This flowchart which represents stages of determining the NCIs by using the proposed multiple objective fuzzy randomness Monte Carlo simulation (MOFR-MCS) approach is shown in Figure 5-2. Briefly, the methodology consists of the following main steps. The first step is determining influential factors of NCIs (NCIs drivers) including stages 1 to 6. The second step is structure and process of simulation model which includes stages 7 to 9 i.e. consensus on the policy parameters (simulation input), simulation model and consensus on the NCIs (simulation output). The third step is fuzzy objective function determination including stages 10 to 12. The following sections describe them in detail respectively.

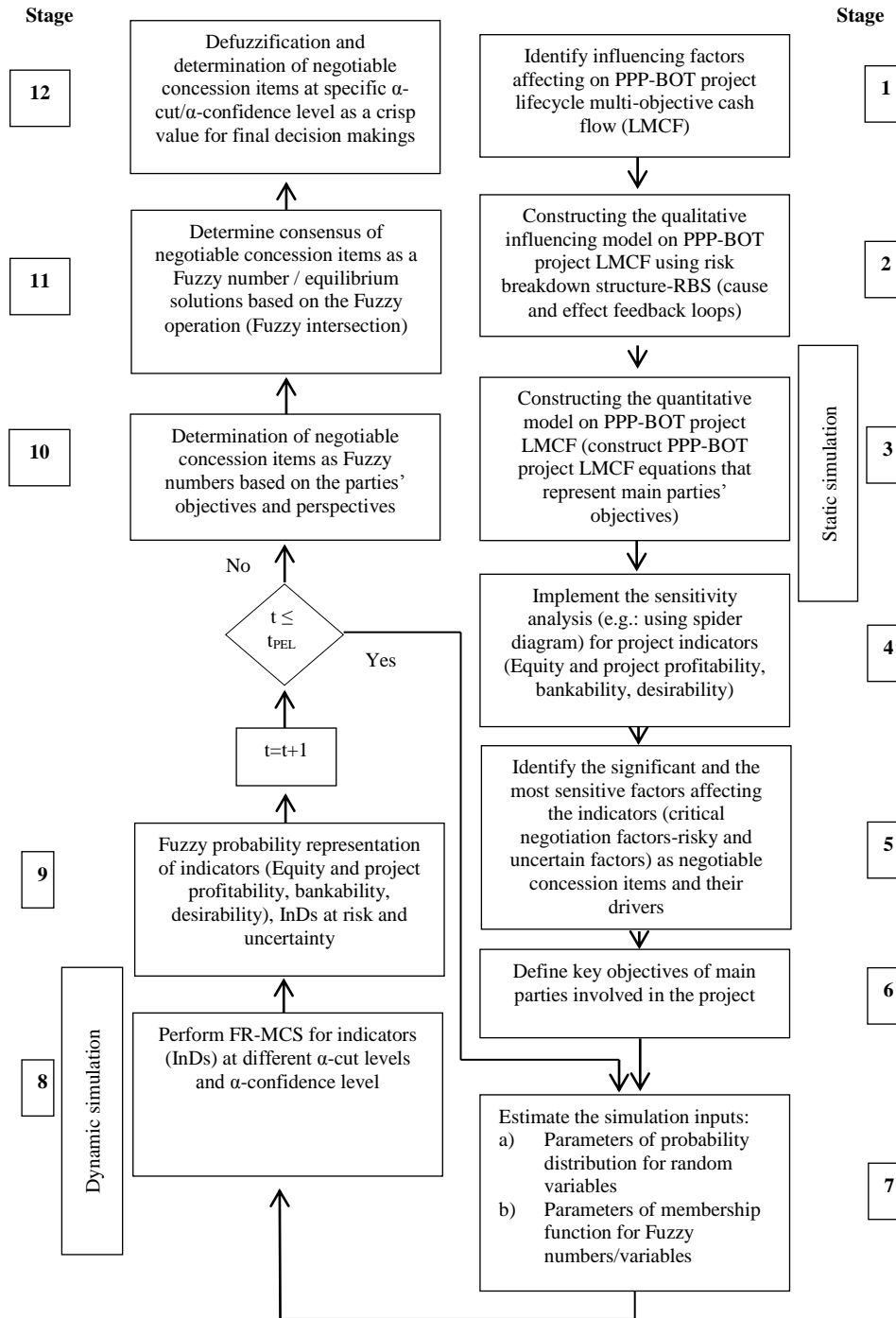


Figure 5-2 Framework of stages for determining consensus of NCIs by MOFR-MCS

5.3.1. NCIs Drivers

Determining the influential factors of NCIs is important. Sensitivity analysis as quantitative method could be helpful to this aim. The most important NCIs during bid (tender) period of the development phase are *concession period*, *price (tariff/toll)*, and *royalty*. An investigation of the

influential factors of concession period length determination (CPLD) in transportation project is conducted by Yu et al. (2014). Their study indicates that there are mainly seven factors involved in this issue, namely, interest rate (I), inflation rate (Inf), traffic flow, toll, the cost of different period (Ct), Investor's expected return rate (R), and investor's capital investment (Ic). Briefly, the previous studies show that the risks and uncertainties, such as a change in inflation rate, project demand and revenue (traffic flow) and operation cost could influence the decision on the concession period effectively. Furthermore, in this research a survey-based case study is conducted to find and complete the existing list of NCIs influential factors. The results of this survey are demonstrated in Figure 5-3. NCIs drivers could be demonstrated through the fish bone diagram. This diagram shows influential factors of concession period as NCI drivers. Key factors are shown in bold.

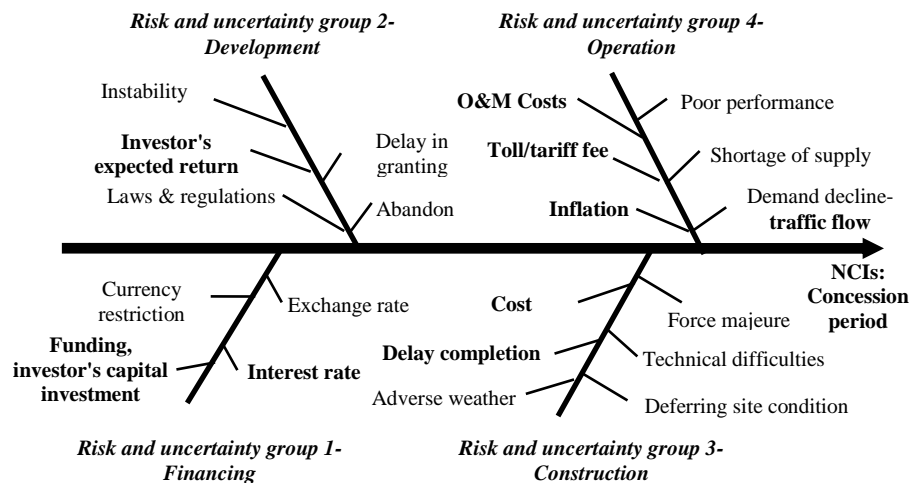


Figure 5-3 NCIs drivers, Fish bone diagram

5.3.2. Simulation Model Structure and Process

Descriptions of the simulation model and its components proposed by writers to evaluate risks and uncertainties and to determine feasible NCIs in

PPP-BOT projects are given in this section. Risk and uncertainty analysis is performed using the FR-MCS technique. A simplified flowchart for the structure and process of simulation model is given in Figure 5-4.

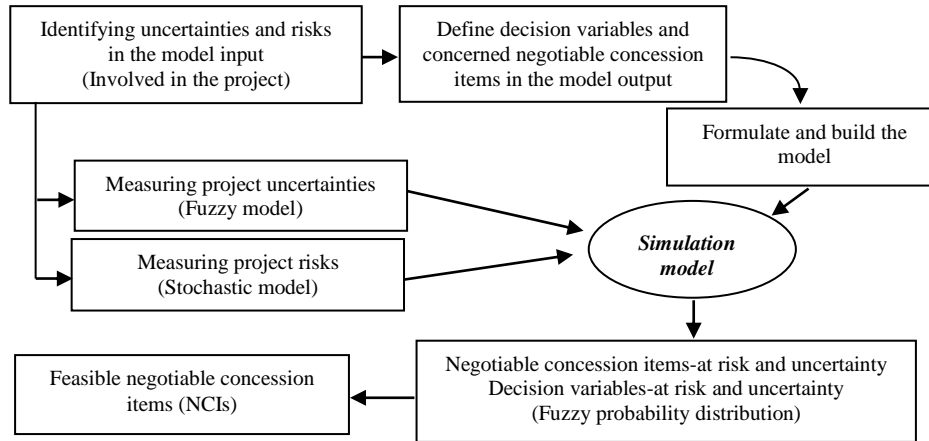


Figure 5-4 Structure and process of simulation model for feasible NCIs determination

5.3.2.1. Simulation Input

Simulation input parameters are categorized into two main categories: a) deterministic parameters and b) uncertain and risky parameters. The first category consists of parameters which values could be considered as stable over long period of time, e.g. tax rate and some kind of operation expenses that could be mitigated by contract such as insurance fee, rental fee and management expenditure.

In contrast, the second category consists of those input parameters that could be subject to variation and change due to risk and uncertainty involved and difficulties in long term estimation and prediction. It comprises three main types of simulation model inputs through the life cycle negotiation simulation.

1. *Macroeconomic indicators and indices*, which is depended on the host country economy, such as debt capital interest rate, discount rate, inflation rate, exchange rate, demand growth rate (e.g.: traffic growth rate), debt/equity (D/E) ratio, etc.

For instance, the discount rate, which is also called the hurdle rate, is the measure of the minimum expected rate of return that the concessionaire aims to get from the project implementation. It is generally influenced by the cost of capital (debt and equity) for the concessionaire. Estimation of the appropriate discount rate requires substantial judgment and often involves an inherent lack of precision. The D/E ratio is specific to the host country and depends on how keen the host government is to stimulate private investment in infrastructure project (Malini, 1999). Financial performance indicators of a PPP-BOT project is quite sensitive to the selected D/E ratio and decline rapidly as the project promoter borrows more than the optimal amount in an attempt to reach the project's debt capacity level (Dias and Ioannau 1995). Demand growth rate depends on the host country economic. For instance, traffic growth rate in a BOT urban infrastructure project depends on toll rates, willingness to pay, perceived benefits to the users, proximity of toll-free roads, availability of alternate modes of transport, industrial activity, development of new growth centres, and efficiency of the toll road (Malini, 1999).

2. *Fuzzy-Stochastic Variables (FSV)*, which are appraised based on the past project experiences and data or estimated based on the experts' judgment, such as construction cost, operation cost, maintenance cost, etc. Each risky/uncertain parameter follows specific probability distribution/membership function (probability (pure stochastic) /possibility model (pure fuzzy)). Furthermore, in some cases, the probability distributions of stochastic variables are derived subjectively from an expert knowledge base, due to the nonexistence of relevant data on PPP-BOT projects. In these cases, probability distribution's parameters, such as mean

and standard deviation, are derived using fuzzy variables/numbers (fuzzy probability model (fuzzy randomness)). In most cases, variables are derived subjectively from an expert knowledge and are represented directly by fuzzy variables/numbers. Construction, operation and maintenance costs are normally defined as stochastic variables in the simulation model input. Construction costs are derived based on the past projects. The yearly operation costs are traditionally represented as a percentage of annual revenue generated from toll/tariff. Annual maintenance costs consist of two main components, regular maintenance costs and overhaul maintenance costs. Yearly regular maintenance costs are typically represented as a percentage of construction costs. Overhaul maintenance costs are periodically costs to maintain a standard level of project. Typically, construction cost and completion time is assumed to follow lognormal distribution, O&M cost obey uniform distribution and market demand, sale price (income) follow normal distribution.

3. *Negotiable concession items (NCIs)*, which are policy parameters, such as concession period, tariff/toll design including the initial level of tariff/toll and tariff/toll adjustment scheme, royalty, construction and operation period, financial return, etc.

5.3.2.2. Simulation Model

Fuzzy Randomness Monte Carlo Simulation (FR-MCS) technique, which was introduced in chapter 4, is used to generate the values of stochastic and fuzzy variables and also their combination approach for each run and iteration. The life cycle cash inflow is generated by toll/tariff revenue which is calculated through the product of toll/tariff rate and yearly quantity in demand.

Normally, cash outflow consists of construction costs and operation and maintenance costs. The indicators as parties' objectives representation and decision variables and also NCIs are calculated for each run and iteration. Simulation functions make links between simulation input and output. Conventionally, spreadsheets and VBA Macros programming are used to implement these links (Malini, 1999). The life cycle computation would not stop at one simulation run. The simulation is repeated for many runs and iterations, each of them using a randomly generated set of values for the stochastic and fuzzy parameters based on the respective probability distributions and membership functions. The experiment is stopped after a sufficiently large number of replications are made so that the steady state is achieved. The proposed simulation produced a range (an interval) of NCIs with the impact of risks and uncertainties taken into consideration using FR-MCS technique. That would be advantageous to parties, the government and private sector. Otherwise, the decision making is based on the deterministic values which do not have any flexibility.

5.3.2.3. Simulation Output

As PPP-BOT negotiation/re-negotiation is a multi-party multi-stage decision process, meeting of all parties' objectives are crucial to the success of the project. Considering multi parties' objectives, involves multi-party risk and uncertainty modelling and management process. So, a method that takes risk and uncertainty into account simultaneously for multi parties is required. Typically, specific financial performance indicator is used to represent each party's perspective and objective. Ye and Tiong (2000) defined the NPV-at-risk, a measure of minimum expected return from the project at a given

confidence level. There are some shortcomings with their approach that current research addresses them. Indicator-at-risk and uncertainty system: IND_{α}^{μ} , which is proposed in this research, offers a decision criterion with a confidence level at a uncertain level (fuzzy randomness approach). These indicators are demonstrated in Table 5-1 for different parties involved.

Indicator at given confidence (α) and uncertain level (μ), IND_{α}^{μ} , is computed. According to the definitions and requirements, the following decision rules as two approaches for decision making can be derived. (1) The calculation of IND at a given confidence and uncertain level. (2) The calculation of confidence and uncertain level at the threshold point of IND. The project is acceptable from the party's perspective at the given confidence (α) and uncertain (μ) levels, if the IND_{α}^{μ} is greater than threshold point; otherwise, it is unacceptable. Alternatively, the project is acceptable if the computed confidence and uncertain level at the threshold point of IND is equal to or greater than (more favourite) the predetermined confidence and uncertain level; otherwise, it is unacceptable. Based on this consideration, IND-at-risk and uncertainty is defined as a particular IND that is generated from a project at specific confidence and uncertain level, that is, the minimum expected IND with the given confidence and uncertain level. In other words, IND-at-risk and uncertainty is the value at which $\alpha\%$ of probable IND is smaller and $1-\alpha\%$ is larger at specific uncertain level, μ .

$$IND\text{-at-risk and uncertainty} = IDN_{\alpha}^{\mu} = \int_{\mu=0}^1 (\mu_{IND} - Z_{\alpha}\sigma_{IND}) \quad 5.1$$

Where Z_{α} is number of units of standard deviation corresponding to the given confidence level of α ; for example, at the 95% confidence level and normal

distribution assumption, $Z_{\alpha} = 1.65$. This means that 95% of probable outcomes fall within the range from $\mu_{IND} - 1.65\sigma_{IND}$ to ∞ .

The simulation output gives indicators in the form of derived random variables (fuzzy and stochastic variables) with associated probability distribution and membership function. Using the details of generated output, one can construct the risk-uncertainty profile for each indicator, which quantifies the risk and uncertainty in terms of the fuzzy probability (i.e. fuzzy CDF) of obtaining a threshold value for the corresponding indicator for a given set of conditions.

The simulation model facilitates evaluation of long term infrastructure PPP-BOT project proposal for financial feasibility and viability, and throws light on the risks and returns under the chosen set of parameters (Malini, 1999). As a consequence, various options and scenarios can be examined with the use of the simulation model. The impact of such options on the financial indicators may be used as management information to facilitate fair negotiations between the government and the concessionaire, and to enable rational decisions regarding sharing of risks and costs. Quantity variation in simulation output is crucial and it is necessary to identify the factors driving variation.

Table 5-1 Indicators of main parties' objectives and perspective

Indicator	Deterministic environment	Risky and uncertain environment
Government's perspective	VFM (Value for Money) SLR ('Total Revenue/Total Cost' ratio @ end of Concession period)	VFM- at-risk and uncertainty SLR- at-risk and uncertainty
Private sector's perspective	EIRR NPV	EIRR- at-risk and uncertainty NPV- at-risk and uncertainty
Lenders's perspective	DSCR (Debt Service Cover Ratio) LLCR (Loan Life Cover Ratio)	DSCR- at-risk and uncertainty LLCR- at-risk and uncertainty

Government's perspective

The value for money (VFM) has been used as a criterion to measure whether the government has obtained the maximum benefit within the available resources. VFM not only measures the cost, but also takes into account the quality and fitness for purpose to determine whether goods and services represent desirable value. The government thus selects a preferred bidder to obtain the maximum VFM through its proposal. In assessing the VFM, the public sector comparator (PSC) is first identified, probably based on similar projects. The difference between the PSC and the bidding price (proposal) is the VFM of the potential project. The SLR is the ratio of the total revenue to the total cost at the end of the concession period.

Private sector's perspective

The main objective of the private sector is to maximize profits, and their decisions are mainly based on the financial viability of PPP-BOT projects. Thus, they look at the financial cash flows to check the project's financial viability and to assess whether they are able to meet their financial obligations, especially debt service. The project may include additional income such as government subsidies or may be limited to the concession agreement. The NPV of equity cash flow and EIRR (return on equity) indicators were, therefore, selected for this research. The return on equity may not be fixed, and may be obtained from the market, such as using capital asset pricing model (CAPM) as a guide, with all its limitations such as market volatility, short series, and insufficient betas.

Lenders' perspective

For lenders, the nature of non-recourse or limited recourse funding clearly carries a rather different credit assessment than a conventional full recourse loan. The key difference between the lenders and the investors is that holding debt rather than equity never has a potential upside gain in the project, only a downside risk (Grimseya and Lewis, 2002). In this case, lenders want to be satisfied that the indicators can measure whether the project can service its debt with a sufficient allowance to cover any contingencies. This research uses the debt service coverage ratio (DSCR) to represent the principal and interest payment ability. DSCR is the ratio of the net operating income to the annual debt service and signifies the ability of project's cash flows to meet the annual debt service requirements. This ratio is calculated each year and therefore provides a continuous view of the project's ability to service its debt. The DSCR is typically acceptable if it is more than 1.5.

The loan life cover ratio (LLCR) is another most commonly used debt metrics in Project Finance. It is the ratio of NPV of available cash for debt service during the debt period to total debt. Unlike period-on-period measures such as the DSCR, it provides an analyst with a measure of the number of times the cash flow over the life of the loan can repay the outstanding debt balance. Most banks have a requirement for a LLCR of around 1.4:1 or 1.5:1. DSCR and LLCR need to be modelled clearly and accurately. Other measures can also be implemented.

5.3.3. Consensus on the Policy Parameters-Simulation Input

Experts and project managers of parties involved in the PPP-BOT project i.e. the concessionaire and the government; have to reach a consensus on the type and parameters of probability distribution for risky variables and the

possible range (e.g. membership function type and parameters) of uncertain variables in simulation input. These risky and uncertain variables affect parties' objectives functions which are called simulation functions. The consensus is reached on key simulation input variables (e.g. financial variables) that affecting the simulation (e.g. life cycle cash flow) and decision variables in simulation output (e.g. project return).

It is needed to observe objective and subjective variables of the project, obtain a consensus of them and feed simulation input. To do this, it is proposed that, subjective variables are observed from a number of experts and are represented as a fuzzy number for each expert. Then for consolidation and combination of gathered values, weighted Fuzzy-Delphi Method (WFDM) is applied to reach a fuzzy number that is representative of experts' opinions of each party involved. At the end, a fuzzy number that represent each party's opinion on specific variable is established.

5.3.3.1. Fuzzy-Delphi Technique

Traditional Delphi method is a structured communication technique, originally developed as a systematic, interactive forecasting method which relies on a panel of experts. The success of the Delphi method depends principally on careful selection of the panel of experts. In the standard version of Delphi method, the experts answer questionnaires in two or more rounds. After each round, a facilitator provides an anonymous summary of the experts' forecasts from the previous round as well as the reasons they provided for their judgments. Thus, experts are encouraged to revise their earlier answers in light of the replies of other members of their panel. It is believed that during this process the range of the answers will decrease and the group will

converge towards the “correct and precise” answer. Finally, the process is stopped after a pre-defined stop criterion (e.g. number of rounds, achievement of consensus, and stability of results) and the mean scores of the final rounds determine the results (Rowe and Wright, 1999).

Although the traditional Delphi method as a survey technique has offered helpful capability, but the problems of uncertainty modelling still exist. The problems may exist in the survey question and the response. Therefore, the fuzzy set theory can be an appropriate method to deal with these problems. Fuzzy Delphi method (FDM) is a generalization of the classical Delphi method which was developed in the sixties by the Rand Corporation at Santa Monica, California. Kaufmann and Gupta (1988) proposed steps for implementation of the FDM (Bojadziev and Bojadziev, 1997). The following are modified steps which are compatible with the research context.

Step 1: The experts and PPP-BOT project managers (of main parties included concessionaire, government, lenders, etc.) $E^{p_i}, E^{g_i}, E^{l_i}$, etc. ($i = 1, 2, \dots, n$) are asked to provide their estimates and appraisal on the key simulation input variables (risky and uncertain variables), X_j ($j = 1, 2, \dots, m$). This is done by determining the minimum $a_j^{p_i}, a_j^{g_i}, a_j^{l_i}$, etc. the most plausible $b_j^{p_i}, b_j^{g_i}, b_j^{l_i}$, etc. and the maximum $c_j^{p_i}, c_j^{g_i}, c_j^{l_i}$, etc. values for these appraisals. The data given by the experts and PPP-BOT project managers are presented in the form of triangular fuzzy numbers (T.F.N). $\tilde{X}_j^{p_i} = \langle a_j^{p_i}, b_j^{p_i}, c_j^{p_i} \rangle$, $\tilde{X}_j^{g_i} = \langle a_j^{g_i}, b_j^{g_i}, c_j^{g_i} \rangle$, $\tilde{X}_j^{l_i} = \langle a_j^{l_i}, b_j^{l_i}, c_j^{l_i} \rangle$, etc. These appraisals could also be represented by trapezoidal fuzzy numbers (Tr.F.N). $\tilde{X}_j^{p_i} = \langle a_j^{p_i}, b_j^{p_i}, c_j^{p_i}, d_j^{p_i} \rangle$, $\tilde{X}_j^{g_i} = \langle a_j^{g_i}, b_j^{g_i}, c_j^{g_i}, d_j^{g_i} \rangle$, $\tilde{X}_j^{l_i} = \langle a_j^{l_i}, b_j^{l_i}, c_j^{l_i}, d_j^{l_i} \rangle$, etc.

Step 2: First, the fuzzy average of all key simulation input variables, \tilde{X}_j , for each party involved in the negotiation is computed according to the equation.

$$\begin{aligned}\tilde{X}_j^{\text{pave}} &= \langle a_j^{\text{pave}}, b_j^{\text{pave}}, c_j^{\text{pave}} \rangle, \tilde{X}_j^{\text{gave}} = \langle a_j^{\text{gave}}, b_j^{\text{gave}}, c_j^{\text{gave}} \rangle, \tilde{X}_j^{\text{lave}} \\ &= \langle a_j^{\text{lave}}, b_j^{\text{lave}}, c_j^{\text{lave}} \rangle, \text{etc.}\end{aligned}$$

Then for each expert the deviation between fuzzy average and appraised fuzzy triangular numbers by experts is computed respectively. It is also a triangular number. The corresponding deviations of each party are given back to the experts and PPP-BOT project managers for revision.

Step 3: Each expert gives a new fuzzy triangular number. The process defined by steps 2 and 3 is repeated until two successive means become, according to the decision makers, reasonably close. Then the process is terminated.

5.3.3.2. Weighted Fuzzy-Delphi Technique

In subjective decision making, the knowledge, experience and expertise of some experts is often preferred to the knowledge, experience and expertise of other experts. This is expressed by weights $w_i^p, w_i^g, w_i^l, \text{etc.}$ ($\sum_{i=1}^n w_i^p = \sum_{i=1}^n w_i^g = \sum_{i=1}^n w_i^l = 1, i = 1, 2, \dots, n$) assigned to the expert i . They represent the relative importance of expert i to others in each party's group.

Fuzzy Delphi method is a typical multi-experts forecasting procedure for combining views and opinions. Fuzzy Delphi method (FDM) has been examined by Khanzadi et al. (2010) to determine the concession period. However, there are some shortcomings and limitations to their study which have been addressed in this research.

5.3.4. Fuzzy objective function determination

Turning to the concept of a decision, intuitively, a decision is basically a choice or a set of choices drawn from the available alternatives. It could be suggested that a fuzzy decision be defined as the fuzzy of alternatives resulting from the intersection of the goals and constraints. This idea could be formalized in the following definition. In defining a fuzzy decision as the intersection of the goals and constraints, we are tacitly assuming that all of the goals and constraints are of equal importance. There are some situations, however, in which some of the goals and perhaps some of the constraints are of greater importance than others. In such cases, the goal might be expressed as a convex combination of the goals and constraints, with the weighting coefficients reflecting the relative importance of the constituent terms.

Since multiparty are involved in the PPP-BOT project the consensus on NCIs is tied to the determination of each life cycle's objective function under risks and uncertainties of each party. The government's objective (Π_g) is to maximize the expected total social welfare and economic performance. It is quantitatively computed by VFM (including the customers' surplus), earning during concession period from royalty (Φ) and post-transferring period from project operation (Ψ). It is mathematically represented by equation 5.2.

$$Max \Pi_g = VFM_{\alpha}^{\mu} + \Phi^{CP\mu}_{\alpha} + \Psi^{PCP\mu}_{\alpha} \quad 5.2$$

Where:

$$\Phi^{CP\mu}_{\alpha} = \sum_{t=1}^{CP} \frac{RY_{t\alpha}^{\mu}}{(1 + r_{\alpha}^{\mu})^t} ,$$

$$\Psi^{PCP\mu}_{\alpha} = \sum_{t=CP+1}^{t_e} NPV_{t\alpha}^{\mu} = \sum_{t=CP+1}^{t_e} \frac{(\text{Rev}_{t\alpha}^{\mu} - C_{t\alpha}^{\mu})}{(1+r_{\alpha}^{\mu})^t}, \Psi^{PCP\mu}_{\alpha} \geq 0$$

$$VFM_{\alpha}^{\mu} = \nabla NPV^{PSC-PPP} = NPV^{PSC} - NPV^{PPP}, VFM_{\alpha}^{\mu} \geq 0,$$

$$C_{t\alpha}^{\mu} = O\&M_{t\alpha}^{\mu} + \text{Tax}_t$$

The private sector only care about their own financial profits during the concession period to repay the debt (principal and interest) and initial investment and make acceptable return on investment($I_c R$). Their object function (Π_p) is mathematically represented by equation 5.3.

$$\begin{aligned} \text{Max } \Pi_p = NPV_{\alpha}^{\mu} &= \sum_{t=1}^{CP} NPV_{t\alpha}^{\mu} = \sum_{t=1}^{CD} -\frac{I_{t\alpha}^{\mu}}{(1+r_{\alpha}^{\mu})^t} + \\ &\sum_{t=CD+1}^{CP} \frac{\text{Rev}_{t\alpha}^{\mu} - C_{t\alpha}^{\mu}}{(1+r_{\alpha}^{\mu})^t} - I_0 \end{aligned} \quad 5.3$$

As an example, life cycle fuzzy objective function from private sector perspective (NPV of accumulated cash flow) is demonstrated in Figure 5-5. As can be seen, the optimistic scenario which is under optimal performance case, is plotted with α cut=0_r, the most likely scenario which is under planned performance is plotted with α cut=1 and pessimistic scenario which is under worst performance is plotted with α cut=0_L.

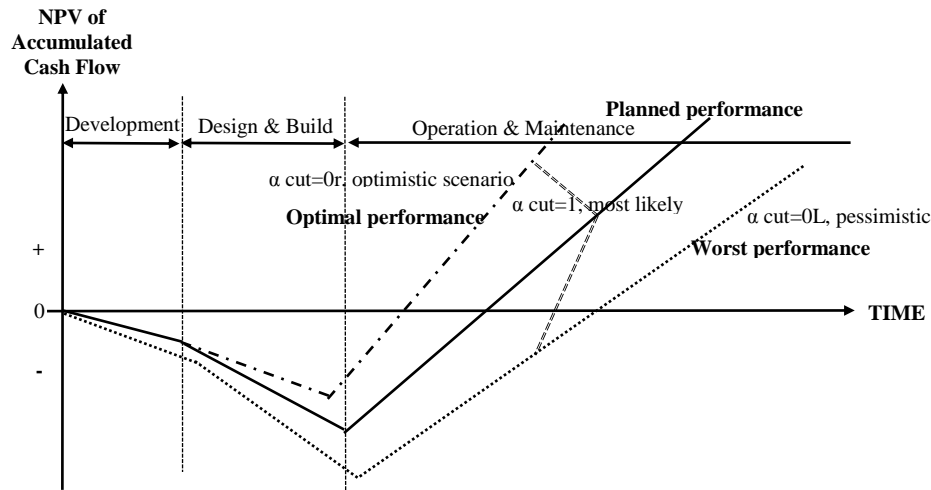


Figure 5-5 Life cycle fuzzy objective function-private sector perspective NPV of accumulated cash flow

5.3.5. Consensus on the NCIs – Simulation Output

The concessionaire and the government also have to reach consensus on the NCIs as decision variables (in simulation output) that fulfil and satisfy lenders and end-users expectation and interest. To do this, based on each party's objective and by using the FR-MCS results, NCI is represented as fuzzy number for each party. Then through using the fuzzy operation (fuzzy intersection) consensus on NCI is achieved as a fuzzy number. Lastly, through defuzzification methods, NCI at specific μ -cut/ α -confidence level is determined as a crisp value for final decision makings. Defuzzification is the conversion method of fuzzy output (possibility distribution of the output) to crisp (precise) value. This crisp value is a NCI that meet all parties' interests and objectives. So the obtained NCI could guarantee the success of the negotiations and prevents prolonged and costly negotiations especially in the development phase of PPP-BOT projects. Figure 5-6 demonstrates the idea of using multiple objective fuzzy representation to establish consensus on NCI. NCI is determined based on the perspective of government, lender and private sector. Fuzzy intersection is proposed to find common ground for multiparty

negotiation, as benchmark of consensus on the NCIs. It is represented as shaded area in the Figure 5-6.

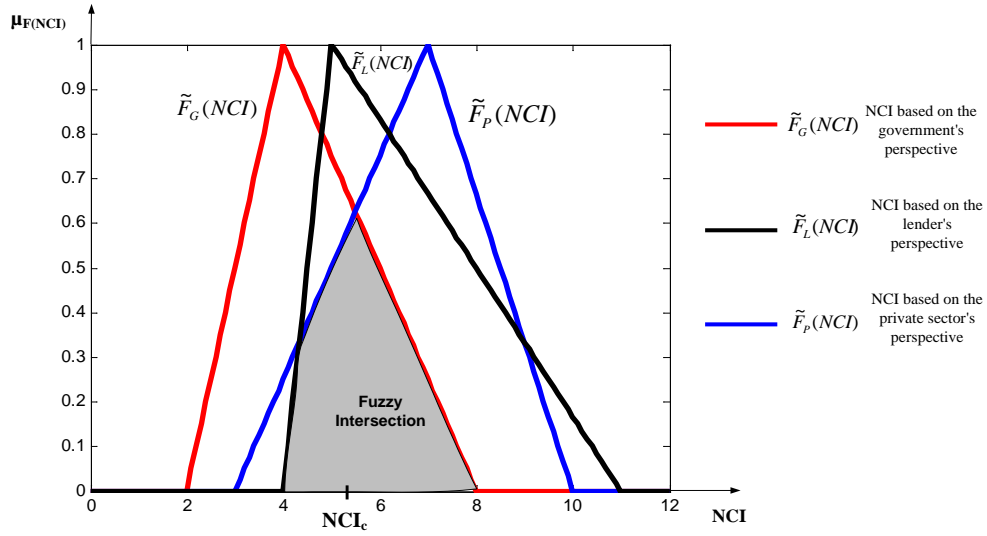


Figure 5-6 Fuzzy intersection of multiparty fuzzy objectives to find common ground for multiparty negotiation

For establishing an appropriate NCI under risks and uncertainties, it is necessary to follow these three steps: Firstly, identify essential and significant risky and uncertain factors as well as concession items involve in life cycle negotiation PPP-BOT project from each party's standpoint (as CSFs if manage properly) that could have serious effects on decision variables. Secondly, having established the deterministic, risky and uncertain parameters in simulation input, the simulation can proceed by feeding these parameters through generating random and fuzzy random variables. By repeating the simulation cycle an enough number of times, the fuzzy CDF of the NCIs can be generated. Likewise, the fuzzy CDF for each possible NCI can also be identified. Thirdly, with the simulation results, NCI that could meet and ensure main parties' objectives is determined (i.e. guarantee the concessionaire to gain the anticipated financial return under the proposed tariff/toll structure at a particular confidence and uncertain levels (fuzzy probability) and ensure the

public sector to meet its objective by considering the constraints of end users and lenders).

The simulation output would include the fuzzy CDF of all different NPV corresponding to various scenarios (NPV min, NPV expected and NPV max) and the criteria and constraint for finalizing appropriate NCIs. In addition, different scenarios could be considered during the simulation process. This approach facilitates trade-off decision making between deterministic and uncertain parameters (e.g. a series of IRR or tariff/toll structure) on the one side and NCIs (e.g. concession period, tariff/toll rate and royalty) on the other side.

In order to take into account the satisfaction level of the parties, it is proposed to use minimum satisfaction of the parties (specific α -cut) before doing the defuzzification. For instance, in the case that is represented in Figure 5-6, maxmin of the parties' satisfaction is 0.6. Robustness of the equilibrium solution (defuzzification result) is an essential and crucial issue that must be considered. The obtained solutions that are located near to borderline and threshold points are not robust. There are so sensitive to uncertainty and risk. Because of this, among major defuzzification techniques, the Level Rank Method (Moller and Beer, 2004) is proposed for defuzzification to meet the requirements of robustness of equilibrium solution. The concept of the Level Rank Method is based on the α -discretization. The membership scale of the fuzzy variable is discretized with the aid of chosen α -levels, and then the arithmetic mean of the interval centres of the α -level sets is computed as defuzzification result.

The idea of using multiple objective fuzzy representation to establish consensus on NCI is consistent with the game theory concept and solution. It means that when the intersection of fuzzy representation exists, the corresponding Game has an equilibrium solution and vice versa when the intersection does not exist, the corresponding Game model does not have any equilibrium solution. In some cases, no fuzzy intersection may be derived. In such cases an appropriate method such as Real Options Valuation (ROV) that could create this common ground is required. This is an interesting issue in PPP-BOT context; however, it is beyond the scope of this chapter. Readers are recommended to refer to the chapter 6 for the details of definitions and procedures.

5.3.6. Fuzzy Multi Objective Function

Since the decision making in PPP-BOT projects is a multi-objective decision making under uncertainty and risk, fuzzy multi objective function based on the centroid method and the fuzzification and defuzzification algorithms after Jain and Chen (Jain, 1985; Chen, 1976; Moller and Beer, 2004) is developed. It enables decision maker to analyse and identify the most preferred negotiation scenario from possible negotiation scenarios that results in a win-win-win concession scheme for government, concessionaire and end user. By this method, the selected negotiation scenario would balance the interests of all major stakeholders simultaneously. Fuzzy set simulation model is also applied to evaluate negotiable concession items (NCIs) under uncertainty.

There are some assumptions in this model. At first current objective function must be transfer to fuzzy objective function, $f_i(x)$. $f_{i_{inf}}$ and $f_{i_{sup}}$ are

the inferior and superior boundaries of $f_i(x)$. $\mu_i(x)$ is the membership degree.

The membership functions for Max and Min objectives are as follows:

$$\mu_i(x) = \left[\frac{f_{isup} - f_{i(x)}}{f_{isup} - f_{iinf}} \right] \quad 5.4, \mu_i(x) = \left[\frac{f_{i(x)} - f_{iinf}}{f_{isup} - f_{iinf}} \right] \quad 5.5$$

The max–min decision role, equation 5.6, is taken to determine the non-inferior (non-dominated) solution where i is the objective index, j is the scenario index and w_i is the weight of objective i .

$$\mu_{ij} = \max_j \min_i \{ (\mu_{ij})^{w_i} \} \quad 5.6$$

5.4. Illustrative Case Study

A case study has been conducted, a BOT toll highway project. *The Toolkit for Public-Private Partnerships in Roads and Highways* provided by the World Bank-PPIAF (V1.1, 2009) demonstrated a financial model. This model has some shortcomings. Although the toolkit provides the capability to take into account some variables as risk; these variables are not able to be changed simultaneously. Therefore, it is still a static model. Furthermore, it is unable to handle fuzzy variable as an input, as a consequence it cannot perform uncertainty modelling. The proposed model for financial modelling has solved these limitations. It is implemented using spread sheets and Macro in Microsoft Excel. Also a special program has been developed by MATLAB (The MathWorks, Inc., Natick, Massachusetts) to perform risk and uncertainty analysis using the FR-MCS technique for the evaluation of uncertain and risky parameters. FR-MCS technique is a hybrid simulation approach for risk and uncertainty evaluation and analysis. The proposed approach permits any type of risk and uncertainty in the input values to be explicitly defined prior to the

decision analysis being undertaken. The proposed approach extends the practical use of the conventional MCS by providing the capability of choosing between fuzzy sets and probability distributions in the input. The outcome of the FR-MCS technique captures both fuzzy and probabilistic uncertainty. They are represented through the fuzzy CDF method. By using the fuzzy CDF method in FR-MCS technique, the aforementioned shortcomings to the existing method are removed. Uncertain parameters are referred to the variables that estimated based on the experts' judgment and risky parameters are referred to the variables that derived from historical data (previous projects). In this case study our focus is on the representation of the uncertain parameters such as demand uncertainty by fuzzy variables and risky parameters such as total project cost by random variables. The membership function of quantity of demand as an uncertain variable is shown in Figure 5-7. The assumptions and summary of project data including expected value of parameters and their distribution or membership function is tabulated in Table 5-2. A total of 1000 iterations are generated. In this case study the following parameters are taken as risks and uncertain variables: concession period, construction cost, operation cost, initial daily traffic, traffic growth, toll rate (VAT incl.), Investment subsidies, equity, debt maturity, interest rate, grace period, inflation rate, corporate tax rate, VAT rate. The components of project cash flow at most likely value of quantity of demand are exhibited in Figure 5-8 and Figure 5-9. The main indicators such as project IRR (PIRR), equity IRR (EIRR) and DSCR are calculated and are shown. Debt and dividend calculations are shown in Figure 5-10 and Figure 5-11. The calculations show the associated amount of annual service debt and dividend payment, ADSCR,

LLCR, PIRR and EIRR. Sensitivity Analysis of indicators PIRR and EIRR to aforementioned key risky and uncertain variables is performed. It is represented by Spider diagram in Figure 5-12 and Figure 5-13. As can be observed from sensitivity analysis-spider diagrams, the financial model outcomes are sensitive to construction cost, toll rate, initial daily traffic, concession period, construction period and tax rate.

Table 5-2 Basic input data of the case study

Input data	Expected Value	Distribution/Membership function
Macroeconomic indicators and indexes		
Project Economic life, project life cycle (yrs)	30	Deterministic
Costs regime during construction	-	<0.1,0.3,0.5,0.1>
Escalation rate during construction/inflation rate during operation period (%)	4	Log Normal distribution, LnN(4,1)
Amortization period (yrs)	20	Deterministic
Tax rate (%)	10	Deterministic
Gov. discount rate (%)	8.16	Deterministic
Cost of debt (%)	5.40	Deterministic
Cost of equity (hurdle rate) (%)	16	Deterministic
Loan Interest rate (%)	6	Deterministic
Loan repayment period/debt maturity (yrs)	10	Deterministic
WACC-discount rate (%)	8.58	Deterministic
Annual growth rate of unit price (%)	5	Normal distribution, N(5,1)
Annual growth rate of quantity of demand (%)	5	Normal distribution, N(5,1)
Cost of finance coefficient for Pre concession period costs calculation	0.05	Deterministic
Cost of tender coefficient for Pre concession period costs calculation	0.05	Deterministic
Increasing rate of annual growth rate of unit price (%)	10	Normal distribution, N(10,1)
Expected Base Cost coefficient for Asset value calculation at transfer date	0.1	Normal distribution, N(0.1,0.01)
Fuzzy-Stochastic Variables (FSV)		
Total project costs (M\$)	170	Normal distribution, N(170,25)
Operation and maintenance costs (M\$/year)	1.73	Normal distribution, N(1.73,0.25)
Annual growth rate of O&M costs (%)	2.5	Normal distribution, N(2.5,1)
Initial daily traffic (vehicles/day)	20,000	Fuzzy variable: Tr.F.N, {18,800, 20,000, 20,000, 20,600}
Quantity of demand (vehicle per year)	7,300,000	Fuzzy variable: Tr.F.N, {6,862,000, 7,300,000, 7,300,000, 7,519,000}
Operating revenue (M\$/year)	27.01	Fuzzy variable: Tr.F.N, {25.39, 27.01, 27.01, 27.82}
Pre concession period (yrs)	2	Log Normal distribution, LnN(2,0.5)
Negotiable concession items (NCIs)		
Construction period (yrs)	4	
Operation period (yrs)	21	
Concession period (yrs)	25	
Unit price of services in first year of operation (\$/vehicle)	3.7	
Debt, Equity (%)	40%,30%	
Government subsidy/contribution, grant fraction, Royalty	30%	

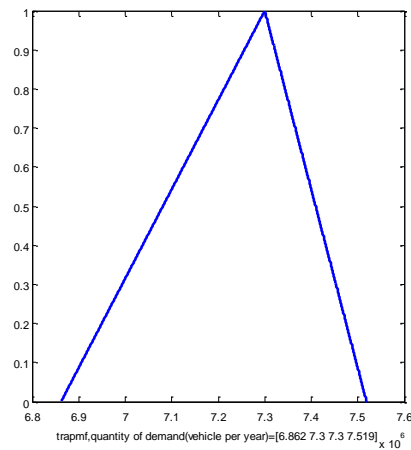


Figure 5-7 Membership function of quantity of demand (vehicle per year) - uncertain random variable

Year	Construction Period				Operation Period			Post concession period	
	1	2	3	4	1	2	21	22	30
Yearly traffic (Million vehicles)					7.30	7.67	19.37	20.34	30.05
Operating revenue (MUSD)					27.01	28.36	71.67	75.25	111.18
construction costs (MUSD)	-17	-51	-85	-17					
construction costs-Cumulative (MUSD)	-17	-68	-153	-170					
Interest During Construction (MUSD)		-0.71	-2.86	-6.43					
Financing Fees and Insurance (MUSD)	-10								
O&M costs (MUSD)					-1.73	-1.77	-2.94	-3.03	-4.00
Depreciation (MUSD)					-8.10	-8.10	-8.10	0.00	0.00
Net operating income (MUSD)					17.18	18.50	60.63	72.22	107.17
Project Cashflow (MUSD)	-27.00	-51.71	-87.86	-23.43	17.18	18.50	60.63	72.22	107.17
Cumulative (MUSD)	-27.00	-78.71	-166.57	-190.00	-172.81	-154.31	557.71	629.92	1356.02
PV (MUSD)	-27.00	-78.71	-166.57	-190.00	-174.17	-158.48	93.84	105.65	187.32
loan interest payment (MUSD)					-6.80	-6.05	0.00	0.00	0.00
Earning before tax (MUSD)					10.38	12.45	60.63	72.22	107.17
Tax (MUSD)					-1.85	-2.05	-6.87		
Net earning (MUSD)					8.53	10.40	53.76	72.22	107.17
Depreciation (MUSD)					8.10	8.10	8.10	0.00	0.00
loan principal payment (MUSD)					-12.60	-12.60			
DSCR ((EBIT+Dep-Tax)/Debt service)					1.21	1.32			
Equity Cashflow (MUSD)	-8.10	-15.51	-26.36	-7.03	4.03	5.89	61.86	72.22	107.17
PV (MUSD)	-8.10	-23.61	-49.97	-57.00	-53.53	-49.15	46.53	49.29	63.78
Cumulative (MUSD)	-8.10	-23.61	-49.97	-57.00	-52.97	-47.08	612.32	684.53	1410.63
IRR and NPV on Project	11.30%	\$49.99							
IRR and NPV on Equity	19.85%	\$17.90							
PV of min Return on equity (M\$)	9.12								
PV of min Return on project (M\$)	16.30								
DSCR min	1.21								
DSCR avg	1.89								

Figure 5-8 Components of project life cycle cash flow (M\$) at most likely value of quantity of demand

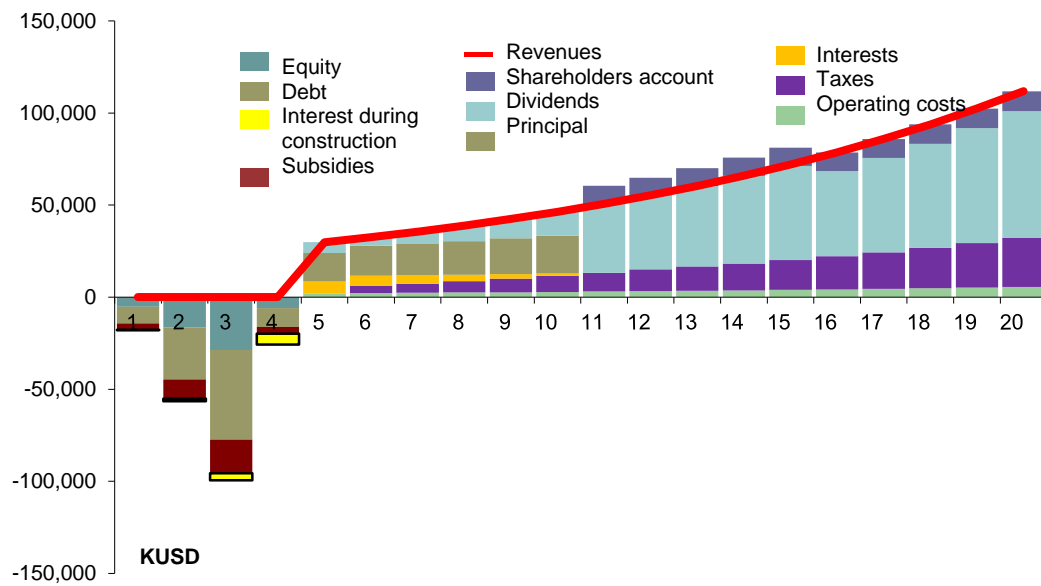


Figure 5-9 Project life cycle cash flow diagram (K\$)

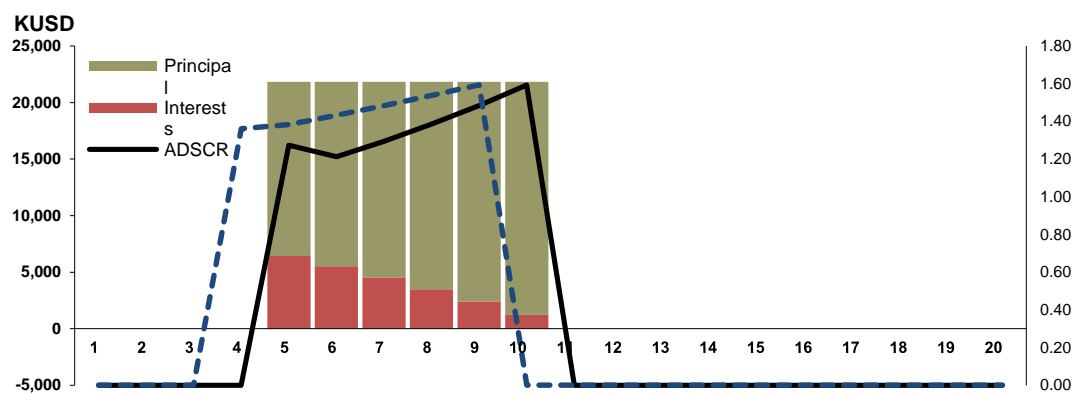


Figure 5-10 Debt cash flow diagram (K\$)

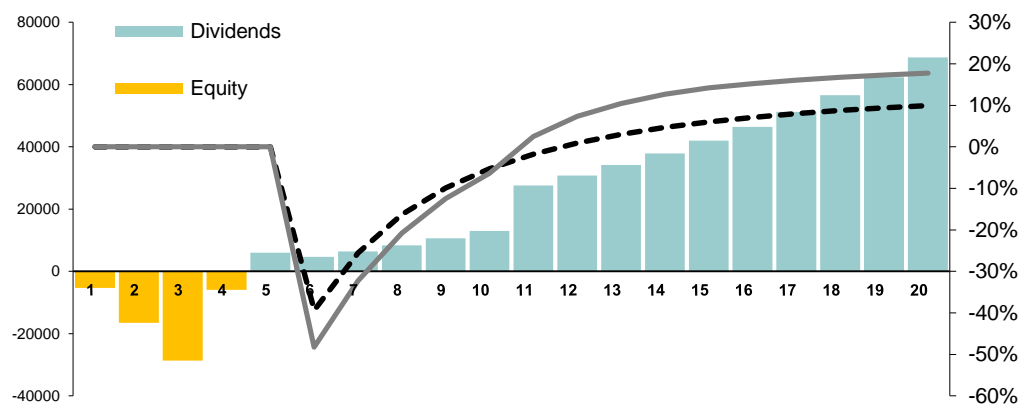


Figure 5-11 Dividend cash flow diagram (K\$)

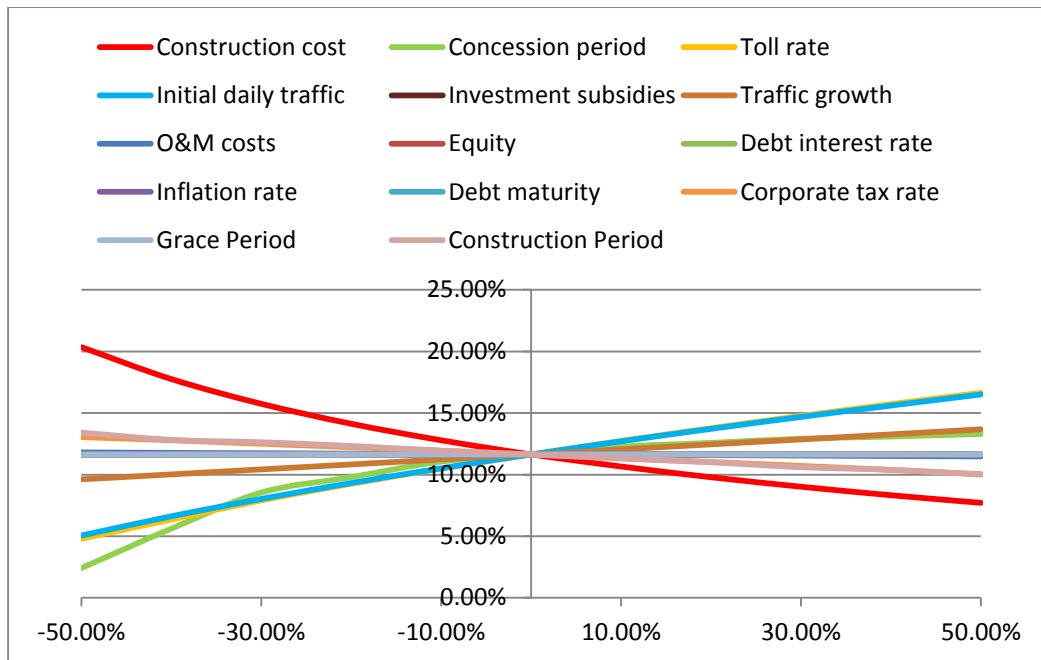


Figure 5-12 Sensitivity Analysis of indicator PIRR to key risky and uncertain variables

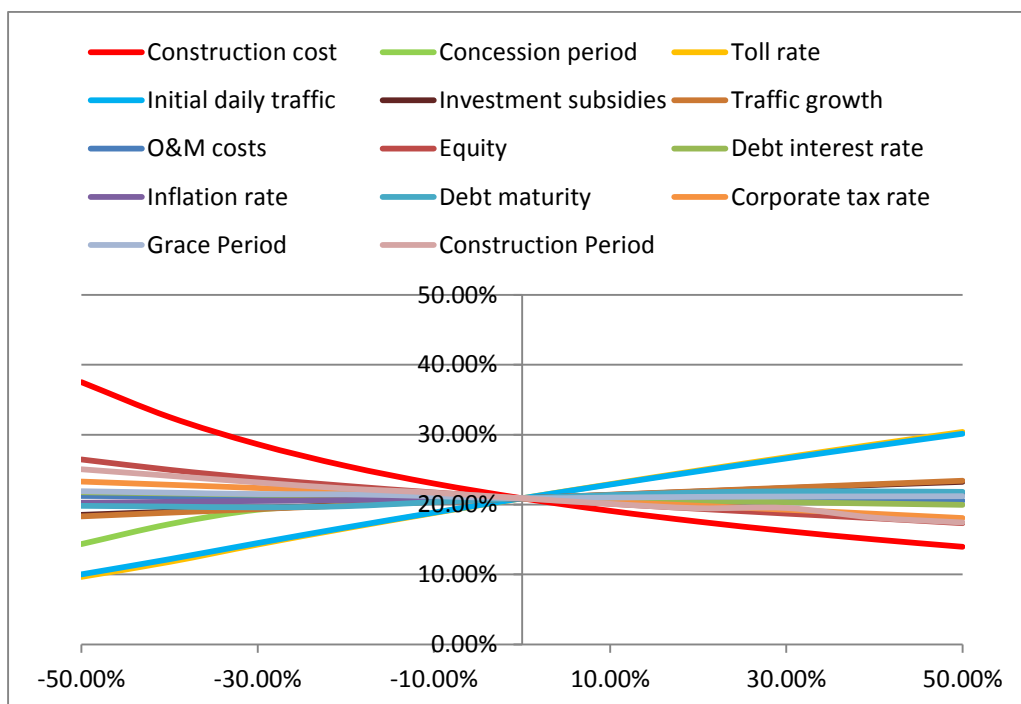


Figure 5-13 Sensitivity Analysis of indicator EIRR to key risky and uncertain variables

Figure 5-14 illustrates three dimensional view of fuzzy CDF for total investment costs (TIC) resulting from the FR-MCS that are generated by MATLAB. The x-axis denotes TIC, y-axis is the probability, and z-axis is the α -value. Figure 5-15 and Figure 5-16 represent the x-y and x-z views of fuzzy CDF resulted in Figure 5-14 respectively.

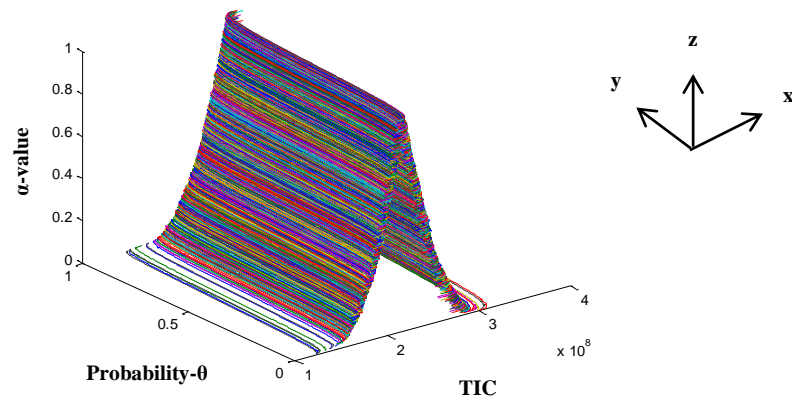


Figure 5-14 Three dimensional view of fuzzy CDF for total investment costs resulting from the output of FR-MCS, x-axis: TIC, y-axis: probability, z-axis: α -value

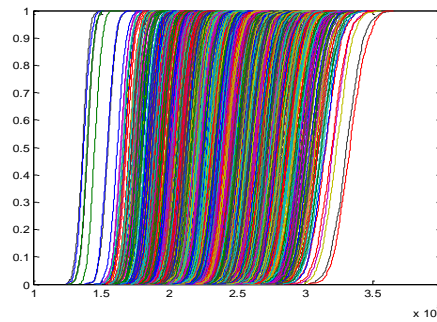


Figure 5-15 x-y view of fuzzy CDF resulted in Figure 5-14

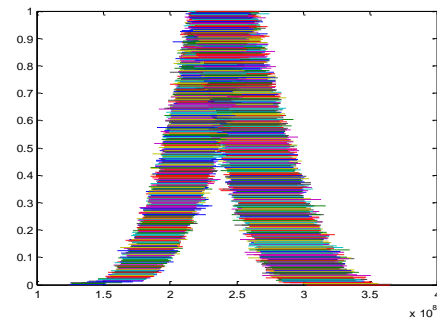


Figure 5-16 x-z view of fuzzy CDF resulted in Figure 5-14

As for decision variables/indicators the procedure is the same. Figure 5-17 shows the three dimensional view of fuzzy CDF for the debt service cover ratio (DSCR) resulting from the FR-MCS. The x-axis denotes DSCR, y-axis is the probability, and z-axis is the α -value. Figure 5-18 and Figure 5-19 represent the x-y and x-z views of fuzzy CDF resulted in Figure 5-17 respectively.

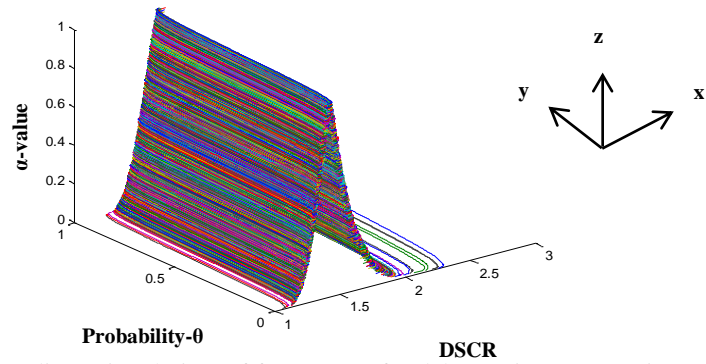


Figure 5-17 Three dimensional view of fuzzy CDF for debt service cover ratio (DSCR) resulting from the output of FR-MCS, x-axis: DSCR, y-axis: probability, z-axis: α -value

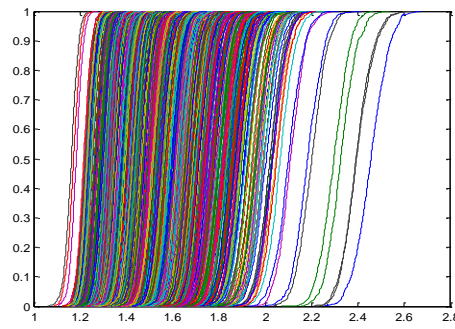


Figure 5-18 x-y view of fuzzy CDF resulted in Figure 5-17

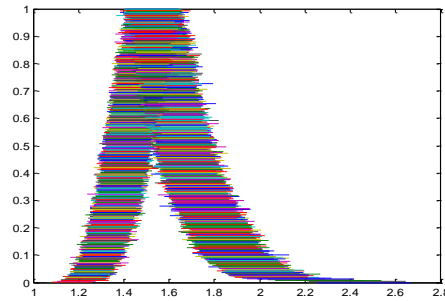


Figure 5-19 x-z view of fuzzy CDF resulted in Figure 5-17

Figure 5-15 and Figure 5-18 elucidate the CDF bound of the simulation output. As expected, for less fuzziness, the CDF bound is narrower. In the absence of fuzziness, purely probabilistic, the simulation is conventional MCS, there is no range for output and it is a CDF.

In this case study the objective functions of the private sector, end user and public sector are Max IRR, Min tariff regime, Min concession period

respectively. Risks and uncertain factors are incorporated in the fuzzy set simulation model in five possible negotiations scenarios with following assumptions: In scenario 1 (Moderate Scenario), the inflation rate follows normal distribution ($\mu = 4\%$, $SD = 2\%$), traffic volume follows normal distribution ($SD = 20\%$ of the first year's expected traffic volume), O&M cost follows uniform distribution in the interval [500, 1500]. In scenarios 2 & 3, tariff regime are 10% and 20% less than the most likely tariff respectively, and minimum expected EIRR (hurdle rate) is assumed 0.12. In scenarios 4 & 5, minimum expected EIRR (hurdle rate) is assumed 0.14 and 0.15 respectively. The tariff regime is set 20% and 10% more than the basic tariff respectively. The concession items of 5 scenarios resulted from simulation are summarized in Table 5-3.

Table 5-3 Concession items of 5 scenarios					
Concession items	Scenario 3 (Pessimistic scenario-VL)	Scenario 2 (Pessimistic scenario-L)	Scenario 1 (Moderate Scenario)	Scenario 4 (Optimistic scenario-H)	Scenario 5 (Optimistic scenario-VH)
EIRR (%)	12	12	13	14	15
Tariff coefficient (TC)	0.8	0.9	1	1.2	1.1
Concession period (CP-years)	28	26	25	21	24

The proposed equations for fuzzy multi objective function (Equations 5.4, 5.5 and 5.6) are used to choose the best negotiation scenario that meet parties' objective functions. Based on the experiences and negotiations, the following assumptions are made on the objective functions possible intervals. They are represented by fuzzy membership function to evaluate five scenarios (See Figure 5-20).

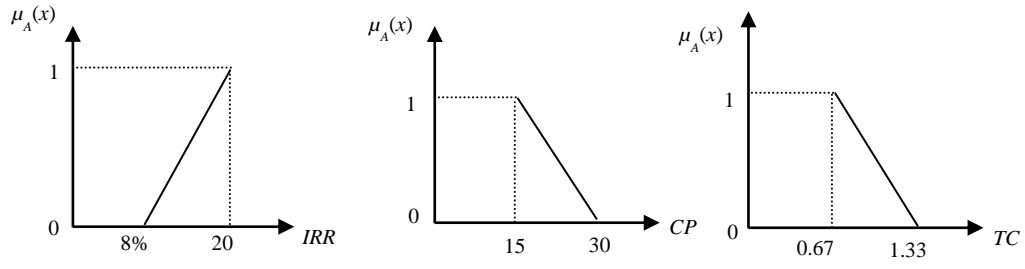


Figure 5-20 Fuzzy membership function of the objective functions

To evaluate the five scenarios and choose an appropriate negotiation scenario, the membership degree of each scenario to the each objective is computed. For instance, the membership degree of scenario 1 to the objective of maximal IRR and the membership degree of scenario 1 to the objective of minimal concession period are computed by using equations 5.4 and 5.5 as follows:

$$\mu_{11} = \frac{13\% - 8\%}{20\% - 8\%} = 0.42$$

$$\mu_{31} = \frac{30 - 25}{30 - 15} = 0.33$$

This computation is continued to construct membership degree matrix. Non-inferior solution can be determined based on the obtained membership degree matrix through the max-min composition by using equation 5.6 as follows.

$$\begin{aligned} \mu_{ij} &= \max_j \min_i \{ \mu_{ij} \} = \max_{1 \leq j \leq 5} \min_{1 \leq i \leq 3} \begin{pmatrix} 0.42 & 0.33 & 0.33 & 0.50 & 0.58 \\ 0.50 & 0.65 & 0.80 & 0.20 & 0.35 \\ 0.33 & 0.27 & 0.13 & 0.60 & 0.40 \end{pmatrix} \\ &= \max_{1 \leq j \leq 5} (0.33 \quad 0.27 \quad 0.13 \quad 0.20 \quad 0.35) = 0.35 = \mu_{25} \end{aligned}$$

It can be concluded that preference order being scenarios 5,1,2,4 and 3.

In order to consider the objective priority, weighting coefficient has been set to $w = \{0.15, 0.8, 0.05\}$. So calculation is changed as follows.

$$\mu_{ij} = \max_j \min_i \{ \mu_{ij} \} = \max_{1 \leq j \leq 5} \min_{1 \leq i \leq 3} \begin{pmatrix} 0.88 & 0.85 & 0.85 & 0.90 & 0.92 \\ 0.57 & 0.71 & 0.84 & 0.28 & 0.43 \\ 0.95 & 0.94 & 0.90 & 0.98 & 0.96 \end{pmatrix}$$

$$= \max_{1 \leq j \leq 5} (0.57 \quad 0.71 \quad 0.84 \quad 0.28 \quad 0.43) = 0.84 = \mu_{23}$$

As can be seen the preference order now becomes scenarios 3,2,1,5 and 4. So by this approach, decision makers can choose a scenario that is more comfortable for all parties involved based on their objective in negotiation.

5.5. Concluding Remarks

This chapter has proposed a mechanism that allows the government and the concessionaire to reach a consensus on NCIs which are agreeable by other parties involved in the development phase of PPP-BOT projects under uncertainties and risks. FR-MCS technique is used to overcome existing problems and provide more flexibility for decision makers through determining NCIs as a bound (interval) via its fuzzy CDF instead of deterministic value from each party's perspective.

The proposed methodology suggested improved decision makings which follow from more knowledgeable assessments of project risks and uncertainties that will lead to select improved project's NCIs which in turn results in improved project performance toward the sustainable project success. This approach helps to attain solutions that meet main parties' objectives involved concurrently. Through this approach the consensus on NCIs could be reached as early as possible to avoid prolonged and costly negotiations in the development phase.

The advantage of hybrid simulation (fuzzy randomness) lies in the fact that by using values lying within a bandwidth (interval) and model those by a

defined distribution density or a membership function, the reality can be modelled better than by using deterministic and probabilistic figures solely. Based on the generated distribution, a range of NCIs for PPP-BOT players is obtained to negotiate.

The simulation model developed in this chapter facilitates determining feasible NCIs of a PPP-BOT project negotiations as may be affected by various risky and uncertain drivers relating to the NCIs e.g. toll structure, toll revision schedule, extent of government grant, and the duration of the concession period. By careful consideration of the results of the simulation study, the government and concessionaire can arrive at a reasonable agreement on the terms of the concession i.e. NCIs and consequently sharing of risks and uncertainties. Both parties could engage in renegotiations to resolve the deadlock by using this mechanism. The proposed simulation's results are demonstrated through the case study.

CHAPTER 6 OPTIONS-BASED NEGOTIATION MANAGEMENT OF PPP-BOT INFRASTRUCTURE PROJECTS

6.1 Introduction

Since the PPP-BOT project promoters have to reimburse their investment costs from project operations, they are concerned not only with expected future incomes but also the risk factors influencing the revenues over time. The higher the risk and uncertainty of the revenues and profit, the higher the return that will be asked for (Ye and Tiong, 2000). The success of PPP-BOT projects largely depends on effectively mitigating the impacts of variety of involved risks and uncertainties.

Moreover, since the debt repayments would just depend on the ability of the project to generate cash flows (bankability concept), the lenders are concerned with the financial performance of the project as well. They are not willing to lend unless most of the risks involved in the project life-cycle are addressed properly. Their decision making is to balance between the degree of secured debt and the interest rate.

According to experiences (Zhang, 2005; Tiong et al., 1992), PPP-BOT projects are more likely to fail in the development phase than in the other phases. Also there is low benefit to private sector in some projects due to more risk and uncertainty taking. Consequently, no common ground is found for associated negotiations in the development phase. In this circumstance the government is pushed to take more risks of the project. Subsequently there will be better expected return to private sector and accordingly the common ground for negotiations could be made.

Government support plays an important role in risk-return trade-off and project success. Since each party of a PPP-BOT project has its own objective and concerns, each has a different risk-return trade-off analysis (Ye and Tiong, 2000). However, the design of government support is still an open issue and a hot research problem. It is very hard to make a decision on awarding the government support rightly when there are uncertainties and risks involved. The government supports which are expressed as Options should be carefully designed and well formulated. Options which arise from certain clauses of the contract are more valuable in risky projects. Correct evaluation of the concession in a bidding process is essential for government and bidders.

The methodology developed in this chapter contributes in two main aspects. It presents a means for valuing an early fund generation option. Also it presents a procedure to calculate equitable bound for guaranteed rate of return for project sponsor and equity holders under uncertainties and risks. The results show that by applying the proposed systematic negotiation mechanism both public and private sectors could take advantage of its flexibility at the negotiation table. The proposed mechanisms could facilitate negotiations on the verge of break down as well as accelerating ongoing negotiations that have been slowed down.

6.2 Government Support

There are two main motivations for government to provide support to concessionaire in a PPP-BOT project. Firstly in order to reduce capital requirement and to improve revenues during the project operation. Thus the concessionaire is able to extent necessary to cover debt service and to earn a reasonable return on equity based on the expected cash flows of the project.

Secondly, it is to protect project sponsors, investors and lenders from insufficient cash flow risk (or financial viability gap) which will be inadequate to cover debt service (Fishbein and Babbar, 1996). Host governments often provide supports such as guarantees to attract private sector investors. It increases the confidence of investors and enhances project attractiveness. The need for government support mainly results from the private sector's trade-offs between risk and return. The kind of support given depends on a number of factors.

In addition to cash subsidies, there are a number of government support categories that could be offered to concessionaire by government agency. These are *guarantee support* and *financial and incentives support*. Each type of support has its own characteristics, comprising of different structures that are appropriate for particular purposes.

6.2.1 *Guarantee Support*

There are several types of support that fall under the rubric 'guarantee support'. These are, inter alia, equity, debt, exchange rate, minimum demand, minimum revenue (MRG), tariff/toll and maximum interest rate guarantees.

6.2.2 *Financial and Incentive Support*

Similarly, there are several types of support that fall under the rubric 'financial and incentive support'. These are direct capital contributions (e.g. grants, subordinated loans (extra loan), debt and equity investment), shadow toll/tariff, concession period extension, revenue enhancements, reduction of front-end cost, free use of project site and associated facilities, preferential tax incentives (e.g. tax breaks, tax exemption for a certain number of years),

comfort letter, interest-free financing, option to defer, to abandon, to alter, to switch and the growth option.

The major objective of these guarantee support and financial and incentives support is to reduce perception of risk for the sponsors and financial institutions. The reduced perception will result in a reduction of the financial cost of the project. With a reduced financial cost, the concessionaire has a greater willingness to invest and could result in a lower tariff for the end user. It also increases the bidders' competitiveness in the tender process. Thus these mechanisms reduce the cash flow volatility, add flexibility to the project and allow for better management of the concession items which are subject to risks and uncertainties. The effectiveness of these mechanisms is a big concern of existing studies (Galera and Solina, 2010). Additionally a PPP-BOT contract could be designed by government supports and incentives to induce the promoter firm to invest in the best quality and achieve best efficiency which leads to deliver superior VFM.

Each government support is applicable for special circumstances. For instance, the government may grant loan (debt) guarantee to a BOT project when the project is not financially viable enough (financial viability gap) or is too risky to be undertaken by private sectors. The implementation of an unattractive project could require debt guarantee. In another case, the project company benefits from negotiation options by negotiating for government rescue when adverse events occur during the construction and operation stages. Such successful negotiations could fend off project bankruptcy (Ho and Liu, 2002; Ye and Tiong, 2000).

In PPP-BOT projects one or more government support may be employed. For instance both Shajiao B and Laibin B power plant projects were protected from force majeure risk to a limited extent. The government's obligation is to make a subordinated loan in case of insufficient revenue. The project company was also entitled to extend construction and operation periods and consequently the concession period consistently if completion delays and/or operation barriers resulting from events of force majeure. Two-period structure of concession period is an incentive scheme that both parties could benefit from. In the case of operation delay the government obligation is to provide funds to meet debt service. In the case of termination, the loan of lenders will be repaid and the equity investment of promoters will be compensated. Both projects benefit from preferential tax and government loan at preferential interest rate policies. Also the government provided the foreign partner with early completion bonus. Under unstable economic situation, the government is willing to provide more preferential conditions to private promoters, to assume more risks, and to allow higher rates of return. In contrast, under stable economic condition, the government is interested to reduce its involvement and limit promoter's return and set a cap on the equity internal rate of return (EIRR) of BOT projects. The concessionaire assumes the hurdle rate as minimum acceptable rate of return (floor). Thus the BOT project internal rate of return is narrowed to an interval with lower bound (floor) and upper bound (cap) (Ye and Tiong, 2000).

In another case in a toll road project (Attarzadeh, 2007; Vassallo and Solino, 2006), the government implements an optional revenue guarantee. If the concessionaire decides to request the guarantee in its bid, it will have to

share extra revenues with the government if the revenues collected surpass the threshold established in the bidding terms. If the concessionaire decides not to get the guarantee, it will have to take the whole traffic risk.

The host governments must identify and distinguish the necessity to offer incentives and direct or indirect support in practically all the PPP-BOT projects and should adopt suitable types of support consistent with the projects' financial viability to increase the private sector's participation and motivation. As can be seen, the guarantees and financial and incentives supports provided by government are represented as risk mitigation strategies and mechanisms to infrastructure concessions. On the one hand, government guarantees can reduce project risks and uncertainties. Thus the presence of guarantees increases the project's value. But on the other hand, they create an uncertain future commitment for the government, which is not free of cost. A study shows that a guarantee costs can average as much as a third of the amount guaranteed (Lewis and Mody, 1998). The cost of the guarantees must be estimated and compared with the equivalent subsidies in order to ascertain which of the approaches are more effective in reducing the project risk and uncertainty.

These supports and incentive schemes have feature of enhancing cash flow to Project Company by limiting the downside. On the other hand, to avoid giving away too much value to concessionaire, the host government would also attempt to counterbalance the grant of these incentives by introducing additional repayment obligations and features, such as demand a reduction and placement of a cap on the tariff/toll rates to benefit the end user. Alternatively, the government could seek additional revenue by imposing higher taxes on the

concessionaire or even call for direct participation as a sharing mechanism in the upside of the project returns. This is similar to hedging feature of Real Options. For instance, currency exchange risk can be successfully hedged through derivative instruments such as currency swaps. Thus these supports and repayments could be formulated as Options that the government provides for Project Company by Real Options Analysis (ROA).

Options add value to the project in such a way that a specific project with a negative NPV could be acceptable if the value of the options for the concessionaire outweighs the negative value of the NPV. So it facilitates a negotiation that is on the verge of break down as well as accelerates an ongoing negotiation that has slowed down. Concessionaire would exploit from offered options by the government upon the agreement were reached, although more risk transferred to the government. Both public and private sectors could take advantage of its flexibility at the negotiation table.

Government support such as debt guarantee as an option is a liability to the government and an asset to the project company. So it is vital for both parties to estimate and quantify the value of the support (this is called options valuation). Generally, the value of such an option is considerable. Failing to consider the value of the option by the government may unknowingly provide the concessionaire a huge support. Consequently the concessionaire will be over subsidized. Alternatively, failing to consider the value of the option by the concessionaire may unwittingly ignore or assign a conservative value to the option in view of its ambiguity. Accordingly the concessionaire will underestimate or overestimate the investment value.

The value of options is often hard to quantify. Usually it is estimated by the value of cash flow with supports minus the value of cash flow without supports. The equity value is the most important evaluation criterion to measure the financial viability of PPP-BOT projects. Then the value of government support such as guarantee and negotiation option is reflected in equity value aim for comparison and decision makings.

By incorporating these options the negotiation bound can be constructed which would enlarge the feasible bargaining range for both parties. In fact, a feasible bargaining range may not even exist between the public and the private sectors if the values of the incentive schemes and the repayment features are omitted. This advantage facilitates decision making under uncertainties and risks.

As can be seen, many options available and could be applied in PPP-BOT negotiations. Early fund generation and guaranteed upper and lower bound of rate of return options are taken to examine in this chapter because of case study.

6.3 Real Options Analysis

In general, an option may be defined as an opportunity to take a beneficial action, within a bounded time frame, when a favourable condition occurs. Accordingly, option theory studies how to model and price this opportunity which is typically either a contractual right (e.g., financial options, flexible commodity contracts) or system flexibility (e.g., expansion or delay options). (Zhao and Tseng, 2003; Chiara et al., 2007)

Options mechanism is a hedging opportunity which limits risks and uncertainties and encourages private sectors participation. Although there is an

option cost to the government, this is considerably less than if the government carries the whole project costs. Using the options mechanism it is possible that the private party could reach common ground in the negotiations a lot earlier because there are obvious financial advantages for them.

Real options theory concerns options theory applied to non-financial or real assets. Real options analysis overcomes some of the shortcomings of conventional NPV/IRR discounted cash flow (DCF) analysis and capital budgeting methods. There are two types of options: the Call and the Put. An option gives the right, but not the obligation to either buy (call option) or sell (put option) the underlying asset at a certain price (strike price) on a specified future date (expiry date). For this right, the buyer of the option pays a premium upfront (non-refundable) to the seller (or writer) of the option. The selling or buying of an asset at the strike price is called “*exercising the option*”. As can be seen, the option buyer has unlimited gain and limited loss (premium). In contrast, the option seller has limited gain (premium) and unlimited loss.

Call Options are used in order to capitalize on an increasing trend in the market (risky project). The payoff for a call option (C) is estimated using the following equation:

$$C = \text{Max}[(S - K), 0], \begin{cases} C > 0 & \text{if } S > K \\ C = 0 & \text{if } S \leq K \end{cases} \quad 6.1$$

Where S is the current price (or stock/market price) and K is the strike price (or exercise price). (See Figure 6-1)

In contrast, the Put Options are used in order to capitalize on a decreasing trend in the market (risky project). The payoff for a put option (P) is estimated using the following equation:

$$P = \text{Max}[(K - S), 0], \begin{cases} P > 0 & \text{if } K > S \\ P = 0 & \text{if } K \leq S \end{cases} \quad 6.2$$

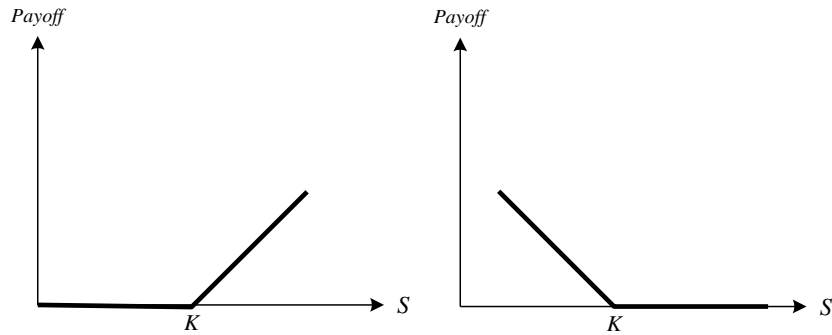


Figure 6-1 European style Call (left) and Put (right) options

As can be seen, an Option provides an opportunity for the decision maker to take some action after risks and uncertainties are revealed. for instance, the owner of a call option will exercise the option only after learning that the current price S is greater than exercise price K .

In the PPP-BOT context the underlying cash flow is the underlying asset. For instance the highway traffic volume (a non-financial variable) is considered as the underlying asset in transportation projects. The strike price is linked to the guaranteed cash flow. The current price is linked to the expected cash flow (Charo et al., 2003; Galera and Solina, 2010). For instance, the payoff of guaranteed minimum traffic volume (GMTV) as a put option and also the payoffs of two cases, with and without this guarantee, are shown in Figure 6-2.

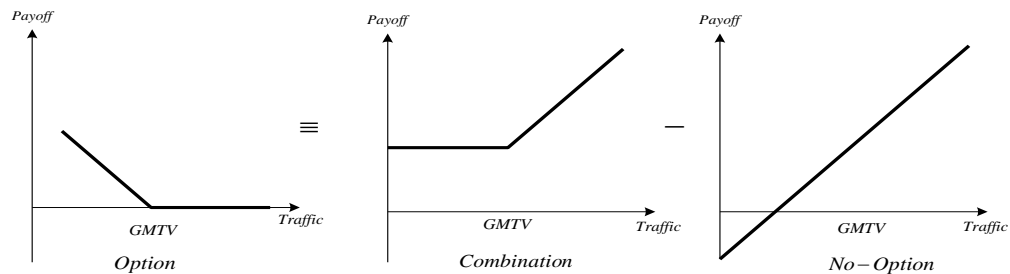


Figure 6-2 payoffs of minimum traffic volume guarantee (GMTV)

The Cash flow (payoff) at year t , CF_t , Option value at year t , OV_t and total Option value, OV , are calculated using the following equations. Where V_t is the traffic volume at year t , V_G or $GMTV$ is the guaranteed minimum traffic volume, x is toll rate, E_t is O&M costs at year t , T is tax rate and OP is operation period.

$$CF_t = \begin{cases} (V_t x - E_t)(1 - T) & \text{if } V_t \geq V_G \\ (V_G x - E_t)(1 - T) & \text{if } V_t < V_G \end{cases} \quad 6.3$$

$$OV_t = \begin{cases} 0 & \text{if } V_t \geq V_G \\ ((V_G - V_t)x - E_t)(1 - T) & \text{if } V_t < V_G \end{cases}, OV = \sum_{t=1}^{OP} OV_t \quad 6.4$$

Generally, the guarantee provided by government is a discrete-exercise type of real option. Discrete-exercise options are ones that can be exercised at discrete points over predetermined period. In general there are three forms of discrete-exercise options. European options, an option that can be exercised one time, only at the end of its life, American (Bermudan) options, an option that can be exercised one time, on specified dates during its life and Australian (simple multiple-exercise) options, an option that can be exercised M times, on specified N ($N \geq M$) dates during its life.

Currently, there are two types of real option pricing and valuation models: the binomial lattice model (binary tree) (Hull, 2012) and Black-Scholes model (Black and Scholes, 1973). In this research, due to the model assumptions, the Black-Scholes model is adopted. Real Options gained popularity through the work of Black and Scholes on European style option valuation (1973). The Black-Scholes pricing formulas for a call option (C, right to buy) and a put option (P, right to sell) at time zero is:

$$C = S N(d_1) - Ke^{-rT} N(d_2) \quad 6.5$$

$$P = Ke^{-rT} N(-d_2) - S N(-d_1) \quad 6.6$$

$$\text{where: } d_1 = \frac{\ln(S / K) + (r + \sigma^2 / 2)T}{\sigma\sqrt{T}} \quad 6.7$$

$$d_2 = d_1 - \sigma\sqrt{T} \quad 6.8$$

$$N(-d_2) = 1 - N(d_2), \quad N(-d_1) = 1 - N(d_1) \quad 6.9$$

C = Current call option value.

P = Current put option value.

$N(d)$ = The probability that a random draw from a standard normal cumulative distribution will be less than d . This equals the area under the normal curve up to d .

$$N(d) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^d e^{-\frac{1}{2}y^2} dy$$

S = Current price.

K = Strike (exercise) price.

T = Time remaining until expiration of option, in years. ($T = 0.5$ means 6 months)

r = Risk-free interest rate, expressed as a decimal (e.g. 0.05), (the annualized continuously compounded rate on a safe asset with the same maturity as the expiration date of the option, which is to be distinguished from r_f , the discrete period interest rate.)

σ = Volatility (e.g. 0.25), Standard deviation of the annualized continuously compounded rate of return of the stock.

6.4 Early Fund Generation Option

The value of completing a PPP-BOT project earlier is a challenging issue especially for the concessionaire. This may lead to an increase in cost but it brings the revenue stream on earlier, which enhances the profitability of the project. It is necessary to evaluate benefits and disbenefits of early completion of the project. This chapter assumes that it is possible to compress project construction time which will result in an increase in overall project cost.

An example of this is BOT power plant project which is completed earlier than scheduled (commercial operating date (COD)). This enables host country and project region's industries to produce goods and services earlier than

originally planned. Early project completion is a win-win option. The concessionaire, government and end users benefit economically and financially from earlier completion of the project and consequently earlier use of the facility.

The early fund generation (EFG) option needs to be evaluated by both government and concessionaire. Figure 6-3 represents cumulative cash flow of PPP-BOT project including the EFG option. Figure 6-4 illustrates the life-cycle's components of PPP-BOT project including the EFG option.

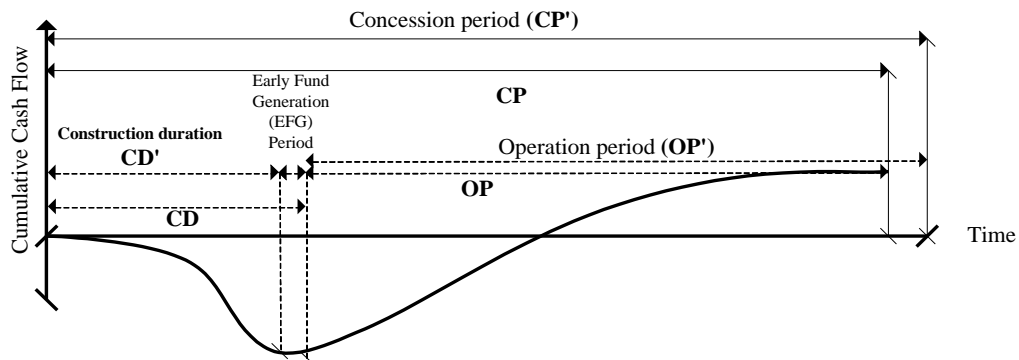


Figure 6-3 Cumulative cash flow of PPP-BOT project including the EFG

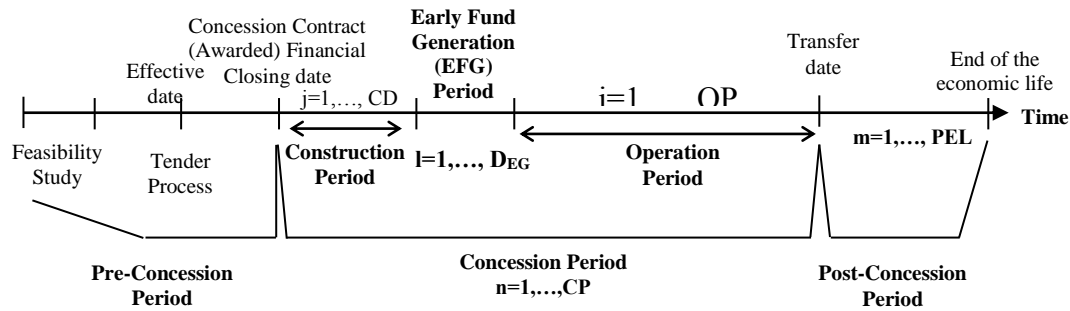


Figure 6-4 life-cycle's components of PPP-BOT project including the EFG

The present value, PV , of a discrete uniform series of the net benefits stream from project operation, R , at the discount rate r , starting at time a and continuing through time b , is estimated by following formula: (Reinschmidt and Trejo, 2006)

$$PV = \frac{R}{r} \left[\frac{1}{(1+r)^a} - \frac{1}{(1+r)^b} \right] \quad 6.10$$

Under the assumption that the benefits, R , are constant in time over the operation period of BOT-PPP project, PV at time 0 (start of construction) is estimated by following formula:

$$PV_b(r, CD) = \frac{R_0[1-(1+r)^{-CP}]}{r(1+r)^{CD}}, CP = CD + OP \quad 6.11$$

where CD is the construction duration, OP is the operation period, and CP is the concession period. The PV of a uniform series of costs over the construction period from time a to time b is:

$$PV = \frac{C}{r} \left[\frac{1}{(1+r)^a} - \frac{1}{(1+r)^b} \right]. \quad 6.12$$

With $a = 0$ and $b = CD$ then:

$$PV_c(r, CD) = \frac{C_0}{r} [1 - (1+r)^{-CD}] \quad 6.13$$

The total net present value of the project, difference of present value of the benefits and present value of the costs, is estimated as follows:

$$PV(r, CD) = PV_b(r, CD) - PV_c(r, CD) \quad 6.14$$

The internal of rate of return, r_0 , is calculated by setting the total net PV to zero, and solving for r : $PV_b(r_0, CD) = PV_c(r_0, CD)$,

$$\text{so: } C_0[(1+r_0)^{CD} - 1](1+r_0)^{CP} = R_0[(1+r_0)^{CP} - 1].$$

The obtained rate of return, r_0 , then compare with hurdle rate to determine whether the project construction acceleration is economically desirable and justifiable.

The present value of the benefit stream for project at shorter construction duration, $CD' < CD$, is estimated as follows. r_0 is assumed as the discount rate to have same internal of rate of return.

$$PV_b(r_0, CD') = \frac{R_0[1-(1+r_0)^{-CP'}]}{r_0(1+r_0)^{CD'}}, CP' = CD' + D_{EG} + OP'. \quad 6.15$$

Now take the ratio of the discounted present value of the net benefits for the accelerated project, $PV_b(r_0, CD')$, to the discounted present value of the net benefits for the original project, $PV_b(r_0, CD)$.

$$\frac{PV_b(r_0, CD')}{PV_b(r_0, CD)} = [(1 + r_0)^{CD - CD'}] \frac{1 - (1 + r_0)^{-CP'}}{1 - (1 + r_0)^{-CP}} \quad 6.16$$

Then the percentage increase in present value of the project benefits due to the earlier project completion is:

$$\nabla = 100 \left[\frac{PV_b(r_0, CD')}{PV_b(r_0, CD)} - 1 \right] = 100 \left\{ [(1 + r_0)^{CD - CD'}] \left[\frac{1 - (1 + r_0)^{-CP'}}{1 - (1 + r_0)^{-CP}} \right] - 1 \right\} \quad 6.17$$

This is the percentage increase in value of the project obtained by shortening the construction duration from CD to CD' . At the discounted r_0 , this is also the maximum percentage increase in the present value of the project costs. The maximum acceptable percentage increase in discounted cost to complete project earlier is the percentage increase in discounted benefits gained from earlier completion. In the case $CP = CP'$ then the percentage increase is:

$$\nabla = 100 \{ [(1 + r_0)^{CD - CD'}] - 1 \}$$

6.5 Guaranteed Upper and Lower Bound of Rate of Return Option

The government usually grants the concessionaire a guaranteed minimum return on equity (Min-GEROR), r^f . This is a right to build and operate the project in which the government compensates for any revenue shortfall in the life-cycle cash flow. The question is how to determine an equitable guaranteed maximum return on equity (Max-GEROR), r^c , under the uncertainty in order to limit the concessionaire's profit. The focus of this section is determining equitable upper and lower bound for the guaranteed rate of return for project sponsors.

Under Min-GEROR guarantee the government subsidizes the shortfall in revenue. It is a put option written to the sponsor of the project by the government. If the actual revenue in year t (CF_t^a) don't reach the level that has been guaranteed (CF_t^{gmin}), as floor on the rate of return to project sponsor, the government would have to make up for the shortfall in revenue. Otherwise, the government would not have to pay any subsidy. The option value is formulated as follows:

$$SF_t = \begin{cases} (CF_t^{gmin} - CF_t^a) & \text{if } CF_t^a < CF_t^{gmin} \\ 0 & \text{if } CF_t^a \geq CF_t^{gmin} \end{cases}, \quad 6.18$$

$$SF = \sum_{t=CD+1}^{OP} SF_t$$

SF_t , shortfall in revenue in year t , is the value of the option in year t and SF is the total value of the option over the operation period.

Conversely, under Max-GEROR guarantee, if the actual revenue in year t (CF_t^a) surpasses the pre-specified maximum level that has been guaranteed CF_t^{gmax} (as cap on the rate of return to project sponsor); the government would then have the right to call for excess cash flow. The government could equitably demand a cut in tariff rates to benefit the end users, boost taxes, or even directly participate in the upside of the project as repayment. The option value is formulated as follows:

$$R_t = \begin{cases} (CF_t^a - CF_t^{gmax}) & \text{if } CF_t^a \geq CF_t^{gmax} \\ 0 & \text{if } CF_t^a < CF_t^{gmax} \end{cases}, \quad 6.19$$

$$R = \sum_{t=CD+1}^{OP} R_t$$

R_t , excess cash flow as repayment in year t , is the value of the option in year t and R is the total value of the option over the operation period. Figure 6-5 illustrates the aforementioned discussion, including Min and Max-GEROR

and the actual revenue equations graphically. As can be seen in Figure, the government has to pay to the concessionaire the shortfall revenue in the period between A and B. Moreover, the government will call for excess revenue in the period between C and D.

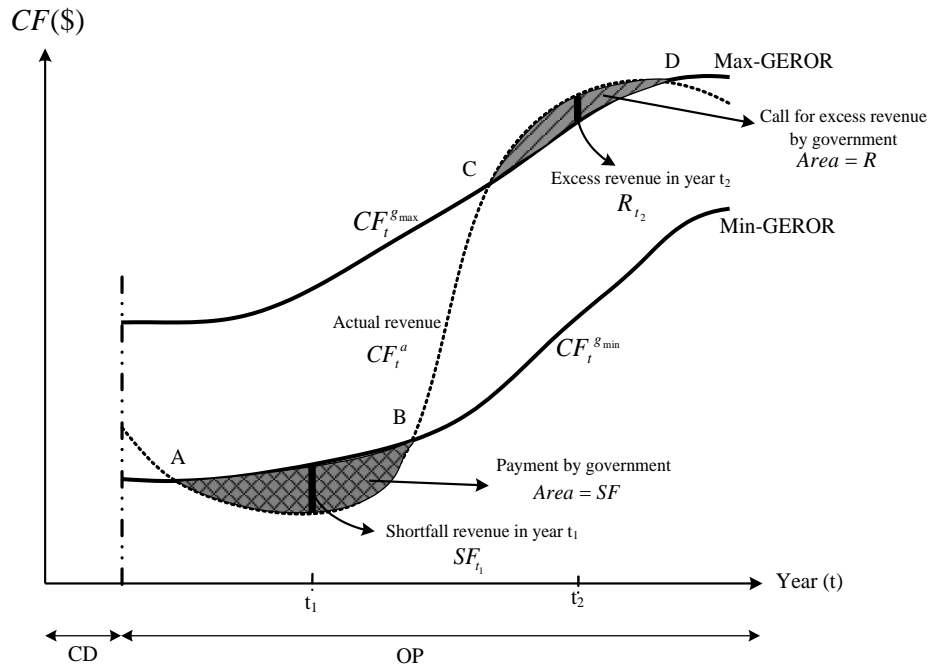


Figure 6-5 Minimum and maximum GEROR and their cash flow

For the purpose of evaluating these two forms of guarantee and determine an equitable cap of rate of return (Max-GEROR), r^c , Black-Scholes model (Black and Scholes, 1973) is applied. To achieve this aim, the following steps are proposed. First the cash flow link to Min-GEROR, r^f , is determined (put option-floor). Fuzzy set theory is applied for uncertainty modelling. The value of the Min-GEROR under assumed scenarios for uncertain variables is determined by representing the uncertain parameters corresponding to different scenarios as fuzzy numbers. Then by assuming the same value of put option for call option, the cash flows link to Max-GEROR for assumed scenarios are calculated (call option-cap). Subsequently yearly cash flow-cap (YCF-cap) and equity internal rate of returns (EIRR) link to the scenarios on

Max-GEROR are calculated and represented as fuzzy numbers. Finally, by utilizing the Level Rank Method of defuzzification (Moller and Beer, 2004), the YCF-cap and EIRR (call option-cap, defuzzified) at specific μ -cut/ α -confidence level is determined as a crisp value. The concept of the Level Rank Method is based on the α -discretization. The membership scale of the fuzzy variable is discretized with the aid of chosen α -levels, and then the arithmetic mean of the interval centres of the α -level sets is computed as defuzzification result.

6.6 Illustrative Case Study

A detailed case study is considered in chapter 7. The following illustrative case study is used to show the concept and the applicability of the proposed Option model and its analysis.

In the Iranian statute, “law on construction and development of roads and transportation infrastructures projects”, the government is permitted to subsidize projects, as cash subsidy, up to 50% of project investment. The government is also permitted to provide equity up to the maximum 10% of project investment. If the ratio of the actual annual income over expected annual income is less than 0.85, the government will make up the shortfall up to the maximum of 25% of the project’s expected revenue. This is classified as minimum revenue guarantee as a mechanism that aims for risk allocation. The Saveh-Salafchegan freeway was constructed under this law with government involvement at 60% and private sector involvement at 40% of the project investment. This project is under operation now (Iranian statute, 1987; Attarzadeh, 2007). Structure of this kind of governmental support is shown in Figure 6-6 and Figure 6-7. E_v is expected traffic volume.

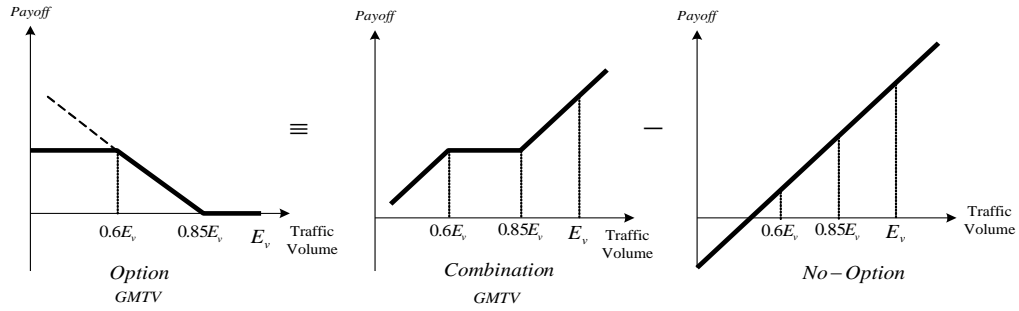


Figure 6-6 Bundle of Options of minimum traffic/revenue guarantee based on the Iranian statute for Iranian toll road/highway projects

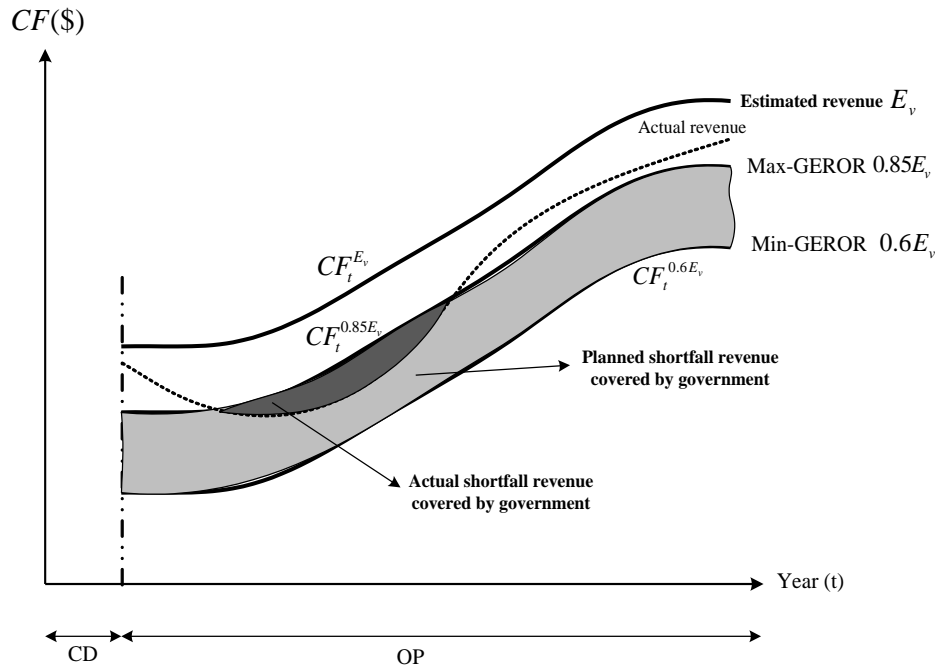


Figure 6-7 Estimated cash flow and Minimum and maximum GEROR based on the Iranian statute for Iranian toll road/highway projects

The proposed method in this chapter is applied to find the equitable guaranteed bound of cash flow (cap) under the uncertainty of traffic volume for the case study, Saveh-Salafchegan freeway project. The traffic volume is represented by triangular fuzzy number “T.F.N” $\tilde{E}_{vTri}: \langle 4.38, 7.3, 10.293 \rangle$ million vehicles/year. Figure 6-8 demonstrates equitable guaranteed bound of cash flow resulted from call and put options.

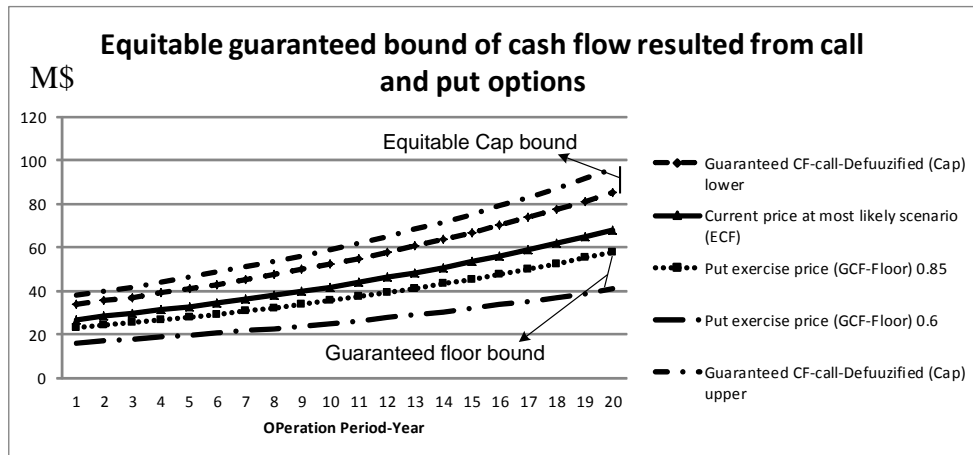


Figure 6-8 Equitable guaranteed bound of cash flow resulted from call and put options for Saveh-Salafchegan freeway project

Base on the Real Options Analysis, the fair bound cap is determined as $(1.25E_v, 1.41E_v)$. The result shows if the ratio of the actual annual income over expected annual income is more than 1.25 (i.e. Actual traffic volume exceeds the expected traffic volume), the government will share the revenue in excess of 1.25 of the expected annual income with concessionaire up to the maximum of 16%. If the ratio of actual annual income over expected annual income is more than 1.41, the government will take the revenue in excess of 1.41 of the expected annual income.

The case study of Iranian toll road/highway projects shows that there are three common sets of mechanism in PPP-BOT scheme. First, extending or reducing the concession period depending on the evolution of traffic. Second, rebalancing the economic terms of the contract when there is a substantial variation in the traffic volume from the original contract (e.g., MRG). Third, if the traffic volume is outside the agreed minimum and maximum bound a sharing mechanism is triggered (Attarzadeh, 2007; Vassallo and Gallego, 2005).

6.7 Concluding Remarks

Options provide flexibility for concession agreement and add value to the project in such a way that a specific project with a negative NPV could be acceptable if the value of the options for the concessionaire outweighs the negative value of the NPV. Some of the existing or possible Real Options in PPP-BOT concessions as guarantees and financial and incentives supports are minimum revenue guarantee (MRG), tariff/toll guarantee, direct capital contributions (e.g. grants, subordinated loans (extra loan)), and concession period extension. The existence of this type of guarantees and financial and incentives supports makes the concession considerably more attractive for the concessionaire and lenders, because it limits the possible adverse results to them. The analysis developed in this chapter shows a valuation model of early fund generation option. Furthermore, it contributes to assess project's financial viability under uncertainties and risks by calculating feasible and equitable bound for guaranteed rate of return for project sponsor.

CHAPTER 7 CASE STUDY AND ANALYSIS

7.1 Introduction

This chapter presents the background and relevant data for a case study, which has been compiled over two study travels to actual projects site in Iran. It will demonstrate the key concepts from earlier chapters. The case study describes the applicability of the proposed methods and mechanisms as a holistic approach to PPP-BOT negotiations management in order to find or arrive at censuses for PPP-BOT negotiation toward negotiation-based risk management.

The framework presented in Chapter 1, research methodology, is used to show how the fuzzy game theory, FR-MCS for NCIs determination and Real Options Valuation can be explicitly embedded in PPP-BOT negotiations. The case study is evaluated and a discussion of how the proposed model differs from the traditional approach is also carried out. Conclusions are then discussed in detail relation to the problem in the chapter conclusions and recommendations.

7.2 Case Study- South Isfahan Power Plant (SIPP), Iran

The infrastructures development is considered as one of the important requirements of economic growth and higher level of public welfare. Electric power infrastructure plays an important role in this issue. One of the most important infrastructures of power network is power plant which constitutes the subject matter of the case study presented in this chapter.

Electric power infrastructures, in addition to the improvement of economic development and social indices, are effective in the prosperity of other

economic sectors. Furthermore, appropriate power system, while allowing for using the potentials of other economic sectors, provides invaluable opportunities for playing an active role in the region and international equations. Also, the effective role of sustainable power infrastructures is considerable in strengthening country's economy in the long term. The above short discussion helps for economic justification of the power plants development.

Recently, the limitation of public funds and the low efficiency of the public sector in implementing infrastructure projects, have directed the attention of different countries including Iran to the capacities and resources of the private sector. Along these lines, creating incentives for non-public sector and reducing associated risks are of great importance of successfully private sector involvement in infrastructures development.

The case study examines the validity of the approaches and models developed in this dissertation. The realistic data and information are utilized from 3 Iranian projects (2 failed projects and 1 successful project) based on a series of interviews planned with the government and the promoter organizations. The causes of successes and failures of the 3 studied projects are specified and then the negotiation positions are determined.

The idea of the construction of a power plant funded by non-governmental investors was first raised in the Kerman province in Iran. Kerman BOT power plant project (KPP), was the first Iranian independent power producer (IPP) proposal initiated by a promoter. Preliminary negotiations started and a general consent on the basic aspects including the initial financial package was agreed in late 1992. Although the KPP project was then approved and listed in

the Ministry of Power (MOP) infrastructure programme, there was no further progress after this. The initial negotiations between promoter and local government were delayed and finally stopped.

The bidding for Parehsar BOT power plant project (PSPP) was carried out in 1999. An international consortium was selected through an international tender. The PSPP was to have been Iran's first IPP after an ECA (Energy Conversion Agreement) was signed in 2001. However, the project was stopped due to structural problems in the implementation process. The main problem was the lack of governmental support (guarantee). Financial closure was delayed due to difficulties in negotiating financial guarantees.

Thus, although using the PPP-BOT approach was introduced into the Iranian infrastructural projects in 1993 but no serious measures were taken practically till 2002. In 1998 some tenders on BOT power plant for some projects were held that were not get into construction stage. Since cancellation of these projects, many projects came into negotiation, but none of them reached the stage of implementation. Thus, the authorities in charge of the Iranian power industry (IPDC) and MAPNA Company initiated the regulation of the PPP-BOT contract and procedure and remove the barriers and impediments in the course of implementation of the projects by defining a new supported approach and regulation to new projects. Despite passing some bills and the law of encouragement and support of foreign investment (Foreign Investment Promotion and Protection Act (FIPPA), see appendix 3 for more detail) in 2001 which is offering some facilities and incentives and also followed by that passing the budget law in the years 2002 to 2004 and offering some guarantees of the state firm in charge of the BOT project by the ministry

of economics and funding as the governmental representative, few BOT power plant projects were successful.

To this end, the south Isfahan power plant project (SIPP) was defined to pioneer and serve as the first Iranian IPP project which has been put into operation. Investment, construction, operation and maintenance of SIPP with the coordination of TAVANIR Company on the basis of BOT (Build, Operate, and Transfer) scheme is considered the first interaction between public and private sectors in the power industry of the country. In the other words, SIPP is the first BOT project which has got into the development phase during the years 2002-2003. The pre-agreement and the ECA contract were signed between Iran Power Development Corporation (IPDC) (on behalf of TAVANIR Company) and MAPNA International Company in middle and end of 2002. SIPP was thus launched.

According to the memorandum of understanding inked in 2002 between IPDC and MAPNA International Company and in compliance with the policies of the Energy Ministry and TAVANIR Company to launch private power plant projects in Iran, agreement was reached to build South Isfahan Gas Power Plant through the investment of MAPNA International Company and at least one foreign partner. A consortium made up of an Iranian company and a German firm was set up to implement the project. Germany's IFIC Holding AG (IHAG) announced its agreement for joint investment in the project with MAPNA International Company (registered in the United Arab Emirates (UAE)) and the two sides signed the partnership agreement in October 2002. SIPP Project Company was registered at Jebel Ali Free Zone in

the United Arab Emirates (UAE) in January 2004. The company launched its Iran branch in September 2004. Negotiations started with Bank Saderat Iran (BSI) in 2002 to receive commercial loans for implementation of the project and finally in 2004 a contract was signed with the Dubai branch of Bank Saderat Iran (BSI) and London investment group PLC. The SIPP project contract structure is shown in Figure 7-1.

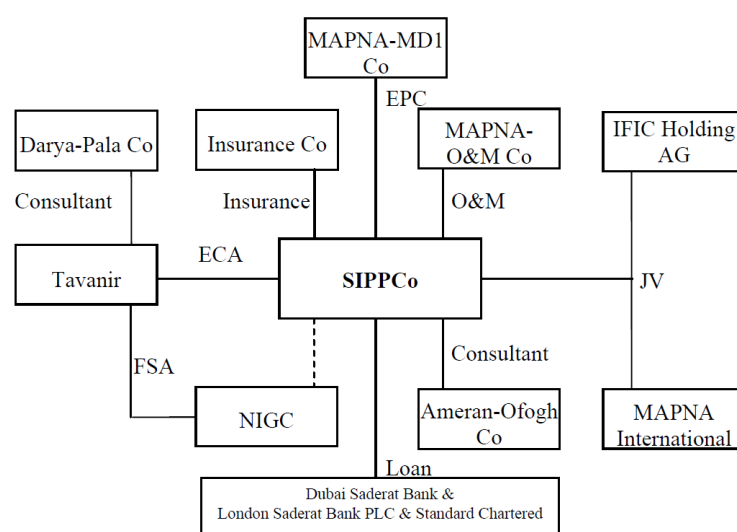


Figure 7-1 the contract structure of SIPP project

The closing date of this project was 2004 when the construction phase started. The timetable for project construction and implementation had been forecast at 36 months in the ECA contract. However, due to measures taken to accelerate the implementation of the project, an intensive timetable was agreed by the two sides and introduced through an addendum aimed at speeding up unit-to-unit production and operation of the power plant. The construction phase finalized in 2007 when the operation phase started.

A contract for operation and maintenance (O&M) of the power plant was signed between SIPP Project Company and a consortium comprising MAPNA Company and MAPNA Operation and Maintenance Company in September

2005. This contract included operation and maintenance of SIPP for a period of 21 years since the start of the contract by taking into account the duration cited in the addendum for early production.

The first unit of this power plant was synchronized in the middle of 2005. The whole project became operational by middle of 2006. The power plant was officially inaugurated by the president in February 2007. Currently, all units of the power plant have been synchronized and have become commercially operational, i.e. the project is fully in operation stage. Before this project was launched, the government controlled all the power plants in the country.

The power plant has six 159-megawatt units. The synchronization and commercial commissioning dates of each unit are shown in Table 7-1. The nominal power generation capacity of the plant at ISO and design condition is estimated at 954 and 734 megawatts respectively. The project was implemented at a cost of 320 million euros in 2002 costs. The concession period is 23 years, including 3 years construction period and 20 years commercial operation period. The SIPP project is located in Majlesi City, 65 kilometers (southwest) from the historical city of Isfahan in central Iran. The information of these projects is demonstrated in Table 7-2. Full data of the SIPP with distribution/membership function and nature of the input variables is demonstrated Table 7-3. The rationale behind the selection of distributions and membership functions is based on the following assumptions (Fente et al., 2000; Law and Kelton, 1991; Wall, 1997).

1. The parameters, e.g. costs must have a specified lower and upper limit. Beyond these limits, the parameters cannot assume any values. Therefore, this assumption infers that selected distribution/membership function should be close-ended.
2. The cost parameters may have any value within the defined upper and lower limits. This assumption infers that the distributions for the cost input variables should be continuous.
3. The triangular and trapezoidal membership and distribution function of parameters can be easily estimated by experts (Chau, 1995).
4. Costs tend to vary greatly depending on several parameters. This assumption suggests that skewness must be expected in the distributions that represent the cost input parameters.
5. Costs probability distributions/membership functions should have a convex shape rather than concave (Back et al., 2000).
6. It has been suggested by many authors that triangular and trapezoidal membership function and probability distribution are appropriate for modelling cost-related data possibilistically or probabilistically (Back et al., 2000).

The parameters of the triangular and trapezoidal possibility-membership function and probability-density function can be estimated using expert subjective judgement (Chau, 1995) or from historical data using moment matching, maximum likelihood estimation, and least-squares fit of the cumulative distribution function (AbouRizk et al., 1994). In any case, whatever the form of the distribution that represents the input variables, an estimate of these variables can be obtained through the mean-variance method.

In this study the mean (μ) of the distribution function of the input variables is assumed to be the estimated value of the base case. The coefficient of variance of the input variables is assumed to be 0.1, so that the standard deviation (σ) will be: $\sigma = 0.1 \mu$. If an input variable has a high uncertainty the coefficient of variance of this variable can increase depending on the perceived uncertainty associated with the variable.

Table 7-1 Synchronization schedule of SIPP units

Unit	Synchronization Date	Commercial Commissioning Date
1	6/8/2005	15/1/2006
2	5/10/2005	15/1/2006
3	6/12/2005	9/5/2006
4	30/1/2006	20/11/2006
5	17/3/2006	11/9/2006
6	8/6/2006	16/4/2007

Table 7-2 Information of 3 projects under study

Project	<i>KPP</i>		<i>PSPP</i>	<i>SIPP</i>		
Type of project	Gas-fired units	Steam units	Combined Cycle	Gas-fired units		
Construction Period (years)	3	5	3	3		
Operation Period (years)	10	8	20	20		
Concession Period (years)	13	13	23	23		
Nominal capacity (MW)	6*123.4=740.4	3*100=300	4*162+2*160=968	6*159=954		
Yearly generated energy (KWH)	2,905,684,992	147,168,000	6,867,664,530	5,664,000,000		
Construction Cost (US\$/€)	US\$ 300 Million (in 1992 costs)	US\$ 220 Million (in 1992 costs)	€ 459 million (in 2001 costs)	€ 320 Million		
O&M Costs	7.25 US\$ Million /year	2.06 US\$ Million /year	33.5 € Million /year	22.33 € Million /year		
Debt: Equity	100:0.0	100:0.0	70:30	70:30		
Energy tariff	0.017 US\$/kWh	0.027 US\$/kWh	0.0175 €/kWh	0.0141 €/kWh		
Energy tariff for excess of the minimum output	0.0012 US\$/kWh	0.0012 US\$/kWh	0.0074 €/kWh	0.0041 €/kWh		
Yearly payment	US\$ 57 Million	US\$ 41 Million	€112.5 Million	Non-indexable portion	Indexable portion	
				Euro	Euro	Rials
				57,798,846	12,833,496	21,483,438,156
Development phase period (year)	2	2	2	2		
Development start date	Late 1992	Late 1992	1999	Mid 2002		
Closing Date	N/A	N/A	2001	5 July 2004		
Commercial Operation Date (COD)	N/A	N/A	N/A	6 July 2007		
Hurdle rate (%)	12	12	14	16		

Table 7-3 Basic input data of the case study-SIPP

Input data	Expected Value	Distribution/Membership function
Macroeconomic indicators and indexes		
Project Economic life, project life cycle (yrs)	30	Deterministic
Costs regime during construction	<0.2,0.5,0.3>	Fraction of construction costs for each year of construction
Escalation rate during construction/inflation rate during operation period (%)	4	Log Normal distribution, LnN(4,1)
Amortization period (yrs)	20	Deterministic
Tax rate (%)	25.00%	Deterministic
Gov. discount rate (%)	8.00%	Deterministic
Cost of debt (%)	6.00%	Deterministic
Cost of equity (hurdle rate) (%)	16.00%	Deterministic
WACC-discount rate	9.00%	Deterministic
Loan Interest rate (%)	8.00%	Deterministic
Loan repayment period/debt maturity (yrs)	8	Deterministic
Annual growth rate of unit price (%)	5.00%	Normal distribution, N(5,1)
capacity of production (GWH)	6430	Fuzzy variable: Tr.F.N, {5658.4, 6430, 6430, 6687.2}
Cost of finance coefficient for Pre concession period costs calculation	0.05	Deterministic
Cost of tender coefficient for Pre concession period costs calculation	0.05	Deterministic
Annual revenue coefficient for O&M calculation	0.25	Deterministic
Increasing rate of annual growth rate of unit price (%)	10.00%	Normal distribution, N(10,1)
Expected Base Cost coefficient for asset value calculation at transfer date	0.1	Normal distribution, N(0.1,0.01)
Fuzzy-Stochastic Variables (FSV)		
Total project costs (M€)	320	Fuzzy Normal distribution, N(320,32) Mean: Fuzzy variable: Tr.F.N, {314, 320, 320, 334} S.D: Fuzzy variable: Tr.F.N, {29.65, 32, 32, 37.25}
Operation and maintenance costs (M€/year)	0.25*REV	Fuzzy variable: Tr.F.N, {20.902, 22.237, 22.237, 22.904}
Annual growth rate of O&M costs (%)	5.00%	Normal distribution, N(5,1)
Initial daily production (kwh/day)	17,616,438.36	Fuzzy variable: Tr.F.N, {16559452.1, 17616438.4, 17616438.4, 18144931.5}
Yearly generated energy (KWH)	6,430,000,000	Fuzzy variable: Tr.F.N, {6044200000, 6430000000, 6430000000, 6622900000}
Quantity of production / yearly (GWH)	6430	Fuzzy variable: Tr.F.N, {6044.2, 6430, 6430, 6622.9}
Operating revenue (ave) (M€/year)	88.95	Fuzzy variable: Tr.F.N, {83.61, 88.95, 88.95, 91.61}
Pre concession period (yrs)	1.5	Log Normal distribution, LnN(1.5,0.5)
Negotiable concession items (NCIs)		
Construction period (yrs)	3	
Operation period (yrs)	To be determined	
Concession period (yrs)	To be determined	
Tariff (Unit price of service in first year of operation) (€ Cents/KWh) (Euro Cents/ KWh)	To be determined	
Debt (%)	70.00%	
Equity (%)	30.00%	
Government subsidy/contribution, grant fraction, Royalty (%)	0.00%	

7.2.1 Fuzzy Game Theory Model

Given the nature of the SIPP project, the *direct negotiation* procedure was selected for the assignment of the project (project awarding) based on the resulted concession items from *bid competition* process of similar project, i.e. PSPP. Among many contracts between a BOT plant and a host utility, the agreement on how much energy must be produced at what price and for how long of time are essential and fundamental. For instance, in the SIPP the government agreed to annually purchase a minimum of 85% of the plant capacity as *capacity fee* (power off-take) based on the “take or pay” form of guaranteed payment and moreover pay a fixed price per kilowatt hour for the operation period which is called *energy fee*.

The game tree and structure of joining SIPP to the electricity market are illustrated in Figure 7-2 and Figure 7-3 respectively. SIPP has two strategies, “Enter market” and “Stay out”. If SIPP choose “Enter market”, Utility has two strategies, “Start price war” and “No price war”. In the case of choosing “No price war” by Utility, SIPP has two options, “Contract fulfilment” and “Profit maximization”. Then Utility has two strategies to choose, “Not regulate” and “Regulate”. The expected equilibrium (Enter market, No price war) is denoted by arrow. The payoff functions were discussed in section 3.6.4 and were shown in Table 3-5. The components of payoff and objective functions of both players are computed for this case study as follows. It is reasonable to assume that if SIPP stay out the payoff functions of both players are less than the case of choosing “Enter to market”. Also if Utility chooses start price war, both players are subject to pay a penalty/cost. As it is argued by Xing and Wu (2001) the utility should pay for private power generation at a rate which is

corresponding with what it would cost the utility to generate the same excess energy using its own facilities, i.e. avoided cost. The electricity is sold to the end-user at average cost. Payoff functions of both players are computed as follows. Note that all values are calculated in present value.

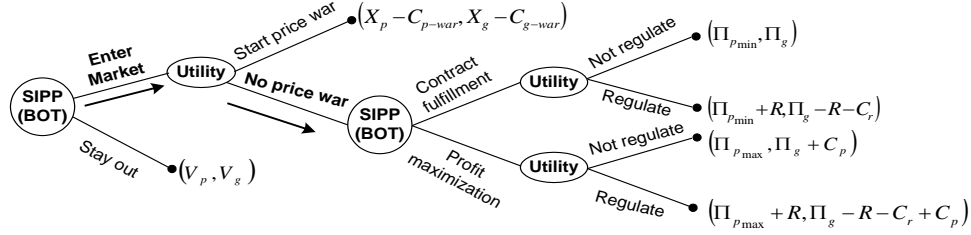


Figure 7-2 Game tree

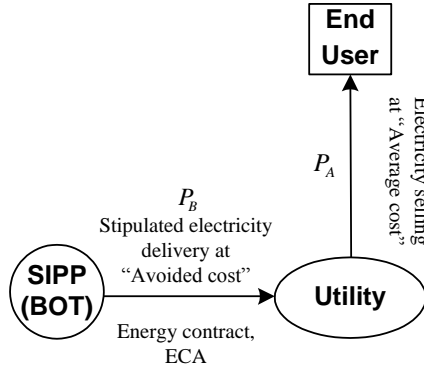


Figure 7-3 Game structure

Objective functions

The objectives for private investor and government are as follows:

$$\text{Max } \Pi_{SIPP(BOT)} = \Pi_p = \sum_{t=1}^{OP} (Rev_t - C_t^p) \quad 7.1$$

$$\text{Max } \Pi_U = \Pi_g = \sum_{t=1}^{OP} [DM_t * P_A - (FC_t^U + VC_t^U * Q_t^U)] - f^U \quad 7.2$$

The government also tries to minimize the payment to private investor.

$$\text{Min } f^U = \sum_{t=1}^{OP} (Q_t^{BOT} * P_B) \quad 7.3$$

$$\text{Where: } Rev_t = Q_t^{BOT} * P_B, \quad P_B = k(a * Q^{BOT} + b) \quad 7.4$$

$$C_t^p = IC_t^{BOT} + FC_t^{BOT} + VC_t^{BOT} * Q_t^{BOT} \quad 7.5$$

$$\text{Breakeven cost "Avoided cost": } P_B = \frac{C^0 - C^{BOT}}{OP * Q^{BOT}} \quad 7.6$$

$$P_A(\text{Average cost}) = \frac{\text{variable cost (operating cost)}}{\text{Capacity factor} \times 8760} + \frac{\text{fixed cost (capital cost)}}{\text{Annual Energy}} = \text{Opex} + \text{Capex} \quad 7.7$$

Constraints

$$\text{Energy balance: } DM_t + R_t \leq Q_t^{BOT} + Q_t^U, \quad t = 1, \dots, OP \quad 7.8$$

$$\text{Capacity requirement: } X_t^U + X_t^{BOT} \geq PL_t + R_t, \quad t = 1, \dots, OP \quad 7.9$$

Fuzzy set is used to deal with the uncertainty in power demand/production forecasting of SIPP. Based on the proposed game model in Table 3-5 of Chapter 3, the fuzzy game theory is applied for determining the expected payoff of players. The power demand/production (GWH) is estimated as a fuzzy variable, i.e. TFN $\langle 5658.4, 6430, 6687.2 \rangle$ using fuzzy Delphi method. Fuzzy Delphi method was explained in section 5.3.3.1. Based on the experiences, the cost function data are $a=0.0509$, $b=116.9$, $c=0$. The game table is shown in Table 7-4. (PM, NR) and (PM, R) strategies are Nash equilibrium and Pareto optimal solution respectively (See Figure 7-4). Based on the fuzzy game theory, the expected payoffs (M€) under demand/production uncertainty are computed as fuzzy numbers.

$$E[\Pi_p] = \langle 6.65, 13.64, 22.62 \rangle, \quad E[\Pi_g] = \langle 377.99, 392.31, 400.03 \rangle.$$

By using the Level Rank defuzzification method (Moller and Beer, 2004) the expected payoffs (M€) are converted to crisp value. $E[\Pi_p] = 13.7$, $E[\Pi_g] = 390.1$. The concept of the Level Rank method is based on the α -discretization. The membership scale of the fuzzy variable is discretized with the aid of chosen α -levels, and then the arithmetic mean of the interval centers of the α -level sets is computed as defuzzification result.

Table 7-4 Public-Private game of SIPP Bid competition (M€)			
		Government	
Private investor	Strategy	Not regulate the contract/bid (NR)	Regulate the contract/bid (R)
	Contract fulfilment (CF)	$\langle (-10.14, 0.23, 5.42), \langle 403.86, 418.75, 426.20 \rangle \rangle$	$\langle (2.32, 12.70, 17.89), \langle 351.01, 364.41, 371.12 \rangle \rangle$
	Profit maximization (PM)	$\langle (10.98, 14.58, 27.36), \langle 404.96, 420.21, 428.94 \rangle \rangle$	$\langle (23.44, 27.04, 39.82), \langle 352.11, 365.87, 373.85 \rangle \rangle$

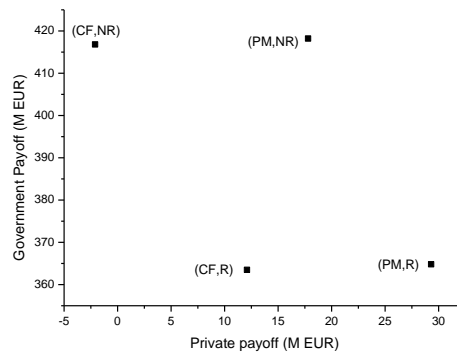


Figure 7-4 Pareto frontier of SIPP Bid competition (M€)

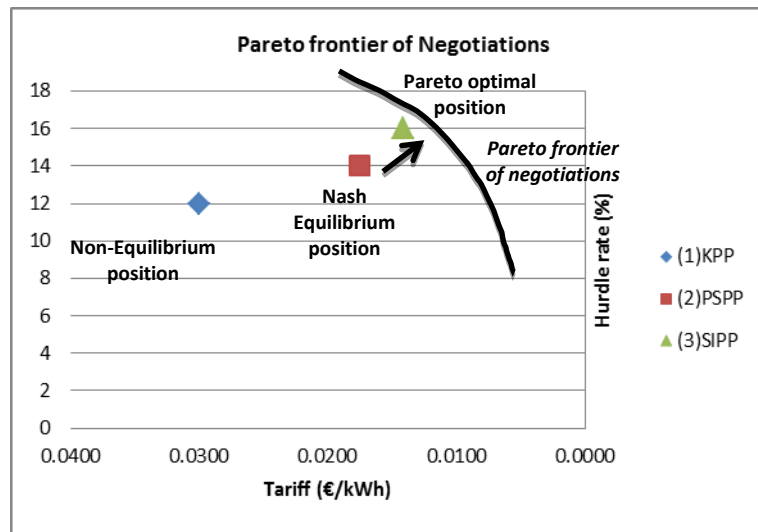


Figure 7-5 Pareto frontier of PPP-BOT negotiations pattern in Iran

Figure 7-5 shows the Pareto frontier of PPP-BOT negotiations pattern in the 3 studied projects. As can be seen, the negotiation solution has moved from non-equilibrium position for KPP project to Nash equilibrium position for PSPP project and then moved to Pareto

optimal position for SIPP project. The power sector in Iran is now achieving some success in its policy of attracting investment in BOT-BOO projects. Given the increasing level of demand for electricity, the acceptance that the majority of this will be met through investment by private capital; the fundamentals are in place for the policy to eventually succeed.

7.2.2 VFM and Optimal Risk Allocation

To calculate value for money (VFM) and optimal risk allocation, 5 scenarios are developed for this case study: 1st scenario is proposal1-Final negotiation position. 2nd scenario is proposal2-Initial negotiation position. 3rd, 4th and 5th scenarios are proposals 2, 3 and 4 respectively. The NPV of life cycle payments to private sector in different scenarios are estimated and shown in Figure 7-6.

The purpose of analysing the VFM for the private funds invested is to compare the proposal submitted by SIPP concessionaire with the public sector comparator (PSC) in order to quantify the benefits of the PPP-BOT approach compared with the conventional approach (Value for Money Report, 2007; Iacobacci, 2010). The VFM analysis is based on a comparison of the total project costs to the government of Iran (IPDC) as of 2002. Based on the above analysis, the IPDC should realize value for money in the order of 1543.23 million Euro by carrying out the project as PPP-BOT compared to the traditional procurement approach invested through the public funds. VFM versus transferred risk to private sector for 5 scenarios are shown in Figure 7-7. As can be seen, the best VFM is achieved in scenario1.

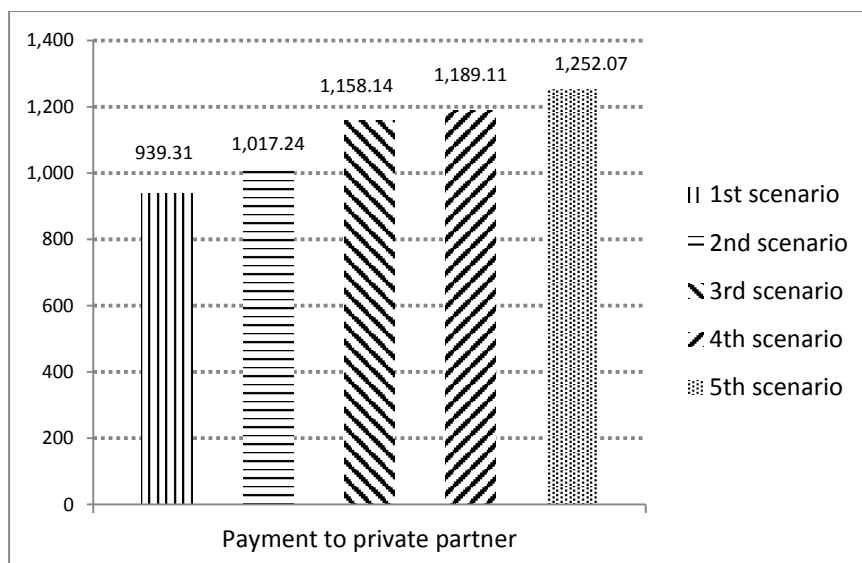


Figure 7-6 NPV of life cycle payments to private sector in 5 scenarios (M€)

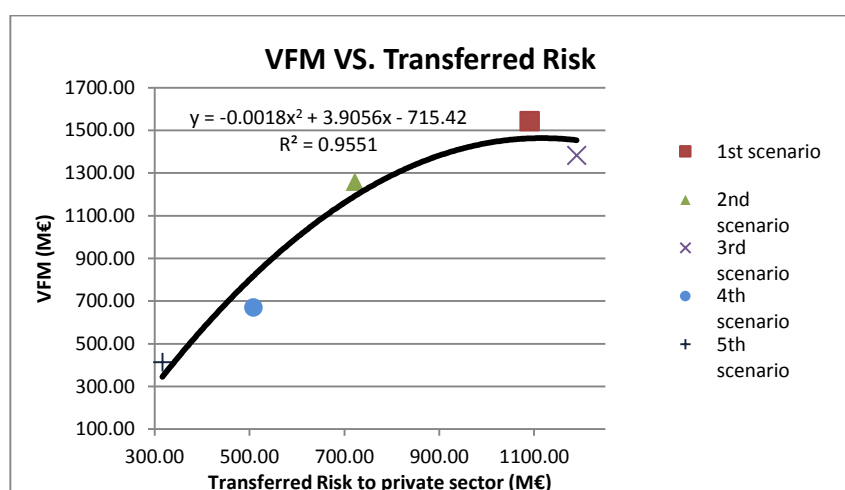


Figure 7-7 VFM VS. Transferred risk to private sector (M€) for 5 scenarios

Definitions

Residual Value

At the end of the partnership agreement period, the SIPP infrastructure will not have reached to the end of its economic life. Accordingly, a value, referred to as the residual value or asset value, will be assigned. This value relates to, among other things, the value of the land, the depreciation of infrastructure, and the condition of these depending on the maintenance

carried out. Table 7-5 shows the total cost of the private sector's proposal to the government which is NPV_{PPP} (PPP approach). Table 7-6 shows the PSC calculation.

Table 7-5 Total cost of the private sector's proposal (M€)

1. Payment to private partner		
	i. Construction payments	320.00
	ii. Availability payments	619.31
2. Agreement monitoring costs		32.00
Total Execution Costs		971.31
Residual (asset) value @ transfer date		(112.00)
Nett project execution cost under the terms of PPP		859.31
Present Value as at 2002, in Millions of Euros		

Table 7-6 Public Sector Comparator (PSC) (M€)

1. Project cost of 35 years		2016.00
2. Revenues		(607.41)
3. Risk quantification		1089.94
	i. Cost overrun risks	483.84
	ii. Revenue risks	303.70
	iii. Other risks	302.40
Nett execution costs		2498.54
Residual (asset) value @ transfer date		(96.00)
Nett project completion cost		2402.54
Present value as at 2002, in Millions of Euros		

Figure 7-8 demonstrates project costs under the conventional approach and its comparison with the PPP approach. The calculated PSC is € 2402.54 million. As is shown in the Table 7-6 and Figure 7-8, the PSC is calculated as follows:

$$PSC = 2016.00 \text{ (Total project cost)} - 607.41 \text{ (revenues)} + 1089.94 \text{ (Quantified risks under conventional procurement)} - 96.00 \text{ (residual (asset) value at transfer date)} = 2402.54$$

The “Quantified risks under conventional procurement” part is calculated as follows:

$$\text{Quantified risks under conventional procurement} = 1089.94 = 483.84 \text{ (cost overruns=20\%)} + 303.70 \text{ (risks related to revenues= 60\%)} + 302.40 \text{ (Other risks-contingency =15\%)}$$

The SIPP project, as a PPP, presented an excellent opportunity for the IPDC by proposing high VFM. The savings generated by carrying out this project as a PPP was € 1543.23 million

in present value terms as at 2002 or 64.23% of the nett costs under the PSC (See Figure 7-8). The magnitude of the VFM savings is due to the transfer of risks to the private partner and to the fact that the private partner estimated higher revenues than those estimated as part of the PSC.

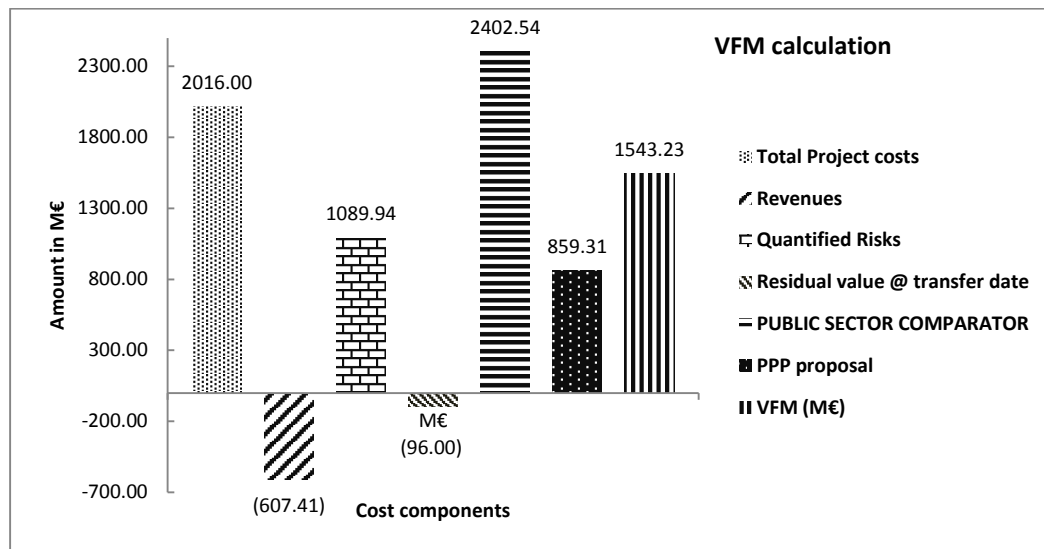


Figure 7-8 VFM calculation summary, project costs for the government under PPP and conventional approaches

VFM Quantitative Evaluation- Sensitivity Analysis

If it is necessary to compute VFM with imperfect information, the likelihood and impact of the risk can be assessed subjectively, but in a systematic manner, by using such things as group expert judgment and statistical techniques. Also, undertaking sensitivity analysis to estimate PSC is a useful way of understanding the impact of changes in these variables on the overall project NPV. HM Treasury (2004c) proposed VFM quantitative evaluation which is carried out by using a spreadsheet. The VFM quantitative evaluation and sensitivity analysis for SIPP project case study is done using this method. The results of the sensitivity analysis of the project are shown in Figure 7-9. As can be observed, the VFM value is most sensitive to capital expenditures (CapEx) and unitary charge (capacity fee).

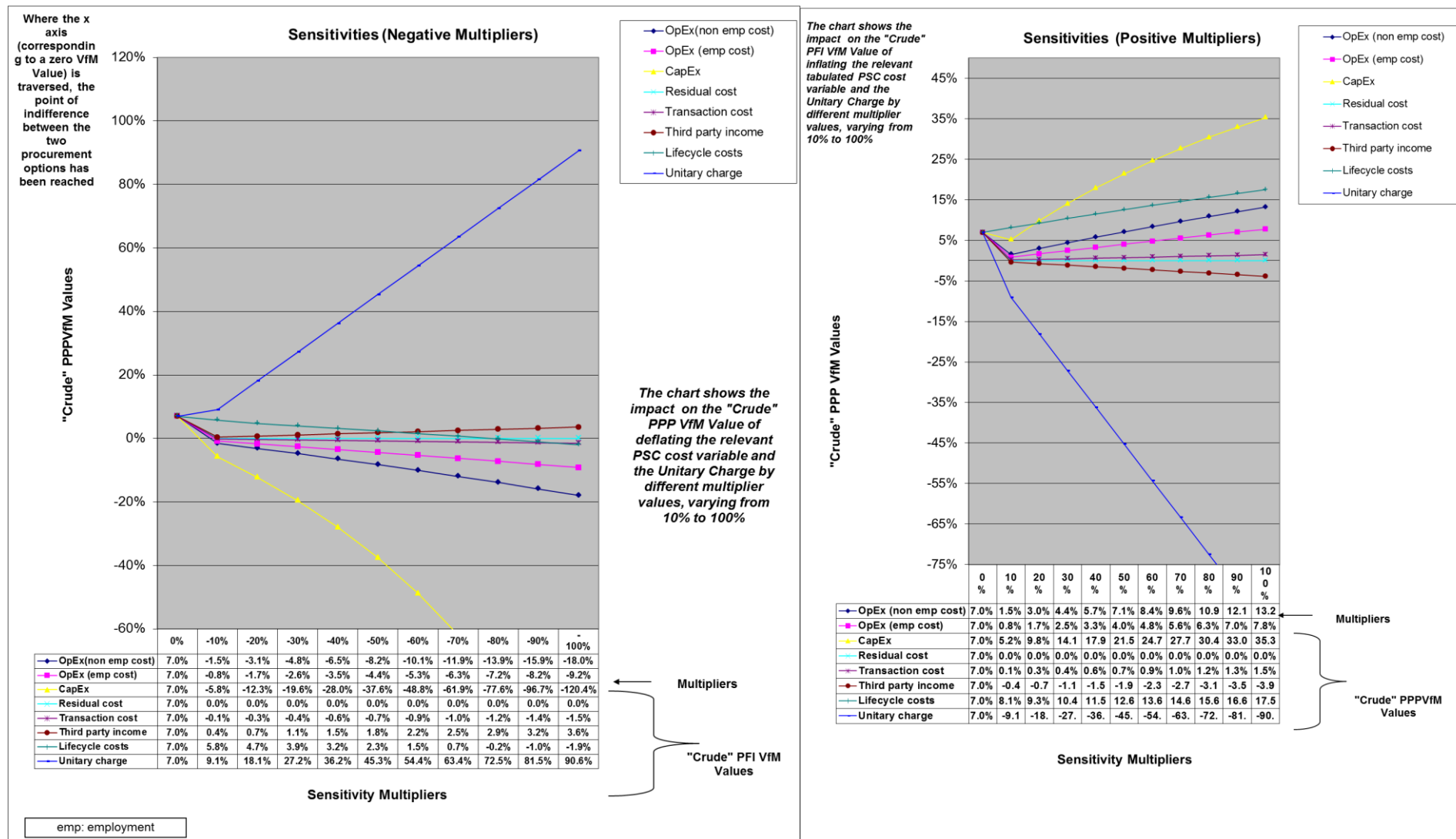


Figure 7-9 VFM Quantitative Evaluation- Sensitivity analysis of Concession SIPP Project with Positive and Negative Multipliers

Table 7-7 shows the summary of risk allocation of the SIPP project. Table 7-8 indicates the degree of risk-taking (adopted risk allocation strategies) by government and Project Company.

Table 7-7 Summary of risk allocation of the SIPP project

Risks	Government	SIPP	Lender	Insurer
1. Political risks				
Revoke, expropriation, sequestration	×			
Governmental authorization	×			
Project abandonment		×		
Changes in law	×			
Increase in taxes	×			
Plant import limitation	×			
Political force major	×			×
2. Commercial risks				
Interest rate	×	×		
Foreign currency exchange rate	×			
Foreign currency convertibility	×			
Electricity price non-payment	×			
Unsuccessful in debt payment		×		
3. Construction risks				
Construction materials supply		×		
Construction materials price increase		×		
Fuel shortage	×			
Damage on the plant		×		×
Delay in plant installation		×		
Site convenience		×		
Plant thievery		×		×
Construction price increase		×		
Environmental damage		×		
Construction force major		×		×
4. Operating risks				
Delay in operation		×		
Operator inability		×		
Operation suspension by means of company		×		
Equipment quality and efficiency		×		
Raw materials supply		×		
Fuel shortage	×			
Power demand fluctuation	×			
Production fluctuation		×		
Operation stops by means of Government	×			
Technology risk		×		
Equipment quality while transfer to Government		×		
Operating unforeseen costs		×		×
Environmental damage		×		
Operation force major		×		×

Table 7-8 the degree of risk-taking by government and Project Company (*: the severity of risk-taking)

<i>Risks</i>	<i>Risk level</i>	<i>Time span</i>	<i>IPDC</i>	<i>SIPP</i>
Political risks	Macro	Long term	*****	-
Financial risks	Macro	Long term	****	*
Legal risks	Macro	Long term	**	**
Revenue and market risks	Macro	Long term	****	*
Investment risks	Intermediate	Short term	*	****
Engineering and Technical risks	Intermediate	Short term	*	****
Construction risks	Intermediate	Short term	*	****
Operation and maintenance risks	Intermediate	Long term	-	*****
Relationship and partnership risks	Micro	Long term	**	**

7.2.3 Negotiable Concession Items (NCIs) Determination

To demonstrate the advantage of the proposed model in determining the NCIs, its application in the SIPP project is presented. The fuzzy Delphi technique is utilized to estimate the value of uncertain parameters. In order to calculate these values and to implement the fuzzy Delphi technique procedure, a group of twenty experts including 10 experts from the public sector and 10 experts from private sector were answered a set of questionnaire separately. Total project costs are estimated based on this method. It is estimated as normal distribution with parameters as fuzzy random variables, i.e. normal distribution: $N(320, 32)$, Mean fuzzy variable: Tr.F.N $\{314, 320, 320, 334\}$, S.D fuzzy variable: Tr.F.N $\{29.65, 32, 32, 37.25\}$.

A special program has been developed by MATLAB (The MathWorks, Inc., Natick, Massachusetts) to apply the FR-MCS technique in order to evaluate the uncertainties and risks in simulation input, including the demand uncertainty. To do this, in this study our focus is on the representation of the uncertainty by fuzzy random number and the risk by random variable. Basic input data of the project comprises of deterministic, risky and uncertain

parameters. Uncertain and risky parameters consist of three components i.e. macroeconomic indicators and indexes, fuzzy-stochastic variables (FSV) and negotiable concession items (NCIs). In this case a total of 1000 iterations are generated.

In this study, the determining of NCIs, such as concession period and tariff, under uncertainty of quantity of production (yearly generated energy) is considered. By using the fuzzy Delphi technique and following same procedure for total project costs estimation, the quantity of production (yearly generated energy) is estimated as fuzzy random variable. The membership function of quantity of production (yearly generated energy (KWH)) as uncertain random variable is represented in Figure 7-10. The quantity of production (GWH) is represented as a fuzzy variable, i.e. Tr.F.N $\langle 6044.2, 6430, 6430, 6622.9 \rangle$.

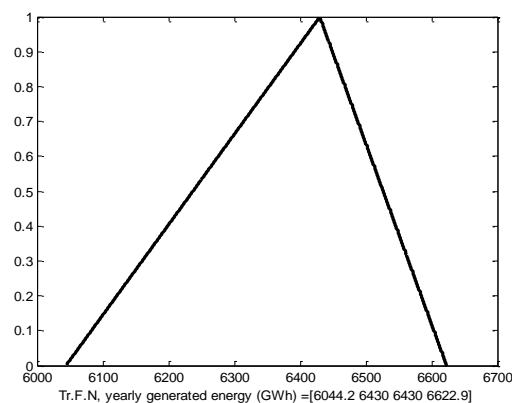


Figure 7-10 Membership function of quantity of production (yearly generated energy (KWH))-uncertain random variable

Fuzzy PDF and fuzzy CDF of total project costs resulted from fuzzy Delphi technique are exhibited in Figure 7-11. Based on the triangular membership function of uncertain random variable and its values - pessimistic, most likely and optimistic values - the following three scenarios are developed; pessimistic scenario, most likely scenario and optimistic scenario.

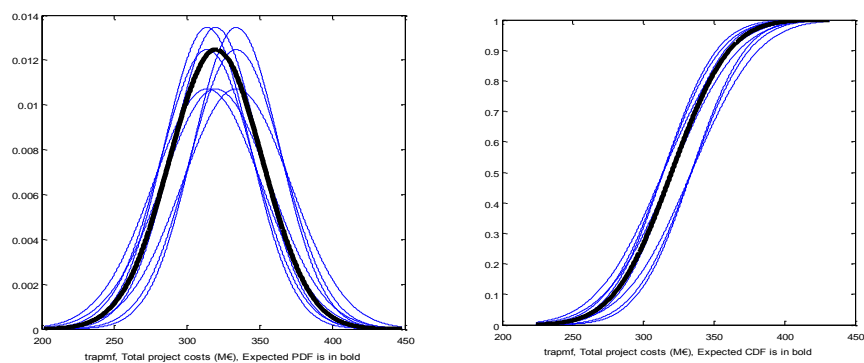


Figure 7-11 Fuzzy PDF and fuzzy CDF of total project costs (M€)

The project life cycle cash flow and its chart at most likely scenario are shown in Figure 7-12 and Figure 7-13.

Year	Construction Period			Operation Period				Post concession period	
	1	2	3	1	2	19	20	21	30
Yearly production-GWH				6004.99	5855.81	5594.75	5709.21	5731.710808	5709.205808
Availability				0.93	0.91	0.87	0.89	0.89	0.89
Operating revenue (M€)				84.95	82.84	79.15	80.77	81.09	80.77
construction costs (M€)	-64	-160	-96						
construction costs-Cumulative (M€)	-64	-224	-320						
Interest During Construction (M€)		-3.58	-12.54						
O&M costs (M€)				-21.24	-20.71	-19.79	-20.19	-20.27	-20.19
Depreciation (M€)				-16.00	-16.00	-16.00	-16.00	0.00	0.00
Net operating income (M€)				47.71	46.13	43.36	44.58	60.81	60.58
Project Cashflow (M€)	-84.00	-163.58	-108.54	47.71	46.13	43.36	44.58	60.81	60.58
Cumulative (M€)	-84.00	-247.58	-356.13	-308.41	-262.28	481.23	525.81	586.62	1124.00
PV (M€)	-84.00	-247.58	-356.13	-312.35	-273.53	41.45	49.40	59.36	117.96
loan interest payment (M€)				-9.26	-7.94	0.00	0.00	0.00	0.00
Earning before tax (M€)				38.45	38.19	43.36	44.58	60.81	60.58
Tax (M€)				-13.61	-13.55	-14.84	-15.14	-15.20	-15.14
Net earning (M€)				24.84	24.64	28.52	29.43	45.61	45.43
Depreciation (M€)				16.00	16.00	16.00	16.00	0.00	0.00
loan principal payment (M€)				-29.41	-29.41				
DSCR (EBIT/Debt service)				1.65	1.66				
Equity Cashflow (M€)	-25.20	-49.08	-32.56	11.43	11.23	44.52	45.43	45.61	45.43
PV (M€)	-25.20	-74.28	-106.84	-96.99	-88.64	14.59	16.93	18.95	28.09
Cumulative (M€)	-25.20	-74.28	-106.84	-95.41	-84.18	486.10	531.53	577.14	980.17
IRR and NPV on Project	9.61%	€ 14.58							
IRR and NPV on Equity	16.03%	€ 0.23							
PV of min Retun on equity (M€)	17.09								
PV of min Retun on project (M€)	32.05								
DSCR min	1.65								

Figure 7-12 project life cycle cash flow (M€) at most likely scenario

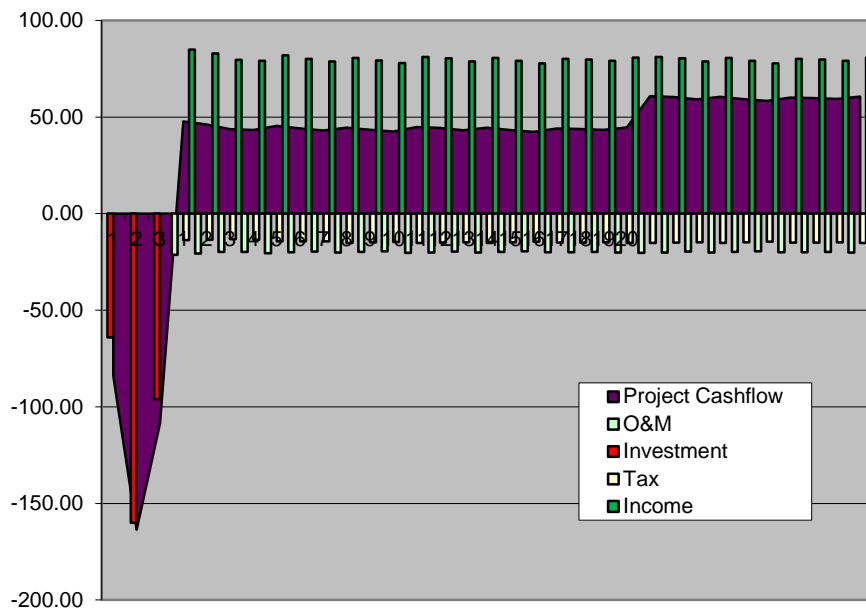


Figure 7-13 project life cycle cash flow chart (M€) at most likely scenario

Figure 7-14 represents cumulative NPV of project and equity cash flow at most likely scenario.

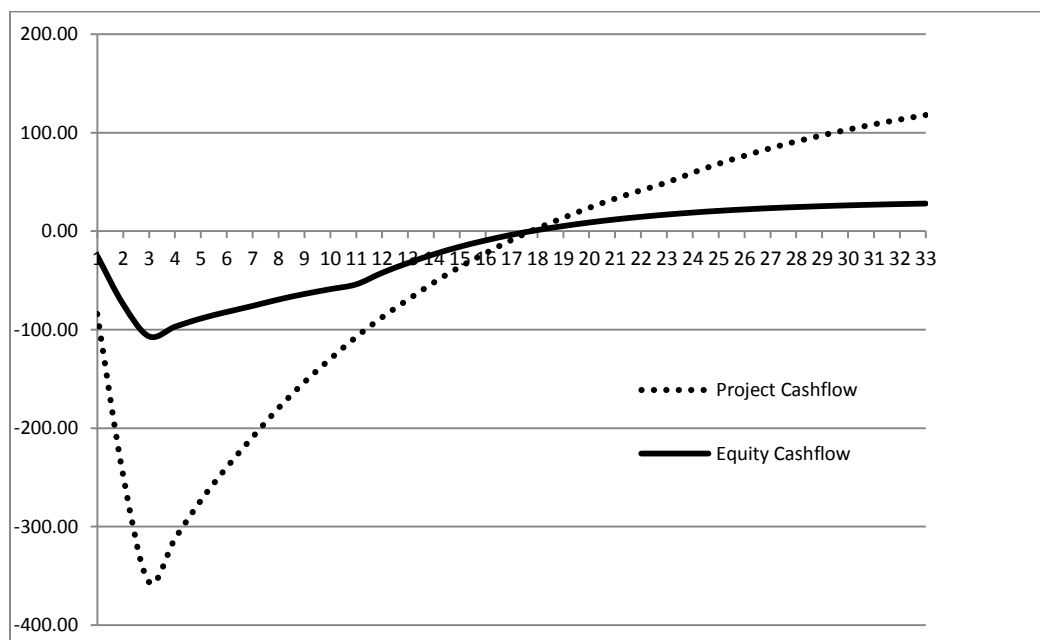


Figure 7-14 Cumulative NPV of project and equity cash flow (M€) at most likely scenario

Based on the private sector objective function, i.e. Π_p equation 7.1, cumulative NPV of equity and project cash flow at 3 scenarios are displayed in Figure 7-15 and Figure 7-16 respectively. The pessimistic, most likely and optimistic values of cumulative NPV of project and equity cash flow are tabulated in Table 7-9.

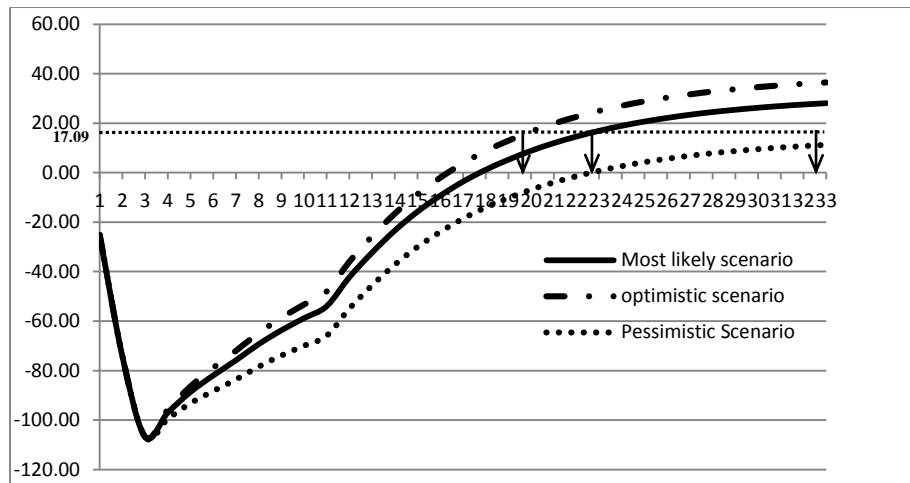


Figure 7-15 Cumulative NPV of equity cash flow (M€) at 3 scenarios

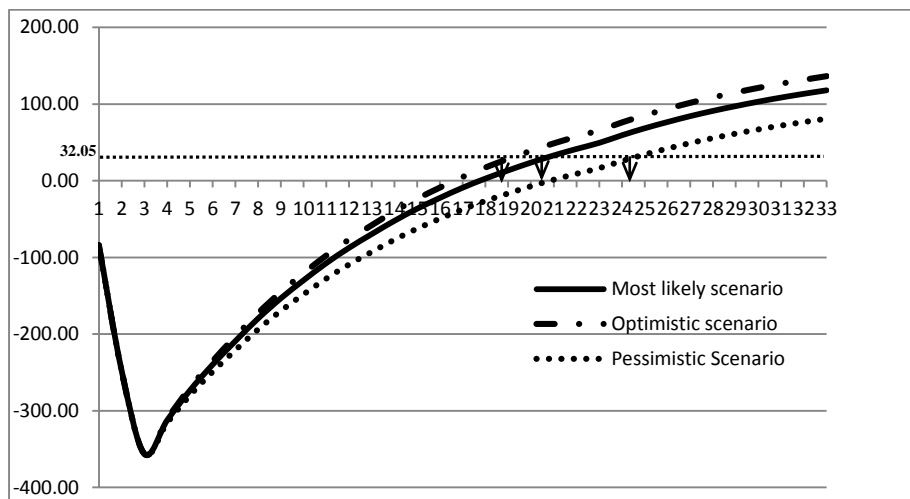


Figure 7-16 Cumulative NPV of project cash flow (M€) at 3 scenarios

Table 7-9 Pessimistic, most likely and optimistic values of cumulative NPV of project and equity cash flow (M€)

Year	Cumulative NPV of project cash flow (M€)			Cumulative NPV of equity cash flow (M€)		
	Pessimistic value	Most likely value	Optimistic value	Pessimistic value	Most likely value	Optimistic value
1	-84	-84	-84	-25.2	-25.2	-25.2
2	-247.58	-247.58	-247.58	-74.28	-74.28	-74.28
3	-356.13	-356.13	-356.13	-106.84	-106.84	-106.84
4	-315.86	-312.35	-310.6	-99.46	-96.99	-95.75
5	-280.17	-273.53	-270.2	-93.19	-88.64	-86.37
6	-249.19	-239.78	-235.07	-88.25	-81.98	-78.84
7	-221.04	-209.11	-203.15	-83.6	-75.86	-71.98
8	-193.93	-179.61	-172.44	-78.41	-69.35	-64.82
9	-169.78	-153.31	-145.07	-73.9	-63.73	-58.65
10	-148.18	-129.77	-120.56	-69.94	-58.83	-53.27
11	-127.67	-107.44	-97.32	-65.9	-53.96	-47.99
12	-109.33	-87.45	-76.52	-54.89	-42.24	-35.92
13	-92.87	-69.51	-57.83	-45.54	-32.3	-25.68
14	-76.91	-52.14	-39.76	-37.16	-23.39	-16.5
15	-62.43	-36.37	-23.34	-29.99	-15.76	-8.65
16	-49.51	-22.3	-8.69	-23.94	-9.32	-2.01
17	-37.3	-8.99	5.16	-18.6	-3.64	3.84
18	-26.39	2.89	17.53	-14.09	1.15	8.78
19	-16.61	13.55	28.63	-10.27	5.22	12.97
20	-7.27	23.73	39.22	-6.87	8.84	16.69
21	1.26	33.02	48.89	-3.95	11.94	19.89
22	9	41.45	57.67	-1.46	14.59	22.62
23	16.31	49.4	65.95	0.73	16.93	25.02
24	25.67	59.36	76.2	2.63	18.95	27.11
25	34.19	68.42	85.54	4.26	20.68	28.89
26	41.85	76.57	93.94	5.63	22.14	30.39
27	49.03	84.22	101.81	6.84	23.42	31.72
28	55.49	91.09	108.89	7.86	24.51	32.84
29	61.33	97.29	115.28	8.73	25.43	33.79
30	66.84	103.16	121.32	9.5	26.25	34.63
31	71.87	108.51	126.83	10.16	26.96	35.35
32	76.45	113.39	131.86	10.73	27.56	35.97
33	80.75	117.96	136.56	11.22	28.09	36.52

The expected return on investment (I_cR) on equity and project cash flow (M€) are equal to 17.09 (=106.84*0.16) and 32.05 (=356.13*0.09) respectively. Thus based on the developed three scenarios, NCIs such as concession period and tariff could be extracted and represented in fuzzy format (fuzzy number). Based on the project cash flow the concession period is represented as fuzzy number: Tr.F.N {19.33, 20.9, 20.9, 24.75}. Based on the equity cash flow the concession period is represented as fuzzy number: Tr.F.N {20.125, 23.08, 23.08, 33}. Furthermore, with the same approach based on the three scenarios, tariff (Euro Cents/ KWh) is represented as fuzzy number: Tr.F.N {1.3580, 1.3833, 1.3833, 1.4389}.

Based on the previous similar projects and project proposal from concessionaire, the minimum value for money (VFM) of the project is estimated 10% of project investment. So the government's objective function, i.e. Π_g (equation 7.2), could be represented as fuzzy number: (NPV-M€): Tr.F.N $\langle 403.86, 418.75, 418.75, 426.20 \rangle$. Thus there is no problem on three scenarios from public sector perspective. $DSCR_{min}$ of three scenarios is represented as fuzzy number: Tr.F.N $\langle 1.55, 1.65, 1.65, 1.70 \rangle$. So there is no problem on three scenarios from the lenders perspective as well ($DSCR_{min} \geq 1.5$). Finally, the concession period and the tariff are represented as fuzzy numbers in a shot in Figure 7-17 and Figure 7-18 respectively. The intersection area is shaded. Finally, by using the Level Rank defuzzification method (Moller and Beer, 2004), NCI at specific μ -cut/ α -confidence level is determined as a crisp value (denoted by NCI_{α}^{μ}) for final decision making.

μ -cut represents the uncertain level and α -confidence represents confidence level. These levels are taken by decision makers based on the uncertainty and risk attitude that each party is taken at negotiation table. The shaded intersection area could be restricted based on the different μ -cut that is adopted by decision makers to reflect their uncertainty and risk attitude. As can be seen in Figure 7-17, the maximum μ -cut for shaded intersection area is 0.7. Decision makers usually adopt the value 0.5 to reflect their uncertain level in deciding the NCI, e.g. concession period. By utilizing the Level Rank method of defuzzification, the concession period and tariff are determined as 22.5 years and 1.39 Euro Cents/ KWh.

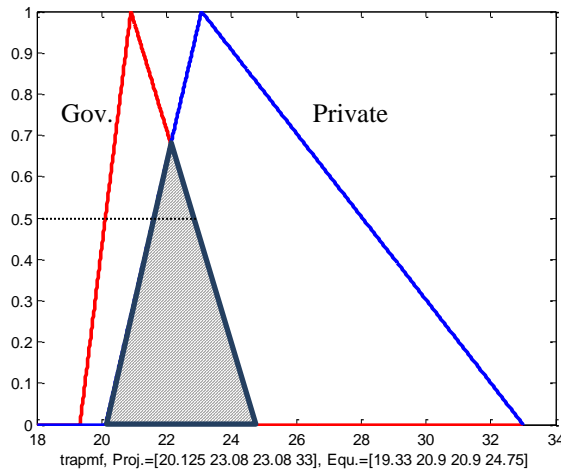


Figure 7-17 Fuzzy representation of NCIs: concession period from private sector and government perspective

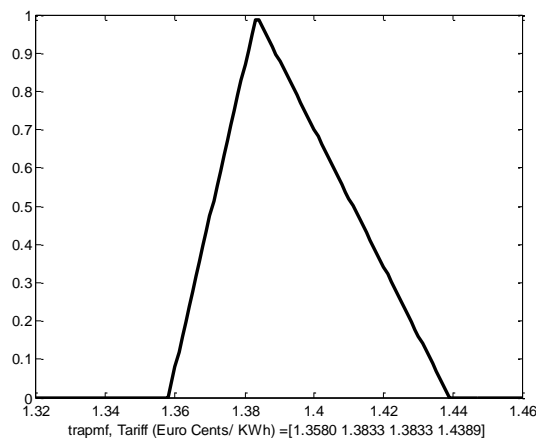


Figure 7-18 Fuzzy representation of NCIs: Tariff from private sector perspective

In the absence of fuzzy variables in the simulation model, i.e. no uncertainties is taken into account in simulation input, the results of the simulation for the NCIs would be deterministic values. In this case, there is no intersection for the NCIs that result from the main parties' perspective. Consequently there is no common values/consensus for the NCIs and there is no success in negotiations.

The proposed method gives a range for negotiation which is based on the characteristics of the players (determine by fuzzy parameters). Whereas, with the crisp method, there is no

bound for negotiation which would lead to failure in this case. This is the main advantage and significant of the proposed method and mechanism.

7.2.4 Real Option Valuation

Real option valuation (ROV) is applied to examine two governmental supports and incentives. The South Isfahan power plant (SIPP) project comprises six power generation units which were brought on stream as each unit was completed. The public and private sectors benefit from the early fund generation (EFG) option by faster construction and earlier operation of the project. The EFG period was design as an incentive to the concessionaire. It was agreed that the government compensate the concessionaire EFG period which is the period of saved time in construction phase.

The original construction period was 4 years and the earlier completion period was 1 year. The concessionaire operates the project for a period of 21 years. Only the first year includes EFG. ($r_0 = 0.16, CP = CP' = 24, CD = 4, CD' = 3, D_{EG} = 1, OP = OP' = 20$). The percentage increase in discounted benefits gained from earlier completion was 16%. The percentage increase in discounted cost to complete project earlier was 8%. So the net benefit was 7% of the present value (PV) of the yearly net benefit which is equal to M€2.23.

The overall contractual package also included granted guaranteed minimum return on equity (Min-GEROR), $r^f = 15\%$. Now the question is that what would be a fair guaranteed maximum return (Max-GEROR), r^c , under the uncertainty of quantity of production (yearly generated energy). Since the input parameters include uncertain random variables, the actual cash flow is also treated as uncertain random variable. Fuzzy set is utilized to model this uncertainty.

The membership function of an uncertain random variable, quantity of production (yearly generated energy (GWH)), was represented in Figure 7-10 . The quantity of production (GWH) as fuzzy variable is: Tr.F.N {6044.2, 6430, 6430, 6622.9 }. A total of three different scenarios (optimistic, most likely and pessimistic scenarios) have been constructed in order to capture this uncertainty in a fuller picture.

The option value of Min-GEROR guarantee is formulated as follow:

$$SF_t = \begin{cases} (CF_t^{gmin} - CF_t^a) & CF_t^a < CF_t^{gmin} \\ 0 & CF_t^a \geq CF_t^{gmin} \end{cases},$$

$$SF = \sum_{t=CD'+1}^{OP'} SF_t$$

Conversely, the option value Max-GEROR guarantee is formulated as follow:

$$R_t = \begin{cases} (CF_t^a - CF_t^{gmax}) & CF_t^a \geq CF_t^{gmax} \\ 0 & CF_t^a < CF_t^{gmax} \end{cases},$$

$$R = \sum_{t=CD'+1}^{OP'} R_t$$

Equations 6.5 to 6.9 are utilized to determine a fair cap of rate of return, r^c . The risk-free interest rate and standard deviation are assumed 5% and 25% respectively. By using the Excel solver the cash flow link to Min-GEROR, $r^f = \%15$, under three assumed scenarios is determined. Then again by using the Excel solver and assuming the same value of put option for call option, the cash flows link to Max-GEROR for three assumptions are calculated. Consequently yearly cash flow-cap (YCF-cap) and equity internal rate of returns (EIRR) link to three scenarios on Max-GEROR are calculated and represented as fuzzy numbers (See Figure 7-19). Finally, by utilizing the Level Rank method of defuzzification, the YCF-cap and EIRR (call option-cap, defuuzified) at specific μ -cut/ α -confidence level is determined as a crisp value. The fair cap of EIRR is determined: $r^c = 19.5\%$. The guaranteed EIRR (bound

within floor and cap) is represented as fuzzy number (See Figure 7-20). The guaranteed bound of cash flow resulted from call and put options during the operation period as final result is shown in Figure 7-21.

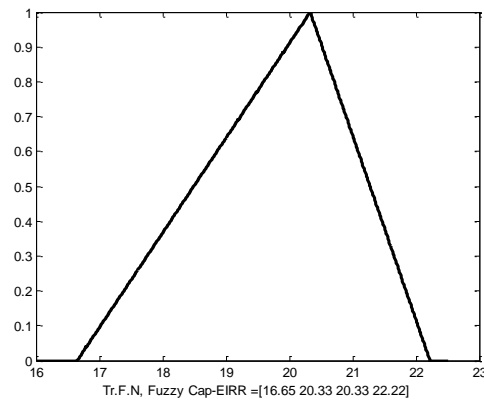


Figure 7-19 Fuzzy representation of cap-EIRR resulted from three scenarios cash flows link to Max-GEROR

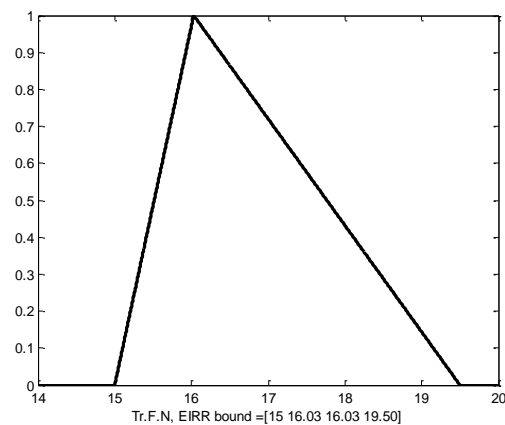


Figure 7-20 Fuzzy representation of guaranteed EIRR (bound within floor and cap)

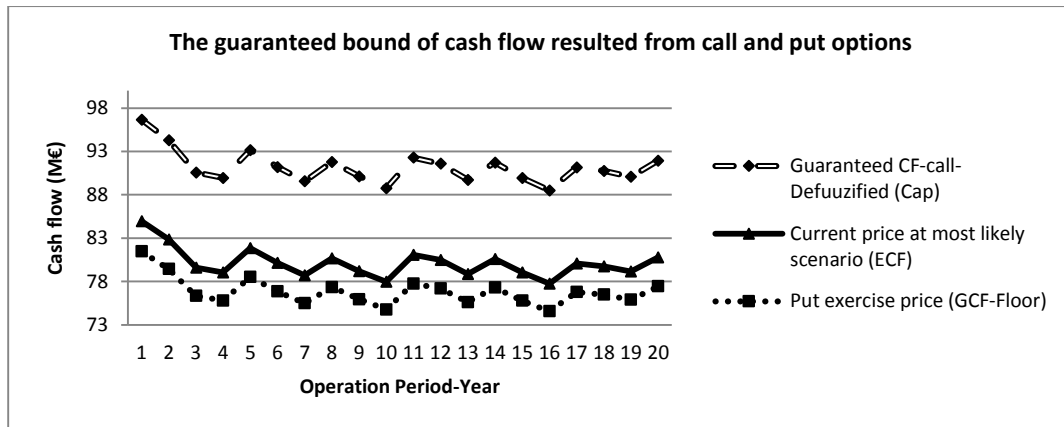


Figure 7-21 the guaranteed bound of cash flow (M€) resulted from call and put options during the operation period

7.3 Concluding Remarks

In this chapter, the different aspects of Public Private Partnerships (PPP) for developing power plant infrastructure with an emphasis on giving necessary guarantees to the private sector are discussed. Preferring Build-Own-Transfer (BOT) contracts over other ones, guaranteeing capital return with appropriate profit over a determined period, partnership of the public sector with a limited share without expecting profit during the contract period, limited and predefined government's interference in pricing, using all investment potentials in the host country, etc. are among recommendations provided by this chapter to create more incentives for the private sector to invest in this field and also to help the government to reach its developmental and social role.

A case study is presented to demonstrate how the proposed methods and mechanisms in this thesis are applied in a real project. The case study is used to illustrate the application of the proposed methods and mechanisms for negotiation risk management, by demonstrating its use on the SIPP BOT project. This case study serves as a validation for the proposed models and mechanisms. Fuzzy game theory, FR-MCS for NCIs determination and Real Options

Valuation are applied to this case study to show how PPP-BOT negotiations can be expressed in development phase. A comparison with the traditional approach is carried out to show the advantages which may be achieved using the proposed methods and mechanisms.

CHAPTER 8 CONCLUSIONS AND RECOMMENDATIONS

To achieve the goals of this study, this dissertation has proposed an overarching systematic framework for negotiation-based risk and uncertainty modelling and management. The outline of the proposed framework follows the structure of this dissertation.

The framework incorporates fuzzy game theory, as a tool for analysing parties' behaviour under uncertainties. The proposed FR-MCS technique helps to establish the game table including the payoff functions and strategies aimed to find the equilibrium solutions under uncertainties and risks. It also has incorporated life cycle financial modelling with proposed FR-MCS technique with the aim of financial viability decision making under uncertainty and risk. Finally, it has incorporated Real Options Valuation and Analysis to arrive at a consensus negotiation position. This position would be equitable for main parties involved under uncertainties and risks for the cases that there is no solution for negotiations.

In summary, the key contributions and conclusions of this work are discussed in the following three sections in detail.

8.1 Negotiation-Based Risk Management

This dissertation has presented a game theory model for determining negotiation positions as an attempt to overcome the problems on determination of negotiable concession items (NCIs) as well as decision variables from different angles. Determining negotiable concession items from a risk management perspective is presently a challenge issue by using existing methods.

Determination of negotiation positions includes a systematic framework based on the Nash equilibrium concept to find the consensus negotiation positions which are critical and

important to ensure the success of a PPP-BOT project. Determined negotiation positions satisfy main parties involved with conflicting objectives in the project.

The game theory was applied in the development phase of PPP-BOT project. The major function of game theory approach is to find equilibrium solutions that no party wants to deviate from these positions. The results show that game theory is a suitable tool to demonstrate and simulate negotiations between parties and analysing their behaviour.

Based on these results, the development phase of PPP-BOT project is divided into two stages: the first stage is bid preparation stage which consists of several shallow negotiations that leads to nominate the selected bidder at effective date and the second stage is deep negotiations stage which leads to final negotiation/arbitration at closing date (financial closure). The former's negotiations are defined by static game while the latter's negotiations are defined by dynamic game.

The application of game theory is also represented by a proposed mathematical model and demonstrated via an illustrative example in chapter three. It also applied in a real project and represented in case study chapter, chapter 7. This model represents the relationship of parties' behaviour in two stages of development phase and is an evidence module based on Nash equilibrium and Pareto optimality concepts to fulfil parties' objectives.

The proposed mathematical model reveals that consequently by increasing the cooperation between public and private sectors, the game type of negotiation is changed from incomplete static game to complete and perfect dynamic game. By this movement the payoff of both players are increased from Nash equilibrium position to Pareto optimality position.

One advantage of game theory is that it can capture and anticipate behaviours in complex projects with multiple players and multiple diverse and inconsistent objectives. Consequently

it proposes appropriate type of game to solve the problems and difficulties involved. This capability facilitates the generation of alternative negotiation outcomes for both public and private sectors which are strategically stable during the development phase of PPP-BOT projects. In addition, game theory provides a method and module for achieving win-win solutions.

Currently, the payoff of game theory is deterministic and this is a major drawback of game theory application. Thus, future research could focus on the integration of utility theory and possibility theory (fuzzy logic) to manage the uncertainties involved in the game. This limitation can be alleviated by extending to fuzzy game theory. Fuzzy game theory is considered in section 3.6.2.

8.2 Uncertainty and Risk Modelling

This thesis has also introduced a new approach for simulation technique under risk and uncertainty for long-term infrastructure projects, which is called FR-MCS technique. The aim of this development is for generalization of the conventional MCS to make decision based on the hybrid simulation approach of randomness and fuzziness. The basic requirement of FR-MCS is to be able to randomly produce random/fuzzy/crisp numbers in simulation procedure (input parameters). Consequently, determine inferior and superior of output values of simulation function by using fuzzy probability (fuzzy CDF).

Probability theory has been successfully used in modelling random variables; however, this is insufficient for modelling imprecise information. Currently, the most popular method to carry out the PRA is MCS and its analysis. However, typically the data required to conduct the conventional MCS is not readily available or it is too costly to collect the required data.

However available data can be utilized through other mathematical tools such as fuzzy set theory. Thus, it is risk analysts responsibility to investigate, gather and efficiently include all the existing information using the most appropriate methods and mathematical tools. The main idea proposed here is to utilize subjective probabilities, i.e. represent the uncertain variable as a fuzzy number, and produce outputs which reflect all risky and uncertain information (i.e., uncertainty due to randomness, imprecision or due to both). In this approach, random variables parameters are treated as fuzzy numbers (Alternative 1). Alternatively, by using subjective approach, random variables are treated as pure fuzzy numbers (Alternative 2).

The proposed methodology has been introduced to integrate fuzzy set theory into PRA studies. α -cut method is used to perform algorithm for generating fuzzy random variable and to implement FR-MCS. Practically, given enough iterations of FR-MCS technique, it will produce a sufficiently small error.

For cases where the necessity of conventional MCS and its analysis is justified but necessary information to conduct this analysis does not exist, the new approach proposed in this research can be conducted as an alternative to conventional MCS. The proposed FR-MCS technique allows fuzzy and probabilistic uncertainty to be considered simultaneously for the risk and uncertainty analysis of PPP-BOT projects. Depending on the project host country, the decision maker can adjust the conservative nature of FR-MCS using lower percentiles of risk.

The proposed technique is applied to a case whose data requirements are comparatively less or easier to obtain. The membership functions of the fuzzy random variables can be formed using imprecise, vague information or expert judgment. Thus, application of the FR-

MCS approach to risk assessment problems instead of conventional MCS approaches may be more realistic for many PPP-BOT cases and may provide decision makers with sufficient information for decision making. The results of conventional MCS and its analysis cannot easily be compared with results of FR-MCS, fuzzy CDF. It is not straightforward. Extensions of possibilistic concepts to various situations of reliability evaluation may lead to some interesting studies and the author aims to extend these results in the PPP-BOT context.

Furthermore the proposed hybrid simulation model developed in this thesis facilitates determining feasible negotiable concession items (NCIs) of a PPP-BOT project negotiations as may affected by various risky and uncertain drivers relating to the NCIs e.g. toll structure, toll revision schedule, extent of government grant, and the duration of the concession period. By careful consideration of the results of the simulation study, the government and concessionaire can arrive at a reasonable agreement on the terms of the concession i.e. NCIs and consequently sharing of risks and uncertainties. The proposed simulation's results are demonstrated through the case study.

8.3 Financial Viability Mechanisms

This dissertation has also introduced a mechanism to study life cycle financial modelling of PPP-BOT projects from the perspective of multi-party involved, which provide the much required level of detail. In addition it has proposed a suitable framework for multi-criteria decision making (MCDM) under uncertainty and risk and their management and control mechanisms.

A PPP-BOT project as long-term infrastructure cannot be successful without all three main parties' involvements. While researchers on PPP-BOT in the past generally focus on

single party's view to analyse the financial viability via financial modelling which as most can be considered as a static model, in this study we cut into from three main primary parties' views involved in the PPP-BOT project to analyse decision variables and indices of their concerns, including indicators SLR for public sector, EIRR and NPV for private sector, and DSCR and LLCR for financial institutions and lenders.

Considering the life cycle financial modelling as long term estimation of costs/revenue and financing plan is effective and essential. The proposed financial model described in this thesis facilitates the study of the financial viability of a PPP-BOT project as affected by various options relating to the financial structure, risks and uncertain variables, as demonstrated by a case study. By careful consideration of the results of the proposed financial model, the project sponsor and the project promoter can arrive at an acceptable and a reasonable agreement on the sharing of risks and the terms of the concession.

Furthermore, the methodology developed in this thesis has contributed in two main aspects. It presented a means for valuing of early fund generation option. Also it has presented a procedure to calculate equitable bound for guaranteed rate of return for project sponsor under uncertainties and risks. The government supports as options should be carefully designed and well formulated. Options which arise from certain clauses of the contract are more valuable in risky projects. Correct evaluation of the concession in a bidding process is essential for government and bidders.

Options provide flexibility for concession agreement and add value to the project in such a way that a specific project with a negative NPV could be acceptable if the value of the Options for the concessionaire outweighs the negative value of the NPV. Some of the existing or possible Real Options in PPP-BOT concessions as guarantees and financial and

incentives supports are minimum revenue guarantee (MRG), tariff/toll guarantee, direct capital contributions (e.g. grants, subordinated loans (extra loan)), and concession period extension. The existence of this type of guarantees and financial and incentives supports makes the concession considerably more attractive for the concessionaire and lenders, because it limits the possible adverse results to them.

The analysis developed in this thesis showed a valuation model of early fund generation option. Furthermore, it contributed to assess the project's financial viability under uncertainties and risks by calculating feasible and equitable bound for guaranteed rate of return for project sponsor. The results show that by applying the proposed systematic negotiation mechanism both public and private sectors could take advantage of its flexibility at the negotiation table. The proposed mechanism could facilitate negotiations on the verge of break down as well as accelerating ongoing negotiations that have been slowed down.

8.4 Recommendations for Future Work

The scope of this thesis has been confined to the negotiations between two main parties, public and private sectors in development phase and the project evaluation from their standpoint. Since this research did not consider third parties, more research is needed to identify and address the role of third parties such as insurers, in addition to major and key parties, i.e. public and private sectors, lenders and sponsors in PPP-BOT projects.

Also it is needed to consider and study negotiations in other phases of project life cycle, including construction, operation and post-concession phases using game theory. As it was discussed in chapter six, Real Options Valuation (ROV), in addition to subsidies (cash subsidies), there are sort of government support categories that could be offered to

concessionaire in mainly two forms of *guarantees* (e.g. minimum revenue guarantee (MRG)) and *financial and incentives supports* (e.g. direct capital contributions). The cost of the guarantees must be estimated and compared with the equivalent subsidies in order to ascertain which of the approaches are more effective in reducing the project risk and uncertainty. This issue still remains to be addressed in future work.

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APPENDIX 1: INTERVIEW WITH PPP-BOT EXPERTS/ PROJECT MANAGERS

Part A: General Information of the Respondent

1. Your organization name
2. Type of your organization.
☐ Government ☐ Private Sector ☐ Academic institutes and R&D centres ☐
NGO
☐ Financial institutions / Banks ☐ Insurers ☐ Off-takers ☐ General Contractor
3. Role of your organization in PPP projects.
☐ Public Sector ☐ Concessionaire ☐ Investors ☐ Sponsors ☐ Advisor
☐ General Contractor ☐ Operators ☐ Lenders ☐ Insurers ☐ Off-takers
4. Please indicate your primary role in your organization.
☐ Project Manager ☐ Expert ☐ Advisor ☐ Researcher
☐ Engineer/ Designer/contractor/operator ☐ Other, please specify:
5. Please indicate your primary role in PPP projects.
☐ Project Manager ☐ Expert ☐ Advisor ☐ Researcher
☐ Engineer/ Designer/contractor/operator ☐ Other, please specify:
6. How many years of construction industrial-related experiences do you have?
☐ 5 years or less ☐ 6-10 years ☐ 11-15 years ☐ 16-20 years ☐ 21 years or more
7. How many years have you been involved in PPP projects?
☐ 5 years or less ☐ 6-10 years ☐ 11-15 years ☐ 16-20 years ☐ 21 years or more

8. How many PPP projects have you been involved?
- ☐ 2 or less ☐ 3-4 ☐ 5-6 ☐ 7-9 ☐ 10 or more
9. In which kind of PPP projects and how many of each have you been involved? (You may select more than one answer)?
- ☐ BOT ☐ BOO ☐ BOOT ☐ BTO
- ☐ Others (Please specify):
10. In which phases of PPP projects have you been involved? (You may select more than one answer)?
- ☐ Development phase (Negotiation and Tender) ☐ Construction phase ☐ Operation phase ☐ Post-Concession Period ☐ Project Life cycle
11. What type of PPP projects have you been involved with (You may select more than one answer)?
- ☐ Power and Energy ☐ Transportation & Urban infrastructure ☐ Hospital ☐ Water and Sanitation ☐ IT& Communication ☐ Housing ☐ School & Education ☐ Police & Prison ☐ Defence & Naval ☐ Others (Please specify):

Part B: Current methods and strategic mechanisms for PPP negotiations in development phase

Based on your experiences, please answer the following questions in details.

1. What are the methods for concessioner selection in tender period (bid process) of PPP projects?
2. Which method is used in your PPP project?
3. What are the criteria for concessioner selection?

4. What is the sequence of negotiations during development phase?
5. Which concession items are focused in negotiations during development phase?
6. What are the negotiation parameters that public sector is willing to negotiate on them before preferred concessionaire is selected and noticed (before effective date)?
7. What are the negotiation parameters that private sector is willing to negotiate on them before preferred concessionaire is selected and noticed (before effective date)?
8. What are the negotiation parameters that public sector is willing to negotiate on them after preferred concessionaire is selected and noticed (after effective date)?
9. What are the negotiation parameters that private sector is willing to negotiate on them after preferred concessionaire is selected and noticed (after effective date)?
10. What are the shortcomings and defects of existing concessioner selection methods and related criteria?
11. Which criteria are most important in development phase to success in negotiations?
12. Did the criteria meet and fulfil the project parties' objectives? (win-win-win solution for public sector, private sector and end-users)
13. What are the most important negotiation parameters in development phase to success in negotiations and achieve the win-win-win solutions?
14. What are the common negotiation conflicts in PPP projects?

15. What are the strategic mechanism that you have taken to find concession items that meet main parties' objectives and interests?
16. Which incentives and subsidies could be applied and proposed by government in PPP concession contract aim to support the project and concessionaire in negotiation?

Part C: Research Concerns and Methodology

Section 1: Negotiations Conflicts and Equilibrium Solutions-Game Theory

Game theory is used in PPP research projects context to simulate negotiations between parties involved in the projects. The aim of using the game theory is to analyse the parties' behaviour at various strategies adopted and to find the equilibrium positions which are called "Nash equilibrium" and are strategically stable. Based on the rational behaviour assumption, no parties want to deviate from these strategically stable solutions. So, knowledge about these solutions and positions could facilitate parties to have understanding of PPP negotiations, predict opponent's behaviour and choose strategies that are best response to them.

Based on the brief introduction on game theory application, please answer the following questions.

1. Please provide the conflicts and challenges that you have encountered in PPP negotiations between the concessionaire and the government.

Please provide the methods that you have employed to overcome these conflicts and find the equilibrium solutions in negotiations.

2. Are you familiar with the term “game theory” in PPP development systems?
☐ Yes ☐ No If your answer to the previous question was yes,
3. Have you applied “game theory” in any PPP negotiation?
☐ Yes ☐ No If your answer to the previous question was yes, Please specify the problem that game theory has been used to solve it
4. What was the contribution of using the “game theory” in your PPP project? Please specify
5. Which strategies have the most efficient and effective effect on increasing the use of “game theory” in PPP practice? (Please select all that can be applied and then rank them)
 - ☐ Improve game theory models to better reflect negotiation realities
 - ☐ Understand the type of Game that reflect players’ behaviours
 - ☐ Model managerial behaviour by game theory
 - ☐ Develop game theory application in development phase of PPP project
 - ☐ Develop game theory application in construction phase of PPP project
 - ☐ Develop game theory application in operation phase of PPP project
 - ☐ Develop heuristics
 - ☐ Link game theory earned values to the value of the whole firm
 - ☐ Others (Please specify):
6. Please provide the problems and subjects that you think can be simulate by game theory and could be potential future research subjects in:
 Development phase
 Construction phase

Operation phase

Section 2: Prediction and Future Estimation-Simulation

PPP infrastructure development as long term project is included prediction and future estimation under risks and uncertainties. Some methods are developed in literature and have been used in practice. The main concerns in these methods are uncertainty modelling and assessment.

7. Please explain the methods that you have employed for prediction and future estimation to model and assess the risks and uncertainties in the PPP projects.
8. Please provide the shortcomings and defects of explained methods for prediction and future estimation to model and assess the risks and uncertainties in the PPP projects.
9. Are you familiar with the term “Monte Carlo Simulation” in PPP development systems?
☐ Yes ☐ No If your answer to the previous question was yes,
10. Have you applied “Monte Carlo Simulation” in any PPP project?
☐ Yes ☐ No If your answer to the previous question was yes, Please specify the problem that Monte Carlo Simulation has been used to solve it
11. What was the contribution of using the “Monte Carlo Simulation” in your PPP project?
Please specify
12. What were the shortcomings and defects of using the “Monte Carlo Simulation” in your PPP project? Please specify

13. Which method you have employed for risks and uncertainties modelling and assessment when you utilized the “Monte Carlo Simulation” technique? Please specify

14. Which strategies have the most efficient and effective effect on increasing the use of “Monte Carlo Simulation” in PPP practice? (Please select all that can be applied and then rank them)

☐ Improve Monte Carlo Simulation to better reflect project risks and uncertainties

☐ Understand the type of risks and uncertainties in simulation input

☐ Model subjective issues by Simulation

☐ Develop heuristics

☐ Link Simulation and game theory to estimate the payoff of game

☐ Others (Please specify):

Section 3: Converges and Arrive at Consensus Solutions-Real Options

In the case that there is no solution in the negotiation (game) between the concessionaire and the government, specifically in negotiations between them in development phase, a mechanism which helps to arrive at a consensus solution is needed. By this approach, negotiation will not be fruitless and consequently project will success at earliest time and lowest transaction cost.

15. Please explain the conflicts that you have encountered in PPP negotiations between the concessionaire and the government which leads to fruitless negotiation.

16. Please provide the mechanisms that you have employed to overcome these conflicts and to arrive at equilibrium solutions in negotiations.

17. Are you familiar with the term “Real Options” in PPP development systems?

☐ Yes ☐ No If your answer to the previous question was yes,

18. Have you applied “Real Options” in any PPP contract?

☐ Yes ☐ No If your answer to the previous question was yes,

19. What was the contribution of using the “Real Options” in your PPP project? ☐ Yes ☐

No

20. Which Options do you propose to apply in PPP concession contract aim to arrive at solution in negotiation?

21. Which strategies have the most efficient and effective effect on increasing the use of “Real Options” in PPP practice? (Please select all that can be applied and then rank them)

☐ Improve Real Options models to better reflect reality

☐ Understand ‘split’ Real Options that are owned by multiple agents

☐ Model managerial behaviour

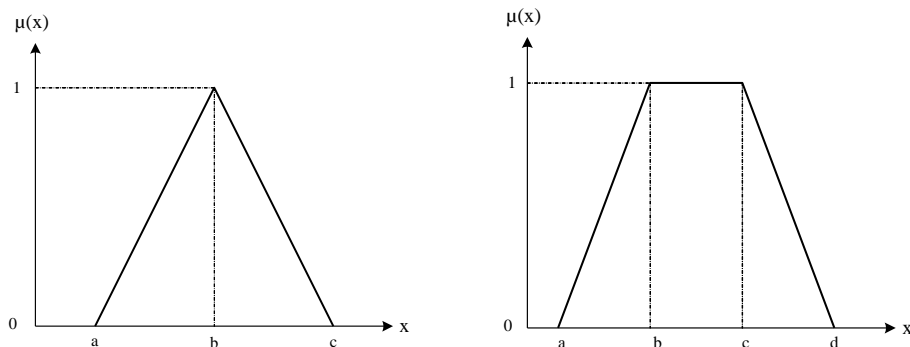
☐ Develop heuristics

☐ Link Real Options values to the value of the whole firm

APPENDIX 2: WEIGHTED FUZZY-DELPHI TECHNIQUE BASED SURVEY FOR RESEARCH ON PPP-BOT PROJECTS

The aim of this survey is to collect the specific project data that feed the input of life cycle simulation based on the weighted Fuzzy-Delphi technique. Please refer to attachment for more details on weighted Fuzzy-Delphi technique.

Briefly, you are asked to provide your estimates (or appraisal) on the key simulation input variables (risky and uncertain variables) using the fuzzy numbers, in the form of triangular fuzzy numbers T.F.N, or trapezoidal fuzzy numbers (Tr.F.N). For T.F.N, a is the pessimistic value, c is the optimistic value and b is the expected value. For Tr.F.N, a is the pessimistic value, d is the optimistic value, b and c are the expected values.



Triangular fuzzy number (T. F. N) $\langle a, b, c \rangle$, Trapezoidal fuzzy number (Tr. F. N) $\langle a, b, c, d \rangle$

Simulation input

There are three main types of simulation model inputs through the life cycle simulation.

Macroeconomic indicators and indexes, which is depended on the host country economy, such as debt capital interest rate, discount rate, inflation rate, demand growth rate (e.g.: traffic growth rate), debt/equity (D/E) ratio, etc.

Fuzzy-Stochastic Variables (FSV), which are appraised based on the past project experiences and data or estimated based on the experts' judgment, such as construction cost, operation cost, maintenance cost, etc. Each risky/uncertain parameter follows specific probability distribution/membership function.

Negotiable concession items (NCIs), which are policy parameters, such as concession period, tariff/toll design including the initial level of tariff/toll and tariff/toll adjustment scheme, construction and operation period, financial return, etc.

General project information and assumptions

1. Project name:
2. Project location:
3. Your organization name
4. Role of your organization in PPP projects.
☐ Public Sector ☐ Concessionaire ☐ Investors ☐ Sponsors ☐ Advisor ☐
General Contractor ☐ Operators ☐ Lenders ☐ Insurers ☐ Off-takers
5. Please indicate your primary role in PPP projects.
☐ Project Manager ☐ Expert ☐ Advisor ☐ Researcher
☐ Engineer/ Designer/contractor/operator ☐ Other, please specify:
6. Which kind of PPP project is adopted for underlying project?
☐ BOT ☐ BOO ☐ BOOT ☐ BTO
☐ Others (Please specify):
7. What is the project status (which phase of PPP project)?

☐ Development phase (Negotiation and Tender) ☐ Construction phase ☐

Operation phase ☐ Post-Concession Period (Transfer)

8. What is the type of PPP project?

☐ Power and Energy ☐ Transportation & Urban infrastructure ☐ Hospital ☐

Water and Sanitation ☐ IT& Communication ☐ Housing ☐ School & Education ☐

Police & Prison ☐ Defence & Naval ☐ Others (Please specify):

9. Concession period (years) , < , , > , <
 , , , >

10. Construction period(years) , < , , > , <
 , , , >

11. Operation period(years) , < , , > , <
 , , , >

12. Total Project cost (\$) , < , , > , <
 , , , >

13. Loan details:

a. Loan interest rate (%) , < , , > , <
 , , , >

b. Loan repayment period (years) , < , , > , <
 , , , >

c. Loan commitment fee (%) , < , , > , <
 , , , >

d. Loan commission fee (%) , < , , > , <
 , , , >

- e. Equity/ Loan ratio: / , < , , > , < , , , >
- f. Loan repayment reserve account (percentage of yearly interest and principal repayment) (%) , < , , > , < , , , >
- g. Repayment method of Interest during the construction period
14. Equity (%) , < , , > , < , , , >
15. Loan (%) , < , , > , < , , , >
16. Subsidies (%) , < , , > , < , , , >
17. Guarantees awarded (\$) , < , , > , < , , , >
18. Risk free rate , < , , > , < , , , >
19. Expected equity rate of return (Cost of equity) , < , , > , < , , , >
20. Project discount rate , < , , > , < , , , >
21. Tax details:
- a. Tax rate: (%) , < , , > , < , , , >
- b. Effective year
22. Depreciation method
23. Minimum dividend rate
24. Construction period details:

Year	Yearly investment regime (%)	Equity investment regime (%)	Loan investment regime (%)	Local Currency (IRR)	Foreign Currency (\$)
1					
...					
Total	100%				
Inflation rate (escalation rate)					

25. Operation period details (Power Plant project):

a. Production Capacity (MW)

b. Energy production (GWh) from year to year of operation
period, (GWh) from year to year of operation period

c. Tariff ,< , , > ,< , , , > \$/kwh

d. Operation and Maintenance (O&M) Costs details

i. Fixed costs ,< , , > ,< , , , >
(%) percentage of construction costs

ii. Variable costs ,< , , > , <
, , , > \$/MWh energy production

e. Escalation rate of O&M costs ,< , , > , <
, , , >

f. Other costs ,< , , > ,< , , , > (%)
percentage of total income

26. Operation period details (Toll Road project):

a. Capacity of toll road project(vehicles) ,< , , > , <
, , , >

- b. Demand (vehicles/day or vehicles/year) ,< , , > , <
, , , >
- c. Toll rate (\$/vehicle) ,< , , > , <
, , , >
- d. Operation and Maintenance (O&M) Costs details
- i. Fixed costs ,< , , > ,< , , , , >
(%) percentage of construction costs
- ii. Variable costs ,< , , > , <
, , , > \$/vehicle
- e. Escalation rate of O&M costs ,< , , > , <
, , , >
- f. Other costs ,< , , > ,< , , , , > (%)
percentage of total income

27. Decision variable-Simulation output (e.g. Financial indicators Criteria)

- a. Concessionaire , Min ,< , , > , <
, , , >
- b. Government ,Min , < , , > , <
, , , >
- c. Lenders , Min , < , , > , <
, , , >

28. Which criteria are adopted for bidders' consideration and selection in development phase (before effective date)?

29. Which procedure is adopted to select and nominate preferred concessionaire from the project bidders?
30. What are the negotiable concession items as policy parameters that are taken for bargaining at negotiable table with nominated bidder (concessionaire)? (after effective date and before closing date)
31. What is the negotiable concession item that is taken for final negotiation?
32. Which kind of incentives and subsidies are provided by government for this PPP project?

APPENDIX 3: IRAN’S FOREIGN INVESTMENT PROMOTION AND PROTECTION ACT (FIPPA)

The government of Iran welcomes foreign investments and urges all the foreign investors to attentively peruse *Iran’s Foreign Investment Promotion and Protection Act (FIPPA)* and its executive bylaws to know their own rights and be informed of the facilities and protections they may enjoy as well as the legal obligations and requirements caused by investing in Iran. In this act, firstly the process of looking into the applications by foreign investors to the Investment Organization of Iran is briefly discussed. Then, some articles from FIPPA and its bylaws, referring to guarantees given to the investors, their rights, facilities granted, the protection extended as well as their commitments and obligations will be offered. It is also devoted to entry and registration procedures for foreign investments once the investment permit is issued.

1- The process of examining the applications by foreign investors to the investment organization of Iran up to permit issuance

The foreign investors who would like to make investments in Iran within the framework of Iran’s Foreign Investment Promotion and Protection Act (FIPPA), need to first fill out a special form (available on www.oietai.ir) and submit it to the organization. The application is presented by the Investment Organization to the Foreign Investment Council and will be pursued until a permit is issued. Choosing the form depends on the type of the foreign investment and the agreement concluded between the parties (domestic and foreign

investors). The form has to be submitted in English except for when the investor is an Iranian expatriate or from Persian-speaking countries like Tajikistan or Afghanistan.

2- Guarantees and protections

Foreign Capital is guaranteed against nationalization and expropriation, and in such cases the Foreign Investor shall be entitled to receive compensation (Article 9 of the FIPPA). Should laws or government regulations lead to prohibition or cessation of approved financial agreements within the framework of this Act, then the government shall procure and pay the resulting damages (Article 17 of the FIPPA & Article 26 of the bylaws). The purchase of goods and producer services of the foreign investment is guaranteed in cases where a state-run organ is the only buyer or supplier of a product or producer service at a subsidized price (Article 11 of the bylaws).

Rights and facilities

Foreign investments subject to this Act shall enjoy the same rights, protections and facilities available to domestic investments in a non-discriminatory manner (Article 8 of the FIPPA).

- The Foreign Investment and its profits may be transferred in foreign currency or goods (Articles 13-18 of the FIPPA).

- Acceptance of foreign investments in all the production, industrial, agricultural, transportation, communications, and services fields as well as in fields related to water, power, and gas supply and energy fields.

- The possibility of the referral of investment-related disputes to international authorities (Article 19 of the FIPPA).
- The possibility of land ownership in the name of the company (registered in Iran) in joint ventures (Article 24 of the bylaws).
- Issuance of visas for three years in Iran for foreign investors, managers, experts and their immediate family members and the possibility of visa renewals (Article 20 of the FIPPA & Article 35 of the bylaws).
- The investors are notified of the final decision regarding their applications within at most 45 days (Article 6 of FIPPA).
- Having a choice to choose the investment method in the project as FDI or Foreign Investment in all sectors within the framework of “Civil Participation”, “Buy-Back” and “Build-Operate-Transfer” (BOT) schemes (Article 3 of FIPPA).
- Acceptance of investments by any natural or legal non Iranian or Iranian person utilizing capital of foreign origin and granting the facilities envisaged in FIPPA to them (Article 1 of FIPPA).
- The foreign investor must choose an audit institute out of the audit institutes recognized by the Association of the Official Auditors of Iran to substantiate their financial and annual reports (Articles 1, 22-23 of the bylaws).

3- Legal commitments and obligations of the investors

- Applications of Foreign Investors in respect of issues such as admission, importation, utilization and repatriation of capital under the FIPPA shall be submitted to the Organization shall only be submitted to The Organization and followed up through it (Article 5 of FIPPA).
- The Organization should be notified of any changes in the name, address, legal shape, or nationality of the foreign investor or of changes of more than 30% in his/her ownership (Article 33 of the bylaws).
- It is necessary for the investor to notify the Organization of the transfer of all or part of his/her Foreign Capital to other investors. In case of transfer to another foreign investment, it is needed to obtain the approval of the Council and the permits from the Organization (Article 10 of FIPPA).
- All the applications of the foreign investor for transferring the profit, capital and the proceeds from the increase in the capital value under FIPPA must be submitted to the Organization accompanied by the report of the audit institute that is recognized by the Association of the Official Auditors of Iran (Articles 22-23 of the bylaws).
- The investor is obligated to bring a portion of the capital into Iran to implement the approved project over the period of time specified by the foreign investment license which is usually 6 months. Otherwise and in order to extend the validity of the license and prevent it from being revoked, the investor is required to submit his/her reasons and justifications for the delay to the Organization (Article 32 of the bylaws).

- The foreign investor is required to announce the entry of its capital including cash and non-cash items to the Organization within the framework of the license issued for the foreign investor so that they will be registered in the Organization and subjected to FIPPA. Failure to register the entered capital is tantamount to not being covered by the FIPPA. (Article 11 of the FIPPA & Article 24 of the bylaws).

- The Iranians who intend to utilize capital of foreign origin in Iran and wish to be subjected to FIPPA must be involved in economic and trade activities abroad and need to submit the relevant documents to the Organization (Article 5 of the bylaws).

- Acceptance of foreign investments in the existing Iranian enterprises and economic companies (purchase of shares) is possible provided that added value is created in that economic unit after the purchase of shares.

4- Other advantages and facilities

- Foreign investors can supply a portion of their capital from domestic and international sources as loans. Needless to say, the borrower will have to guarantee the repayment of the loans received.

- Foreign capitals can enter the country as cash currency, machinery and pieces of equipment, raw materials, technical know-how, and other forms of intellectual property and they will be promoted and protected.

- 80% of the incomes made by the producer and mineral units based in lesser developed zones will be exempt from tax for 4 years.

- 100% of the incomes made by the producer and mineral units based in lesser developed zones will be exempted from tax for 10 years.
- Tourist installations are exempt from annual tax for 50%.
- 100% of the income generated by the exporting industrial and agricultural, conversion industries goods and their completion are exempt from tax.
- 50% of the incomes generated by exporting goods aimed at developing the non-oil exportations are exempt from tax.
- 100% of the incomes generated by exporting transit goods are exempt from tax.
- Re-investments made by cooperative and private companies aimed at developing, restoring and completing industrial and mineral units will be exempt from tax for 50%.