Risk Analysis In Public Procurement

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CERTIFICATE FROM THE SUPERVISORS

This is to certify that thesis entitled ***"Risk Analysis in Public Procurement"*** submitted by ***Sri. Sunil Kumar Sharma*** who has got his name registered on ***28/05/2013*** for the award of Ph.D (Engg) degree of Jadavpur University, is absolutely based upon his own work under the supervision of ***Prof. Subhash Chandra Panja*** *and* ***Dr. Atri Sengupta*** and neither his thesis nor any part of the thesis has been submitted for any degree/diploma or any other academic award anywhere before.

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Abstract

Public procurement is a very vital policy instrument and an important government function. However, numerous problems such as cost and time over-run, and quality failures continue to affect its outcomes. This research, therefore, aims at analyzing risks present in the public procurement for finding remedial measures to improve the procurement performance.

Initially, an extensive literature review was undertaken to develop a procurement risk perspective. The review provides theoretical foundation of public procurement, examines the existing risk assessment techniques to identifies useful ones, and provides valuable direction for conducting a comprehensive risk analysis. Thereafter, this research attempts to develop an appropriate risk analysis technique by integrating grounded theory, fault tree analysis and failure mode effects and criticality analysis. It uncovers functional level vulnerabilities and uncover their interconnectedness. Minimal cut set method was applied to simulate potential pathways leading to unfair contract awards. It also ranks the criticality of identified risk factors and deduces important risk mitigation measures.

We further study the work execution phase by using socio-technical system concepts to improve our understanding to set up a game model. The model identifies six important risk factors and infers several improvement measures. This study extends the analysis by applying evolutionary game theory with supply chain perspective. Using replicator equation helps us in capturing the dynamism of execution phase in mathematical formulations which reveals that a stable state is dependent on several critical factors like cost of adequate supervision, penalty structure, and cost of rework. The evolutionary analysis describes a macro environment and tells about how the project environment can be changed from undesirable states to more desirable alternative equilibrium states. It thereby assists in devising measures for promoting these shifts.

This study also models quality failure costs and monitoring strategies which characterize circumstances describing optimal monitoring. It shows that modelling quality failures along with their economic implications can provide a consistent basis for risk management. The study offers useful insight for both academics and practitioners and provides future research agenda.

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CHAPTER

1

INTRODUCTION

1.1 INTRODUCTION

An effective public procurement system, which can be defined as purchase for people by the agent of people by using public funds, i.e., taxes (Murray, 2009), has a crucial role in making society better in developing as well as developed countries. The history of Public procurement dates back to thousands of years. The earliest procurement order was inscribed on a red clay tablet in Syria (Coe, 1989). This order, which dates from between 2400 and 2800 B.C, was issued for procurement of 50 jars of fragrant smooth oil. The silk trade development between China and a Greek colony in 800 B.C is an additional historical evidence (Thai, 2001). Initially, procurement was regarded as a clerical activity. With time, it has transformed from a subordinate's function to that of strategic importance. The significance of procurement activity is inexplicably linked with economy of the times. In this regard, most important changes pertain to increasing emergence of importance of organizations in societies. Organizations are the basic units of modern societies and enable people to achieve collective and individual goals through their socio-technical mechanisms. Their output ranges from the infrastructure and development of societies to delivery of public services. As a result, procurement function also got diversified ranging from purchase of simple goods to complex products like airliners, high speed rail, from small works to large projects and from traditional services to modern technological innovations.

The form of organization changed during British Industrial Revolution when individual mode of production were being replaced by a collectively organized mode. This change necessitates required coordination of activities in terms of time-phasing of the inputs, increased specialization of labour and standardization of products. With further innovations like new steel making processes and increased mechanization, organizations acquired multidivisional form which required the innovations to handle increasing complexity of the production process (Kapás, 2008). Innovations in structures of organizations also occasioned the growth of supportive financial, and logistic infrastructures including state-of-the-art material management practices. Consequently, procurement acquired substantial significance during the Industrial Revolution when it became more than a part of an employee's skill-set (Whitemore, 2015).

When plants needed resources for manufacturing, many of them hired "materials" men to arrange the acquisition, storage, and movement of input supplies. Subsequently, goods and services were supplied by commissaries who received commissions for arranging supply of goods and services (Thai, 2001). It was Oklahoma State Government that first created a board to centrally procure goods and services for all the state departments (Page, 1980). This is the first formal procurement structure that came into existence in 1810. During Second World War, project form of organization evolved to urgently develop and deliver complex armaments and organize enormous task forces of troops and various items (Nicholas and Steyn, 2008). Subsequently, project form of organization emerged in the defence, engineering and construction sectors to optimise efficiently the management of organisational resources. Thereafter, knowledge has become a critical input in the industrial enterprise for deriving strategic competitive advantage (Omotayo, 2015). In this process, variety and complexity of procurement activities have increased tremendously (Terzi et al., 2011). At the same time, its size has increased significantly. As a result, purchasing has now assumed strategic significance in both public as well as private organization. Both public and private procurement share many similarities such as value for money, price determination, quality, vendor development, ethics, and market analysis. However, unlike procurement in the private sector, public procurement includes public concerns and efficiency considerations (Choi, 2010).

Realizing the importance of procurement functions and potential to serve key policy objectives like sustainable development (Brammer and Walker, 2011) and driving innovations (Aschhoff and Sofka, 2009), it has got the attention of researchers, governments and international bodies. The objective of regulatory and monitoring public procurement (PP) is mainly threefold, viz., (i) Equity, (ii) Integrity and (iii) Economy and Efficiency (Kelman, 1990). Equity implies that bidders are not arbitrarily excluded. Integrity is necessary to reduce chances of unethical behaviour. The goal of economy and efficiency signifies the value for money in the purchase of goods and delivery of public service and projects. However, inefficiency, corruption and disregard of value for money considerations in PP has overshadowed its key aspects of transparency, efficiency and competitive supply in the past (Amemba et al., 2015). It has obstructed the progress towards achieving the national development objectives (Tan et al., 2009). The need of research effort is, therefore, the prime necessity as the potential for improvement is quite enormous in terms of increase in efficiency, reduction in waste and achieving better outcomes i.e. value for money and promoting best practices.

Despite innovation in organization structures for effective coordination and efficient monitoring and supervision, management of human behaviour and channelizing it into correct direction remains always a challenging task. Multifunctional organizations and temporary forms like projects provide significant degrees of freedom and discretions in decision making which entitle officials working in key positions with substantial power and influence. The concentration of power not only helps in achieving the major organizational goals, but also contributes to some of the worrying actions (Coleman, 1974). Examples include, bid rigging for getting the contract and price fixing in the market for electrical equipment industry (Pfister, 2009) and setbacks to project such as abandonment or completion below standard (Oyewobi et al., 2011). Stanford Business (2003) reports that way back in 1872, the directors of the Boston Pacific Railroad fraudulently collected the profits by getting actual construction work done by another company which were owned by them. These incidents indicate that transparent tendering and contract award are essential for efficiency and effectiveness in the procurement process.

With information-communication technological development, organizations are now leveraging these improvements to streamline their procurement process for improving delivery of service and program efficiency. However, the issues pertaining to contract execution phase remains largely unaddressed. A large chunk of public procurement goes into large infrastructure and construction projects which aim at long-term social and economic development and involve huge expenditure. Globally, megaprojects alone make up 8 percent of total World GDP (Flyvbjerg, 2014). Further, annual global infrastructure expenditure will rise from $4 trillion in 2012 to more than $9 trillion by 2025 (PwC, 2016). However, there remains general dissatisfaction with the procurement outcome (Wells, 2014) in terms of cost overruns, time delays, benefit shortfalls and quality failures. Several factors like complexity, capability limitation and project characteristics can undermine the performance outcome (Locatelli et al., 2014). Complexities, multiplicity of stakeholders and fragmentation of controls in the procurement process make performance monitoring a difficult exercise. Most of the existing studies have concentrated either in tendering or in execution phase in an integrated manner though vulnerabilities present in one phase will affect other.

Efficiently managing the procurement spending remains an unaddressed policy concern and management challenge (Thai, 2001). Reforms have been recommended by various international bodies like OECD, European Union, World Bank, ITO and governments, however, public organizations have yet to address several deficiencies and weaknesses present in their procurement processes. Actually, the basic processes of procurement cycle are not robust enough and remedial measures and/or actions are required in processes, methods, practices, monitoring mechanisms and human resources which cannot be addressed by national procurement regulations and laws (Thai et al., 2005). It emphasizes that the need to relook within the organization regarding vulnerability or weaknesses remained un-addressed. This requires development of an organizational perspective of procurement risks thus research efforts are needed to identify the procurement risk and find remedial measures.

Risk of resource waste and underperformance is always a key concern in procurement process. The harmful and unproductive work practices causing loss of efficiency leading to wastage of resources and quality failures need to be considered in the analysis. However, the observed problems of procurement does not tell the entire story (Kelman, 1990). Hence, it becomes necessary to develop a systemic view of the problems by considering entire value chain associated with procurement in the analysis. In this regard, inventory management emerges as an important activity. Inventory makes up a quite considerable part of the existing assets in the organizations (Mwayongo, 2017). It is important to understand the issue of inventory control and align their purchasing strategies accordingly (Babbar et al., 1998) to ensure undisrupted supply and derive cost benefits. Further, causes of waste and other problems include decisions that are made with a lack of information or understanding

(Vrijhoef and Koskela, 1999). Considering the success of supply chain (SC) philosophy into other industry, it has therefore been considered for application in construction industry (McDermott and Khalfan, 2006) for making efficient choices for mitigating the performance risks. Further, quality failure costs usually range from five to twenty percent of the project value (Nylen,1996; Barber et al., 2000; Palaneeswaran et al., 2008; Jafari et al., 2013) and would give rise to performance uncertainties in the projects. Organization can draw sustainable advantage from efficient monitoring of quality failures. However, this requires appropriate modelling of the quality failure costs for suggesting efficient monitoring strategies.

1.2 ORGANIZATIONS STRUCTURE AND CONTROLS: A SYNOPTIC ILLUSTRATION:

An organization is defined as the planned coordination of two or more people who are functioning on a relatively continuous basis to achieve a common goal or set of goals through division of labour and a hierarchy of authority (Robbins, 1983). The persistent collective action focussed towards a common purpose differentiates organizations from other social units like friend groups or club. Organizational structure is designed with focus on mainly three core dimensions, viz. complexity, formalization and centralization (Hendrick and Kleiner, 2001). Complexity, in-turn, consists of two components. These are namely; differentiation and integration (Kleiner, 2006). Differentiation actually denotes the presence of different organizational units, and numerous steps and interactions whereas integration reflects multiple interactions with coordinating mechanisms. Formalization is considered as the degree of standardization. The notion of formalization is receiving continually increasing attention for resolving the problems arising due to complexity. For instance, standard precast structures and prefabricated items are being used in construction projects on the line of manufacturing organization to improve the project performance. These efforts aimed at using innovation in organizations structures for reducing the waste by efficiently managing the flow of materials supply during work execution. Further, centralization pertains to decision-making and also reflects the extent to which authority is bestowed in some important positions. However, decision-makers have a limited time, resource and capacity for handling various organizational tasks and problems. Simon (1957) termed this limitation as bounded rationality. It is a common problem witnessed in complex organizational systems consisting of a large number of interacting elements. Organizations therefore provide a formal framework in the form of rules, policies, and access to information to channelize the decision-making behaviour for creating a capacity to realize particular goals and values.

As a planned and deliberately structured unit, organizations constantly and self-consciously reviewing their activities to elicit the performances it needs by controlling the undesired outcomes and activities. Actually, control structures are the arrangements that outline the way for directing, evaluating and rewarding the people (Aldrich, 1999). In practice, organization uses a wide array of techniques, viz. supervision, rules, job descriptions, statistical process charts, budgets and audit mechanisms, etc. Organizational control literature review reveals that organizational leaders target controls either at outcomes or at the antecedent behaviours associated with those outcomes (Merchant, 1985). Outcome-oriented controls involve influencing the current behaviour through its consequences like rewards or punishments by linking it to desired results as an attempt to eradicate corruption. Process-oriented controls focus on using active intervention prior to and during the conduct of work for ensuring that individuals are working for attaining organization’s goals. For example, process-oriented method would involve ongoing monitoring of the key personnel’s behaviour like repeatedly awarding the contract to certain vendors.

Organizations use activity systems for carrying out their work by processing raw materials, and information with the help of people. Organization can be structured in various ways for allocating the set of responsibilities for different functions to different entities for transforming input resources to predefined output. This transformative process is affected mainly by three factors, viz. technology, process and people. Technology represents the technological subsystem whereas people constitutes the personnel subsystem as shown in the Figure 1.1. As human factor is contributory or detrimental to the productivity, the study of human behaviour is very important in conceptualizing the organizational controls. Human behaviour has been looked into theoretical perspective prevalent in PP literature along with emerging risk based approach for developing theoretical basis for analyzing issues and problems pertaining to PP.

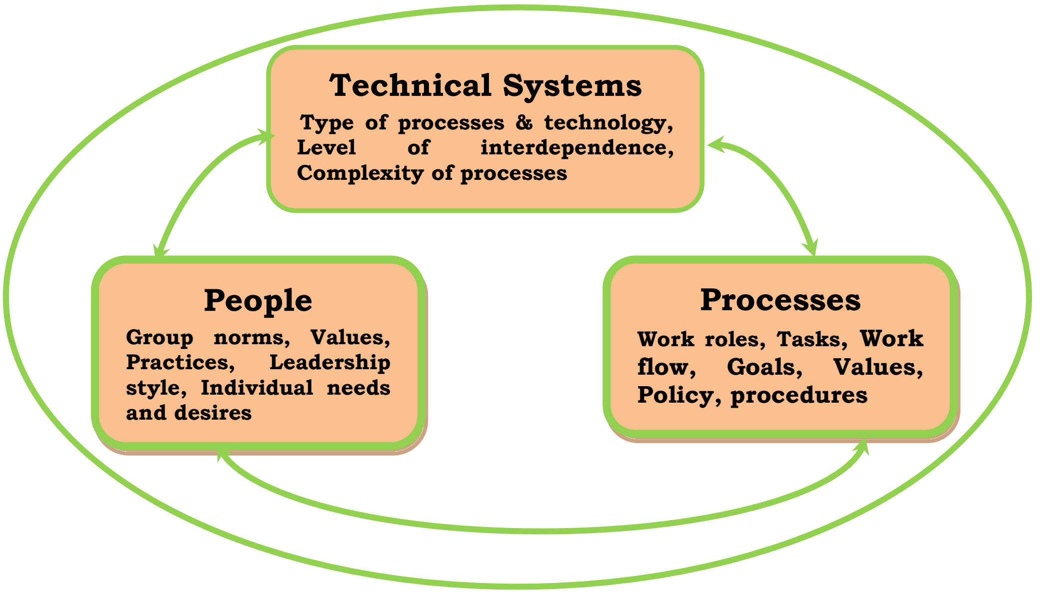


Figure 1.1: Socio-Technical System

1.2.1 PREVALENT THEORETICAL PERSPECTIVE:

PP embraces a wide range of diverse means that are used by organizations to acquire goods, works, and services from various sources. It includes acquisition, contracting, renting, leasing, and purchasing, etc. The subject of public procurement have been approached from diverse directions, for instance, “contracting out (Fitch, 1988; Michaels, 2010); challenges of contracting (Van Slyke, 2002Shick and Weikart,2009;). project management (Morroig, 2006), public-private partnerships (Gansler, 2003), strategic management (Rendon, 2005; McCue and Gianakis, 2001), procurement and technology interface (Vaidya et al., 2006), post disaster procurement (Woods, 2006; Moon, 2005), innovation (Xu et al., 2014), ethical aspects (McCampbell and Rood, 1997; Susan Rose-Ackerman, 1999; Kelman, 1990; Schooner, 2001; 2006; Ferwerda et al., 2017), fuzzy set theory (Lee, 2009); supply chain management (Apte etal., 2011), inventory management (Navon, 2006), quality aspects (Sadigh et al., 2009, Pi and Low, 2005), theory of lean (Erridge, 1998).

Flynn et al. (2014) finds that commonly used theory in public procurement research are auction theory, principal-agency theory, transaction cost, contract theory. Other theoretical perspectives are based on organization behaviour, theory of lean, general system, and fuzzy set theory. The theory of auction and competitive bidding comes in many models and deals with behaviour of people in many different situations of auctions or bidding These models though characterised by various parameter like number of bidders, sellers, the information available, type of auction, etc., cannot structure all the procurement situations. Agency theory describes the relationship where principal entrusts the work to the agents who carry out it (Eisenhardt, 1989). Agency problem occurs when involved entities like buyer and vendors, work with conflicting goals. According to this theory, moral hazard and adverse selection are two impediments that adversely affect the performance. Moral hazard implies that agent does not apply mutually agreed effort. Whereas, adverse selection signify the situation when agents misrepresent their abilities which cannot be verified by principal (Eisenhardt, 1989). Consequently, risk of underperformance and waste arises in the public procurement.

In transaction theory, actions are considered as transactions rather than individual behaviour. The transaction cost would occur for every transaction involving transfer of any goods or services through a technologically separable interface (Willamson, 1981). An organization tries to minimize its transaction costs of exchanging resources which provides the basis for the decision like make or buy. Organization behaviour (OB) theory explains how individuals and groups behave in organizational settings. It focuses on organizational controls and on the normative and cognitive aspects in the organization. OB concerns with improving productivity, turnover, and deviant workplace behaviour. It has been applied in understanding unethical behaviour. It emphasizes that unethical and deviant behaviour can be reduced through by involving both formal elements such as reward systems and formal training etc., and informal elements like prevalent norms and work culture (Trevinõ and Weaver, 2003; Misangyi, 2008). By combining economic and OB perspective, it is inferred that it is required to understand ways and behavioural repertoires of employees, the resources for action available to them and how the process and functions can be modified to counter their influence or power to manoeuvre the outcomes and, thus, likelihood of undesired outcome is reduced.

1.2.2 RISK PERSPECTIVE:

A general dissatisfaction arises in the public procurement outcomes because of various problems such as cost and time over-run, substandard works and quality failures, unfair contract awards, benefits shortfall and project failures. Increased incidents of general dissatisfaction with procurement outcomes have generated research interest for finding a comprehensive way to describe and understand public procurement process. Risk perspective is one of recent development occasioned from such attempts. Risk is generally defined as the possibility that an adverse event will take place and unfavourably impact the desirable outcome. In case of public procurement it might affect fairness, quality, cost, and time objectives Risk, therefore, can be conceptualized as combination of two factors, viz. the probability of occurrence of an adverse event and its consequences (Walaski, 2011).

Risk analysis aims at identifying, analyzing the different risks and responding to them (Koleczko, 2012). It enables the organizations to identify, assess, and manage to facilitate effective decision making. However, it's required to identify risk factors associated with each procurement phase, analyze their probability of occurrence and consider the potential impacts (Sorunke et al., 2016). In this regard, Enterprise Risk Management which is a generalized approach for organizations to assess and manage risks was first published by COSO (Committee of Sponsoring Organizations) in 2004. Subsequently, public organizations have built procurement risk management approaches by using three primary pillars, viz. procurement plan, contract award, and management (Richard Pennington, 2007).

Risks faced by organizations may vary from simple to complex ones. For many risks and associated causal risk factors, knowledge gathered from estimators, engineers, procurement professional and audit personnel will help in proper assessment and finding appropriate mitigation measures. Rather than being limited to identification of technical causes or individual failures, comprehensive risk assessment would entail technical, organizational and cultural recommendation (Manuele, 2008) because quantifications cannot account for all perspectives and thus provide partial insight. Therefore, qualitative judgement would remain an integral part of risk assessment as quantitative data can alone not describe complete risk scenario. The qualitative analysis facilitate integration of best practices from related field for mitigation of risk. Here, significant overlap found to exist between supply chain management, inventory control and public procurement. Risk perspective is being used successfully in various fields, viz. social, and physical sciences, medical and engineering. It's quite congruous with interdisciplinary approach which allows combining multiple theoretical perspectives. Combining multiple perspectives helps in developing the systemic view of the problem under study. It would also allow to build capacity and defence in the organization to address various risk present in the procurement process.

1.3 RATIONALE AND PURPOSE OF RESEARCH:

The relevance and rationale of the research efforts into PP can be easily appreciated by browsing the extent of money invested in public procurement by various governments as a key share of GDP and government expenditure in all the countries. As seen from the Figure 1.2, public procurement accounts for a large slice in the economic activities in both developing and developed countries. On an average, governments are spending 10-12% of its GDP on PP in developed countries. In developing countries, this rises to 15-20 % of GDP and might range from 25 to 40% of government expenditure. South Asia has the very high share of public procurement in GDP of about 19.3% and India procures 20% of GDP, (World Bank, 2016). As per another report of UNODC (2013), estimates of public procurement vary between 20% of GDP to 30% of GDP in India. In fact, there are ministries in the Government of India, where approximately half of their budget is spent on PP alone (UNODC, 2013). Thus, it is essential that the PP function is performed in a manner that secures best value for public money. However, efficient public procurement remains an under-exploited resource tool. The need of research effort is therefore necessary as the potential for improvement is quite enormous in terms of increase in efficiency, reduction in waste and achieving better outcomes i.e. value for money and also in promoting best practices.

A cost-effective value for money in public purchasing can help in saving valuable resources. In fact, small savings through improved performance of the public procurement can enable the government to relocate their resources to other valuable areas like heath and education for fostering the economic growth, and development, and supporting other policy initiatives. The potential savings and efficiencies' enhancement would be certainly higher for developing nations. In the past, value engineering, market forecasting, requirement consolidation, input standardization, open tendering, long-term contracting and vendor base expansion have been used as a cost reduction measures. PP constantly aims at finding better means of attaining these ends (Choi, 2010).

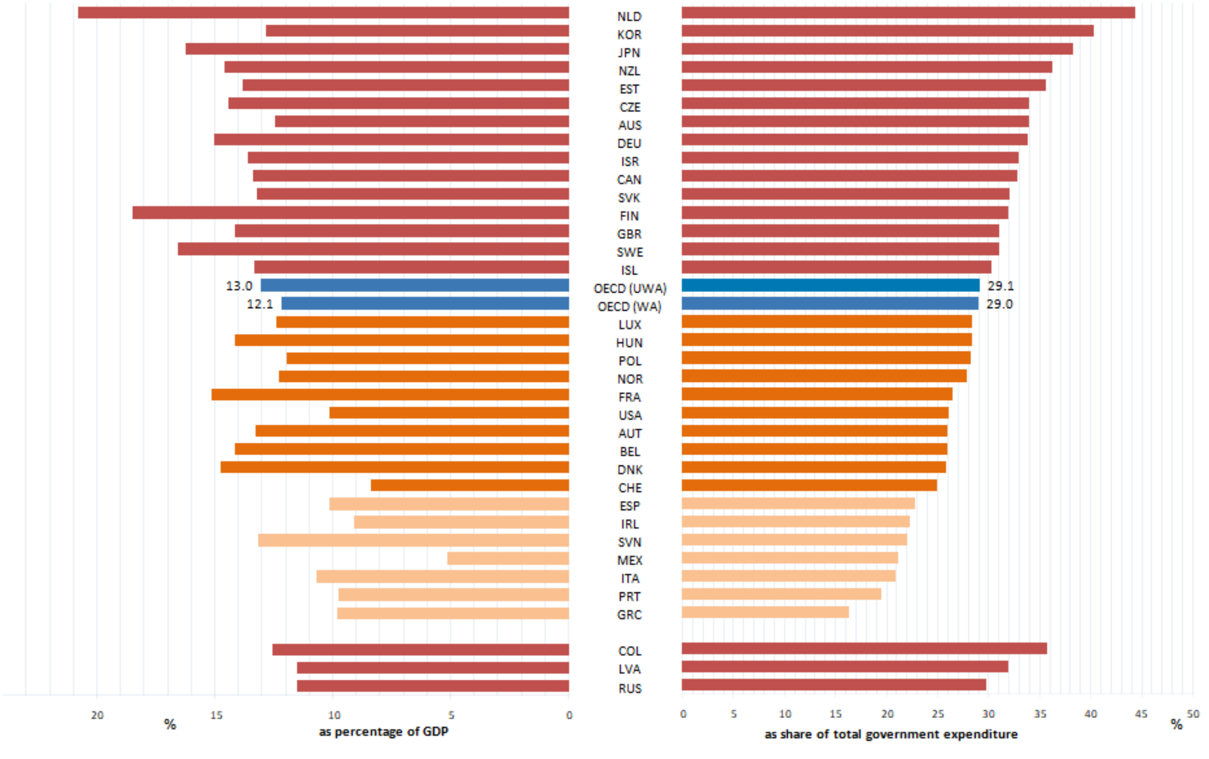


Figure 1.2: Public procurement as % of GDP and as part of the overall government expenditure

(Source: OECD Government at a Glance, 2015)

Apart from saving resources, public procurement regimes can impact the effectiveness of public service delivery, evolution of governance systems, pace of economic development, and ethical behaviour. As regards bribes for circumventing health and safety standard, Kenny (2006) documents that construction accounts for about seventeen percentage of fatal work sites accidents causing about 60,000 deaths annually across the world. TI (2011) reported that an earthquake caused 11,000 deaths in Turkey in 1999 and more than half of the structures were non-compliant with building regulations. PP rules and procedures can create a multitude of opportunities for bribery (OECD, 2009). Improving integrity and ethical behaviour in PP would help in achieving better procurement outcome and fighting the menace of corruption in the society. Reilly (2016) mentions that procurement corruption imposes huge costs resulting in market inefficiencies, business uncertainty, sub-standard products, and an unfair playing field for honest businesses. Other unwanted outcomes are; undue time and cost overruns, low quality, and poor investment returns (Locatelli et al., 2017). Risk of waste and underperformance is also a key concern in procurement process. However, it is possible for the organizations to undertake preventive steps for reducing and limiting these inefficiencies, and unethical practices. Therefore, this research aims at developing an organizational perspective of PP risks. It would help in relating the preventive efforts to issues and vulnerabilities in the organizations that can be generating the various risks in public procurement and consequent poor procurement outcomes.

These weakness and problems pertain to all the three phases of the procurement process and they are interrelated. Organizations are required to undertake in-depth analysis of the practices, routines and rationalizations (Gault, 2017). This study, therefore, aims at the providing a systemic view of these problems by developing an appropriate risk identification and assessment tools for analyzing their interdependencies and criticality. It would enable the organization to foresee the problems beforehand and undertake timely intervention for reducing the likelihood of unwanted outcomes like resource being wasted, misappropriated.

1.4 AN OVERVIEW OF PUBLIC PROCUREMENT

Public procurement is a cyclical process consisting of three key steps. It can also be conceptualized as three main phases as shown in **Figure 1.3**. In simple words, the process can be characterised as beginning from pre tendering activities which include set of important activities like assessment of needs, developing the procurement plan by combining the needs of various units in an organization for utilizing the economies of scale.

Figure 1.3: Public Procurement Phases

The first phase also includes defining the requirements of the work or goods by drafting the specifications. If specifications are very narrow or non-generic and requirement is made by tight tolerances, it may limit the bidders participation as such requirements would act as barriers. Consequently, it would affect the procurement costs. Another important pre tendering activity concerns with the decision making regarding choice of procedures. Organizations may opt either open tendering or limited tendering or negotiated procedures. Generally, open tendering procedures are adopted when procuring the quantities beyond a threshold value where any interested bidder can participate. Apart from ensuring transparency in public procurement, open tendering is expected to maximize economy and efficiency in public procurement by promoting healthy competition among tenderer. In the limited tendering, eligible bidders are either identified by using certain pre- qualification criteria or selected from a pre-approved list. In the negotiated procedures, procurement managers may carry out direct negotiations with specific bidders regarding quality standards and costs. This kind of procedure is usually adopted when procurement quantity is not very high or purchase is made at accelerated pace due to emergency situations. Direct contracting is another alternative procurement procedure which doesn't need detailed bidding documents. Here, suppliers are requested to give a price quotation or an invoice along with their sale terms and conditions.

The tendering stage actually involves mainly five activities; prequalification of bidders, preparation of tender documents, inviting the tenders and evaluation of bids and awarding the contract. Pre- bid meetings are usually held while preparing the bid proposal. Its main objective is to clarify any concern or doubt the bidders might have regarding the scope of work, bidding procedures and bid documents. Preparation of bid documents is a critical activity and consumes lot of effort and time. The tender or bid document should provide all the information which a prospective bidder may require for preparing his bid. Bid document generally provide information pertaining to scope of work, duration of the contract, eligibility criteria of bidder evaluation General and special conditions of contract, etc.

While inviting the tenders, it is required to ensure that widest publicity is given and adequate time provided for bidders to participate in the procurement process. It ensures transparency of the procurement process and helps in increasing the number of prospective bidders and intensifying the competition. The intensified competition is expected to provide the best possible quality and cost for the goods and services sought to be procured. In bid evaluation, procurement committee assess bid offers in respect of technical and financial criteria and undertakes a comparison of ‘technical suitability’ and ‘rate reasonability’ to determine the tender which represents the best bid or offer best value for money. They also verify and validate statements and documents submitted by the bidders of the most suitable bid. Finally, procurement managers would award the contract to the bidder whose bid provides the most economically advantageous offer for their organisation. A formal order is issued notifying the successful bidder requesting him to accept the contract award offer within stipulated time period.

Third phase involves drafting the contract, contract management, changes in the order, resolving the disputes and making payments. After awarding the contract, contract agreement should be finalized as because placing the contract with unambiguous and transparent terms and conditions is essential requirement for effective implementation. Though contracts’ conditions (general and special contract conditions) are finalized along with bid documents during initial phase, potential failures or risks that may crop up subsequently should be taken care of at this stage. Contract provides the basic foundation for exercising its effective management. Contract management refers to the procedures for ensuring that the contractor is executing the work or delivering the services as per the terms and conditions. It involves continuous monitoring and auditing for supervising the execution so that outcomes agreed are actually delivered by suppliers or partners. Attention is required to be paid to contract change orders. All contract variations need to be scrutinized individually as well as collectively before issuing the change orders. In case departmental expertise is not available, independent outside experts may be engaged for ascertaining the actual need of changes and estimating their financial implications.

1.5 ROLE OF PUBLIC PROCUREMENT:

Public procurement is an important business function of the government that may affect every section of society. As a business function, it aims at procuring required infrastructure like roads, power plants, hospitals and public services of appropriate quality at a reasonable cost. The role of public procurement is depicted in Figure 1.4 which highlights its significances.

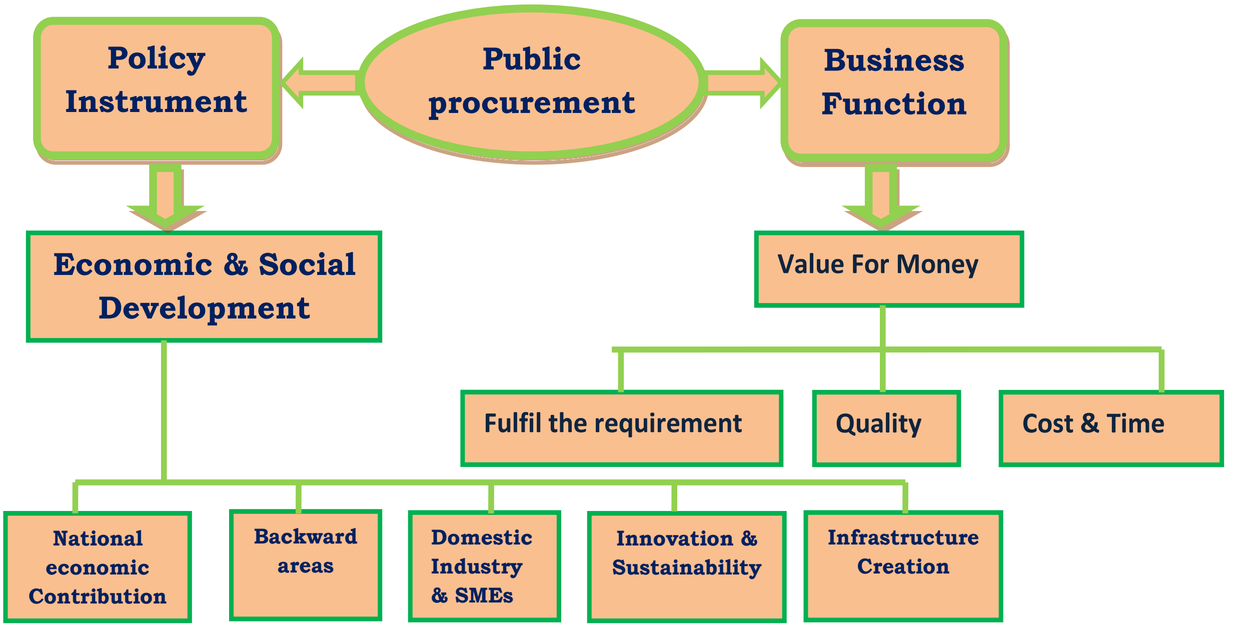


Figure 1.4: Role of Public Procurement

It also serves as a policy tool by the governments for achieving other social and economic objectives like development of domestic small and medium enterprises and fostering innovations. In essence, it is actually a central policy issue having key importance in the economy of all the countries across the world. This is evident from the fact that it provides goods and services for large section of the population and supports economic activities and private sector growth through infrastructure creation and development.

Public procurement generates a significant portion of overall demand for goods and services in a country and thereby can make a profound impact on a nation or industry. Therefore, investing efforts in building procurement capacities has the potential to bring about significant benefits. On the contrary, malpractice within public procurement is a government's major source of corruption and financial loss (Phillips et al, 2007) and there remains general dissatisfaction with its outcomes.

Thus, public procurement is said to be much more than a process or procedure. It is a fundamental and integral part of the governance and public financial system (OECD, 2005). A well-designed public procurement system can provide governments with a means of achieving other strategic goals, such as environmental protection, innovation, job creation and better labour standards. Effective procurement practices provide governments with a means of bringing about social, environmental and economic reform.

1.6 PROCUREMENT CONTRACTUAL ARRANGEMENTS: A BRIEF OUTLINE

Lump Sum Contracts or Fixed Price: Lump sum contracts are the contracts in which payments are linked to outputs (contract deliverables), such as reports, drawings, and bills of quantities, bidding documents, and software programs. These contracts are easy to administer because payments are due on clearly specified outputs.

Time Based Contracts or Fee Based Contracts: In case of larger value and relatively complex assignments or where the scope of the work or services cannot be established with sufficient precision or services are related to activities by others for which the completion period may vary, these contracts are used.

Percentage Contracts: In percentage contracts, fees paid to the consultant are estimated as percentage of actual project construction cost. The percentage may be fixed on the basis of market norms for the services, estimated labour, and material costs etc.

Performance Based Contracts: The focus of Performance Based Contracts is the purpose of the work rather than how the work is done. The contract sets out the overall cost for a particular service or works along with required quality standards, outcomes and outputs.

Design and Build Contracts: It is a project delivery base contractual system which is used in the construction industry. In this contract, design and construction services are contracted by a single entity thereby it is expected that contracting authority would have less risk in the construction of a large contract. Actually, the contractor is responsible for the risk of design failure or success in the contractual relationship.

Turnkey Contracts: This contract provides a single point of contact for all facets of the project namely; design, technology, installation and commissioning and the start up of the facility. Contractor completes a project and then hands it over in fully operational form. In simple words, owner needs to do nothing but "turn a key" for getting desired outcome.

Supply Contact: Public supply contracts are the contracts for other requirements than works – involving the purchase, lease, rental or hire purchase, with or without option to buying items/products. In addition, the delivery of such products may include installation and commissioning provisions.

Service Level Agreements: This is a contract between a service provider and the end user that spell out the terms of service that and supplier will provide and how the agreement will be monitored. They are usually drawn up for a specified time period.

Public Private Partnership contract: A Public Private Partnership contract is the contract where a public sector organization enters into an agreement with a private organisation to provide a public asset/infrastructure or deliver public services. The agreement clearly outlines the responsibilities of each party and clearly allocates risks among them. In these contracts, private partner bears significant risk and management responsibility and remuneration is linked to performance.

Works contracts: Works contracts are defined as those contracts which include either the work execution or both the execution and design of works. It generally involves construction, alteration, demolition, installation, or repair work; and preconstruction and post-construction activities.

Cost plus Contract: It is a type of contract agreement wherein the purchaser agrees to pay the cost of all labour and materials plus an amount for contractor overhead and profit (usually as a percentage of the labour and material cost).

1.7 PROBLEMS IN PUBLIC PROCUREMENT

Public procurement serves as an important function to provide required input for delivery of public services; typically goods, services and civil works. These inputs should be procured at low costs with appropriate level of quality to ensure best value for money. However, it has got unique problems and challenges which remain unaddressed. These problems are varied in nature and emanated from various factors embedded in different phases of procurement such as pre tendering, tendering and work execution activities. Literature review suggests that key issues pertain to unfair contract award, poor quality, excessive time and cost overruns, inadequate maintenance, low returns and project failure or abandonment. Other major performance problems are non conformance with agreed delivery time followed by not conforming to quality requirements by suppliers (Serpell and Heredia 2004).

Another significant issue pertaining to PP is that basic processes are not robust enough and procurement regulations and laws are not capable of offering remedial measures. (Thai et al., 2005). Basheka (2011) also found that organizational determinants are the major factors that account for the increasing trends of procurement corruption. As procurement reforms are beyond procurement regulations, organizational factors must be integrated into modelling for considering the ways and means of informing the procurement outcomes. Further, existing literature suggests that the cost of public investment and the value of existing capital may differ substantially and that up to the extent of the government investment in developing nation may be missing (Pritchett, 1996). Similar findings were suggested later on by Golden et al. (2005); Olken et al. (2007). Flyvbjerg (2007) studied a sample of 258 transportation infrastructure projects and found that the frequency of cost escalation was about 86% and that the average cost escalation was about 28%. Myller and Lessard (2000) also undertook a study on the performance of large scale engineering projects executed during the period 1980 to 2000. His study shows that about 40% of large scale engineering projects perform poorly leading either to total abandonment or restructuring for financial distress.

Awarding the contract in a fair and objective manner is one of the key steps for achieving the right price and finding eligible vendor who can provide acceptable quality. However, even with seemingly objective fixed criterion weight, it is still possible to create an unfair evaluation system by placing more emphasis on particular evaluation factors for favouring those bidders that score highly in the corresponding factors. In this regard Søreide (2002) identifies that procurement activity is particularly susceptible to corruption and found to be associated with invitation, pre qualification, and technology choice.

Solojentsev (2006) suggests that concepts of probability of bribes and corruption are close to reliability and safety in engineering and they are closed to the nation of risk in economy, business, and banks. Savage (2007) and COSO (2012) recommend use of Fault tree, Event tree etc to break a complex risk occurrence which can be qualitative and serve as basis for quantitative models. ICAC (2011) also suggests use of process mapping to understand the procurement process and the vulnerabilities as procurement process in most of the organizations has evolved over a period of time.

Effective risk management minimizes losses and negative outcomes and identifies opportunities to improve services to stakeholders and the public at large (Robillard, 2001). However, the first major issue with existing models is that they do not consider the interrelationship between various risk elements or causal factors. It is essential as the vulnerability in need assessment phase may result in avoidable wastage during execution. Another difficulty arises from the mathematical complexity of bidding model which limits their applicability and usefulness. The intricacies of procurement process and multitude of stakeholders make procurement process analysis and modelling a complex exercise. Thirdly, these models do not help in uncovering the vulnerabilities embedded in various processes which is essential for realistic risk scenario planning. Fault tree analysis can be used as an analytical tool to decompose the risk and establish the interrelationship between various risk elements which can also provide empirical foundation based insights for improving organizational controls.

As regards execution phase, problem mainly pertains to quality failures and difficulty in ensuring effective monitoring. In fact, the costs of quality failures may go up to 20% of a project’s contract value (Jafari et al., 2013, Abdul-Rahman, 1995, Nylen, 1996). The problem is more severe in case of infrastructure procurement where contractor and procurement officials interact repeatedly over a long period of time leading to cooperative strategies which may interfere with organizational goals. The problem arises because of several factors. Firstly, in case of large projects, due to large number of participants and fragmentation of activities, formal control system cannot be completely observed. In fact, formal control is replaced by informal procedures that provide flexibility and realistic phasing of decisions for handling the uncertainties (Wells, 2014). As a result, control and monitoring functions during project execution are usually exercised through decisions and actions of multiple human actors rather than formal controls.

Secondly, procurement systems working with lowest cost bid criteria often results in undesirable outcomes such as opportunism where suppliers may take the work at unreasonable rate and attempt to improve the profit levels on the project through reductions in quality of materials. Consequently, it would lead to poor quality assets and high maintenance costs. Thirdly, information asymmetry exists between owners and contractors in the performance stage of the construction project. Asymmetric information represents a situation in which one person has more or superior information than others. The owners cannot know whether contractors are following the contract strictly or adopting any shortcut. Similarly, supervisors do not have enough information about contractor's management technology, capacity and degree of subjective effort (Yan et al., 2014). This creates an opportunity for suppliers to take advantage by artificially increasing unit costs, using cheaper materials, withholding resources, deliberately underperform (Handley and Benton, 2012). It is quite common that construction contractor makes unnecessary design change, reporting of inflated quantity and supply of substandard material etc. Xiao et al. (2011) mention that with competition getting fiercer, profit of supervision became less and less therefore phenomenon of the collusion between supervision and contractor occur frequently during course of construction. However, the earlier studies (e.g., Lo et al., 1999; Zarkada-Fraser and Skitmore, 2000; Vee and Skitmore, 2003; Bowen et al., 2012; Sohail and Cavill, 2008; Ma and Xu, 2009; Hao, 2011; Auriol et al., 2011; Olusegun et al., 2011; Tabish and Jha, 2011; Goldman et al., 2013) have mainly focussed on bidding phase in the area of public procurement. Sometimes, supervisory unit may also fail to detect the poor quality and non-conformances while examining the work during project execution. As seen from the above examples and discussions, reasons for these risks may range from issues in control over the engineering quantity, safety and supervision/inspection regime to the moral risks induced due to procurement system characteristics. Game theory and evolutionary game theory models can help in analyzing these situations because their structure can be set up to be compatible with real world setting. Additionally, these models enable researchers making predictions about effects of changes in the parameters on performance outcomes. In a large project, due to lack of complete information, contractors and suppliers behaviour became dynamic as strategies yielding high payoff would spread and replicated more often through hit or trial learning, copying or inheriting strategies of others. Evolutionary game theory can incorporate these conditions for analyzing interaction of interdependent and interacting multi-agents.

Another unique characteristic of construction projects is that if the deficient work or poor quality material gets covered up and accepted in one stage, it would not be detected in subsequent inspections. When owner put adequate supervision effort continuously and exercise the contractual option to reject the defective work, quality would come in acceptable range but continuous inspection being costly is not resorted to. However, when supervision is relaxed, quality may deteriorate for contractor may even deliver goods below the specification and use shortcuts without being detected. These risks, if remain unaddressed cause deterioration in quality of the project thereby make performance uncertain. Such quality deteriorations will not be dependent on past history of quality and therefore make modelling a complex and difficult exercise. Due to unique feature of construction or engineering projects, these defects are going to stay and would reduce the project worthiness i.e. poor quality assets and high maintenance costs. Put simply, what happens at a given time during the construction phase of the project has an effect on the evolving risk profile of projects. Such variations can be modelled as to follow a geometric Brownian motion. In fact, Wiener process and the Gamma process are two classes of stochastic processes that have been widely used in degradation modelling (Noortwijk, 2009) as they can easily describe systemic behaviour.

This key insight needs to be included in the research work for appropriately modelling the quality variations for controlling and responding to performance uncertainties. The risk of contractual underperformance would depend upon cost of adequate monitoring the supervision unit and the contractor (Sharma et al., 2016). This implies that the fundamental issue of supervision design can be stated as to how effective supervision can be ensured without excessive spending. Actually, project management have inbuilt provision in the contract for rejecting deficient work, delaying the acceptance of substandard work until brought to acceptance level, abandoning the project, etc. However, these choices can be effectively exercised as costs of quality failures are considered in the modelling of monitoring strategies. As a result, there is a need of integrating major analytical methods into a coherent framework, which can be used to integrate the unique characteristics of quality uncertainty for providing an economic basis for decision making. This can help in achieving the value of the money in the projects and driving forces behind a new research direction.

1.8 RESEARCH ISSUES

Execution phase needs researcher attention especially because controls and monitoring mechanism here is found to be weak leading to increased risk of underperformance. It would take long time for sociological and political communities to undertake long term processes of cultural and policy changes to handle the corruption (Locatelli et al., 2017. The establishment of mechanism of auditing, oversight and control can be costly and time consuming therefore an appropriate system for identifying opportunity of corruption must be devised (Anderson et al., 2012). Risk analysis methods may help in discovering the vulnerabilities or risk factors in the system and applicable to procurement where objective data is available. Therefore risk perspective in public procurement needs to be high on research agenda list. However, while adopting risk approach, it is required to be considered that identifying risks like an auditor in a check list manner would not help in developing the holistic perspective and finding remedial measures. Similarly, quantitative analysis alone does not develop broader picture and nor it provides empirical basis for risk mitigation.

A part of the explanation for poor construction outcomes in low-income countries relates to mismanagement, but corruption is also an issue that has to be addressed (Wells, 2014). Several factors may give rise to performance failures. For instance, estimating errors may lead to the acceptance of unrealistically low tender prices, which means insufficient funds in the contract to deliver to the specification. Multiplicity of causal factors, interdependence and complexities of processes need an interdisciplinary research effort to borrow knowledge from other disciplines. Supply chain philosophy, Safety, disaster management can be of great value by providing new insights and practical conditions which need to be incorporated in modelling for realistic risk assessment. Being a socio-technical system, an organization is affected by three pivotal elements, viz. a technological subsystem, personnel subsystem interact and the external environment. In fact, supervision quality has a major influence on the overall performance and efficiency of construction projects. Thus, factors like human capability and limitations need to be included in analysis otherwise analysis would most likely yield suboptimal results. Further, Supply chain perspective highlights the dynamic nature of human behaviour and prevalence of incomplete information in the large projects thus research should observe as to how evolutionary strategies of various participants get stabilized. However, there exist few researches which explore the collusion of main body of construction project by using evolutionary game (Wen et al., 2014). It would help in structuring the organization policies, procurement mechanism and resources in a way that creates the scope for maximising the potential.

Another major concern pertains to uncertainty in the project performance which arises due to various factors like corruption, characteristics of procurement system and capacity constraints. It is the fact that quality of project works would vary according to the contractor's performance on the site and the materials used during construction. If the quality of material and construction on the project is ensured by monitoring and proper supervision during construction, the asset created is likely to last longer without rework or failure. However, literature review demonstrates a gap in the incorporation of a dynamically scheduled inspection policy that reduces the monitoring costs, risk of collusion and corruption in construction projects. Thus there is a need of modelling the monitoring strategies, quality failures and project value so as to provide an economic basis for exercising various options project owner can exercise. In this context, some of the research issues which are highlighted by the earlier scholars are :

(i) Study and Development of effective vendor selection methods,

(ii) Risk analysis in public procurement,

(iii) Developing of effective inventory and Construction Supply Chain Management,

(iv) Study of unproductive and wasteful practices in Public procurement, and

(v) Study of Public expenditure management.

Due to the scant attention of the scholars on risk analysis issue, the present research work focuses on the risk analysis in public procurement in the Organizations.

1.9 OBJECTIVES OF RESEARCH WORK

Keeping in mind, the above-mentioned research issues, the research objectives are set as follows:

(i) To conduct a comprehensive review of literature pertaining to public procurement, inventory management practices, supply chain, unethical behaviour, risk assessment techniques, and project performance;

(ii) To identify risk factors and their effects on public procurement;

(iii) To develop a comprehensive risk model by considering external as well as internal influencing factors in public procurement; and

(iv) To model monitoring strategies, quality failures costs for reducing underperformance risks in the contract execution phase.

On the basis of the objectives as mentioned above, the research methodology and framework is developed and discussed in the following sections.

1.10 RESEARCH DESIGN

In the theoretical framework of this research, corruption is considered as both an analytical concept and an empirical phenomenon. As an analytical concept, it allows us to uncover the vulnerabilities to corruption embedded in procurement process and serves as a tool for applying the quantitative methods like evolutionary game theory, real option theory and wiener process based real option modelling. Actually studying corruption at the empirical level, made it possible to develop a systemic perspective of problem and simulate more real-life scenarios and practicalities of public projects in the modelling of impact of corruption risks and performance. By studying PP cases and practices, we gain interesting and important insights into the dimensions of procurement risks. This also helped in uncovering the preconditions embedded in organizational functions and processes for corruption and the circumstances under which it can thrive. It is considered as a good practice in research to clearly spell out the basis of knowledge gathered. In order to ensure quality of the research work in terms of validity and reliability, it is essential to use appropriate methods. Therefore, an integral part of the research work is noting the reflections made from time to time concerning methods and the philosophical implications on the research. In fact, the research design work begins with identifying the research paradigm, ontological position and epistemological stance. These reflections should be made for developing awareness about the paradigms that the research is founded upon. If these issues are neglected, researchers may end up making inappropriate choices. By understanding the purpose of research and specifying research questions, it became possible to discuss the underpinning philosophical assumptions.

1.10.1 PHILOSOPHICAL UNDERPINNING AND CHOICE OF METHODOLOGY

Lincoln et al. (1998) suggested that a research inquiry should be based on the concepts of ontology, epistemology and the methodology. Methodology choice would depend on what problem we are studying. However the research problems, that are examined, are experienced in different ways depending on the researcher’s assumptions about the world. In simple words, researcher’s assumptions about the possible realities and relation between knowledge and the world can be considered as research paradigm. Morgan (2007) refers to paradigms as systems of beliefs and practices that influence how researchers select both the questions they study and methods that they use to study them. Traditional approach considers two main paradigms i.e. positivism and interpretive (Remenyi et al., 2005; Huczynski and Buchanan, 2007). While some researchers (Crotty, 1998; Sayer, 2000; Saunders et al., 2009) have identified four paradigms namely; positivism, realism, interpretivism, and pragmatism.

However, a research paradigm is intrinsically associated with the concepts of ontology, epistemology and methodology (Crotty, 1998; Saunders et al., 2009) **as shown in Figure 1.5.** Ontology is concerned with the form and nature of reality. The distinctions within ontology range from ‘realism’ through ‘internal realism’, to ‘relativism’ (Marsh and Furlong, 2002;

Collins, 2010). Epistemology offers a general set of assumptions about ways of inquiry into the nature of the world (Smith et al., 2012). Researchers can adopt epistemological stance of positivism at one end and phenomenological epistemology (interpretive) stance at other end of continuum. While Realism or objective ontological assumptions will favour an epistemological consideration of positivism, subjective ontology would encourage a phenomenological epistemology.

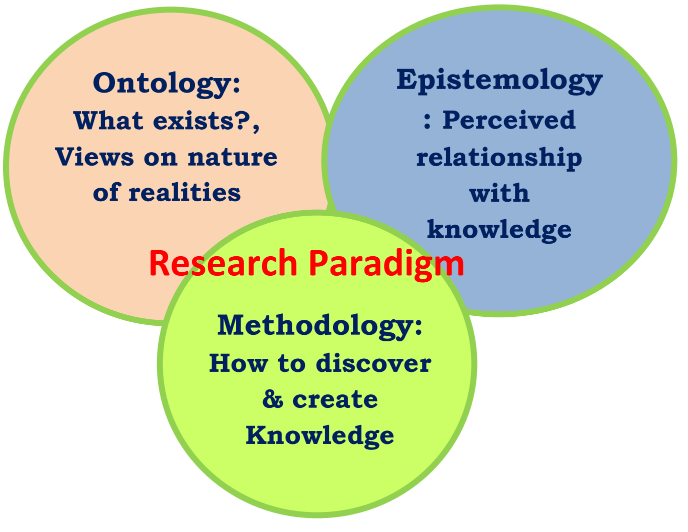


Figure 1.5 Research paradigm elements (Adapted from Saunders et al., 2009)

This research deals with issue of corruption risk. However, risk is something that is unknown or has an unknown outcome. Estimation about occurrence and severity of risk most of the time turns out to be subjective one. These probabilities can be very rarely known with certainty. In fact, knowledge about risk is knowledge about lack of knowledge. Considering these key characteristics or realities, it is appropriate to adopt a middle position in ontological assumption and a middle-range viewpoint on the epistemological stance for this study. Moreover, any economic or technological exchange or work execution is a socially constructed phenomenon and a part of objective reality. Such a phenomenon can therefore be studied by adopting mixed method approach in the research methodology. Consequently, pragmatism is considered the most appropriate research paradigm for our study.

The methodological choice in this thesis is therefore to use mixed methods research where the quantitative and qualitative methods are combined together. Applying a combined theoretical approach and using different data sources and analytical methods allow us to develop a fuller picture and better understanding of the phenomenon. Thus this approach also suits to understand and analyze research problem. In this regard, greater justice will be done by using the combined approach in a study of such a multifaceted phenomenon as PP and that by so doing it will enable comprehensive analysis. However, the research study moves from a qualitative to a more quantitative-oriented analysis as the research work progresses.

1.10.2 RESEARCH FRAMEWORK AND METHODS:

With a view to illustrate the research process, a conceptual research framework is developed on the basis of chosen ontological and epistemological stances and research paradigm. The framework is presented in **Figure 1.6**. This framework elaborates the relationship between different phases of research, research methods and objectives.

Data Collection Studying corruption in itself is difficult as corruption is an inherent secret phenomenon, difficult to observe. Moreover, the problem gets compounded as corruption is complex and multilayered phenomenon involving multiple actors. Therefore the access to data poses difficulties. As this research effort being interdisciplinary in nature, literature on risk assessment based concepts were referred from other disciplines like safety, disaster management and economics. While borrowing concept of risk from safety management field, it is noted that Schröder-Hinrichs et al. (2011) documents that one of the main sources of the evidence that is available and can be used for evidence-based safety risk modelling is accident reports that are prepared by expert accident investigators.

Since obtaining primary data about an accident that has happened in the past is nearly impossible, using accident reports as a secondary source of data is unavoidable (Mazaheri et al., 2013). Similar difficulties exist in corruption studies. It is therefore appropriate to use past corruption cases as data. Models based on the intuition of the developers rather than the evidence may not tender useful input for risk mitigation. Lack of background knowledge about the underlying causes of a system or improper presentation of the available background knowledge leads to uncertainty in the used risk models (Aven and Zio, 2011). The main difficulty and criticism of evidence based approach is related to the analysis of a huge amount of qualitative data where no standard analysis approach exists. As Grounded theory studies use rigorous data coding procedures designed to increase the validity of data interpretation (Douglas, 2003), this research uses grounded theory for analysing past cases.

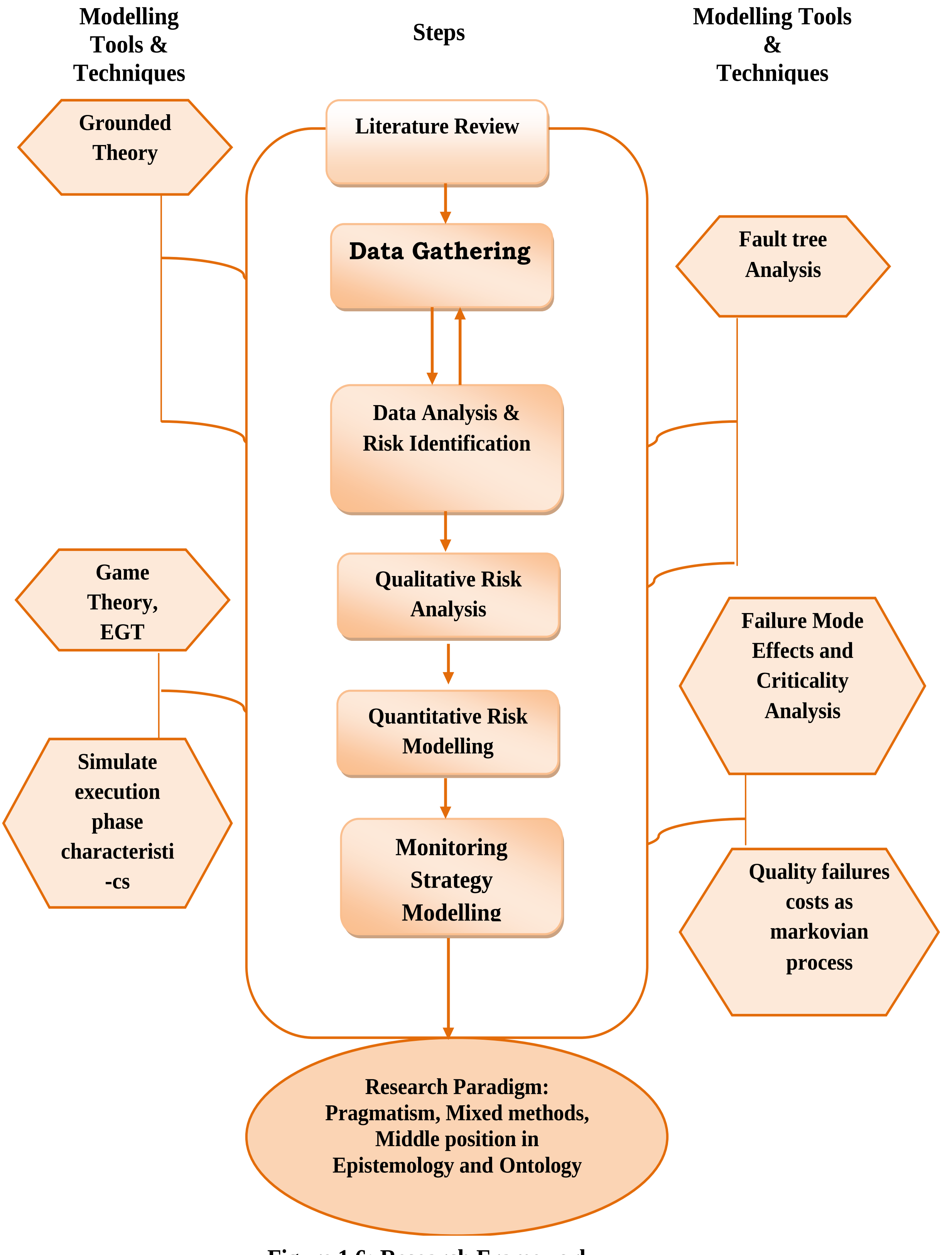


Figure 1.6: Research Framework

The other reason for choosing the Grounded theory is that it suits well to or research philosophy. This study adopted a middle position in ontological assumption and chosen a middle-range viewpoint on the epistemological stance. Grounded Theory Method (GTM) also articulates a middle ground between *"extreme empiricism and complete relativism and uses which systematic data collection to develop theories that address the interpretive realities of actors in social settings"* (p.634, Suddaby, 2006,). Therefore, Grounded theory suits to subject topic. In fact, a similar approach was adopted by Turner's (1976) in his study of the conditions under which failures of organizational foresight can contribute to the incidence of large scale disasters.

Data Analysis: A notable advantage of the GT method is in its systematic approach to data analysis. Systematic procedures such as simultaneous collection and analysis of data and the constant comparative logic and theory that emerges from data provide GT with rigor that is not accounted for in other qualitative approaches (Charmaz, 2006). There exists simultaneous involvement of researchers in data collection and analysis activities. During the data analysis, if a researcher finds the need to collect additional data, he again enters in data gathering phase to collect the same. It continues till the point of theoretical saturation i.e. researcher continues data collection process until no new categories can be identified, and until new instances of variation for existing categories have ceased to emerge i.e. theoretical saturation has been achieved. GT uses rigorous coding, constant and memo writing procedures to improve the validity of findings.

Other methods used in data analysis are described below;

Fault Tree Analysis: The FTA is a deductive failure analysis developed on the principle of multi-causality. It is a top-down deductive model that traces failure paths and shown as a graphical representation of a process failure connected to its causes through logic gates. It was initially developed for analyzing technical systems where causes of failure events are deduced. Subsequently, its application has been widely extended. Authors find FTA as an appropriate methodology to analyze various procurement risk as it provides an effective approach to the identification and deconstruction of risk and uncover the interrelationship between risk elements. Secondly, it enables us to combine inductive and deductive reasoning in risk identification. It is very important as the concept of cause-consequence analysis is a combination of the inductive and deductive reasoning of logic diagrams (Yaneira, 2013). Therefore inductive and deductive processes are not mutually exclusive in our research enquiry and form an integral part of the mixed method approach. If deductive methods alone are chosen for constructing Fault tree, some of the failure contributors may get omitted. In fact, FTA is often used when another technique had identified a hazardous situation that requires more detailed analysis (Manuele, 2008). It is therefore felt appropriate to use output from grounded analysis to develop Fault trees for analyzing risks in the PP process.

Game Theory: Game theory is simply analyzing strategic behaviour of players that will affect the actions of other agents. In game theory, the objective is to find an appropriate strategy or the optimal sequence of decisions that leads to the highest payoff. Game-theoretic model is chosen as a quantitative method in this research as theses adhere to the principle of methodological individualism (Requirement that causal accounts of social phenomena explain how they result from the motivations and actions of individuals) and because of their strictly logical nature they become testable. A game theory approach is preferred as it can effectively clarify the basis for decisions of procurement officials to pursue individual goal rather than organizational interests. Further, it explains as to why unethical practices become systemic and widely prevalent despite their unwanted outcome remain "common knowledge". This condition seem to have a case of an extremely robust negative equilibrium (Bardhan, 1997). As a result, none of the "players" in such a game have reasons to change their strategy. It is therefore argued that it is possible to combat corruption by changing incentive structures in the organization and tackling the problem of contractual underperformance in the projects.

Evolutionary Game Theory: From the literature (e.g., O'Brien, 1999; Proverbs and Holt, 2000; Serpell and Heredia, 2004; McDermott et al., 2006), it is found that supply chain philosophy is being adopted to improve the performance of the large projects. However, presence of large number of players and resultant fragmentation tends to weaken the integration force. As a result, central coordination and control is replaced by decisions and actions by multiple players in case of large projects and assumption of rationality became unrealistic. The behaviour became dynamic in nature and reflects limited rationality i.e. individual may learn from others or through trial and error before opting the more successful strategy. Somehow, however, this insight had not previously been applied in the past models. Our insight was that strategy adjustments may take place which will be largely driven by additional information that should be taken into consideration. Evolutional game theory is therefore considered appropriate to analyze the problems as it can deal with dynamic environment characterized by player's lack of complete information.

Quality Failures Cost Modelling : Uncertainty in the project performance comes from many sources and often involves many participants in the project (Hendrickson et al., 2003). The problem multiplies with the size of the project as uncertainties in project outcome increase with size (Dey et al., 2002). However, its impact diminishes by risk management, specifically by decision-making (Antunes et al., 2015). An economic basis is required to develop an effective policy dealing with performance uncertainty. In this regard, Geometric Brownian Motion (GBM) process can be used to model the cost of quality failures which can facilitate modelling of quality failures and monitoring strategies. GBM is a type of Wiener process that has been frequently used in various disciplines, such as supply chain management, biology, physics, economy, financial engineering and stochastic calculus (Hsu & Wu, 2011). Wiener process is in essence a series of normally distributed random variables and can capture the performance uncertainties arising out of collusion, opportunism and underperformance in construction project. The Brownian motion might be used universally as a consequence of normal distribution of random variable and its application capabilities (Valis, 2014). It may help in modelling costs of quality failures to reducing the performance uncertainty and risk of underperformance. Public organizations can effectively use such model as an important value-adding part of project management. These models can provide effective method for monitoring the project worthiness to exercise the option to delay the acceptance or abandon the project depending upon the cost of quality failures or worthiness of the project.

1.11 OUTLINE OF THESIS:

Chapter-I provides a brief account of evolution of organizational structure and controls and highlight the need of developing an appropriate risk identification and assessment tools for analyzing procurement risks for achieving better procurement outcomes. It, then, introduces various kinds of problems in public procurement. Providing a brief description of various phases of public procurement cycle and the procurement methods along with type of contracts and justifying the requirement of a detailed study of various phases of procurement and monitoring of projects performance. This chapter highlights the primary and potential area of the research. Developing an analytical method of identifying the risks in public procurement and operationalizing the interrelationship between risk elements along with assessing the risk of collusion and corruption in the work execution phase and finding risk mitigation measures are the basis objectives of this research work. Keeping these objectives in perspective, this chapter elaborates on philosophical orientation of research methodology and develops a research framework.

Chapter-II presents a comprehensive and up-to-date review of relevant literature associated with various risks in PP. An extensive review of papers in Journals and conference, texts and reference books has been carried out to develop an understanding of public procurement process, and identifying associated research challenges. It analyzes various counter productive work practices prevailing in PP, reviews literature pertaining to project performance, and inventory management practices and examines existing risk assessment techniques. Unethical practices being one of the unaddressed issue in PP, it systematically reviews the problem of unethical behaviour in public procurement and draws the knowledge from the review of unethical behaviour in the organizations and related methodological issues. This chapter presents theoretical foundation of PP and develops an organizational perspective of PP risks. It borrows knowledge from several well established disciplines dealing with risk assessment by adopting interdisciplinary approach and combines earlier research findings meaningfully to identify useful risk analysis techniques and provide valuable direction for conducting a comprehensive risk analysis in public procurement. The risk assessment techniques, found useful in this context, are integrated in subsequent chapters to build a systematic risk analysis approach for analyzing risks in PP. In particular, review of literature clearly indicates the following research areas:

(i) a need to develop a risk identification method for extending risk assessment exercise to wider section of activities undertaken by various organizations,

(ii) a need to better operationalize the elements of risk analysis and interrelationship between various risk factors,

(iii) a need to focus on the analysis of contract management phase of public procurement cycle to lessen the underperformance risk,

(iv) to draw the policy inference to mitigate the procurement vulnerabilities and strengthening the controls,

(v) to develop the inventory of opportunity of corruption and opportunism embedded in the various functions and processes, and

(vi) to develop more efficient monitoring methods to reduce the performance failure risks arising out of unethical practices like collusion and opportunism and contract capacity factors.

Chapter-III focuses on vulnerabilities embedded in the functions and activities associated with the procurement in the organizations. It methodizes a systematic risk analysis approach that combines risk management approach of fault tree analysis (FTA) and Failure Mode Effects and Criticality Analysis (FMECA) with the grounded theory (GT) method for mapping various risks in the public procurement. This chapter provides a unique approach for breaking the risks into risk elements and operationalizing the inter-relationship for making the analysis and modelling possible. Considering the implications of unethical behaviour in PP, this approach is applied to unethical behaviour in PP. Following analytical procedures of Grounded theory, 866 useful codes emerged that were subsequently condensed, aggregated, and clustered into 274 axial codes leading to the formation of seven core categories. The knowledge build through grounded application is used to construct the fault tree. It then uses minimal cut set method to simulate the possible multiple pathways that may lead to unfair contract award. Thereafter, FMECA is applied for finding out the criticality score for risk factors involved in basic events and finding mitigation measures. The criticality analysis computes criticality numbers (C_r) for each risk factor for ranking them. It also provides empirical foundation based insights about several critical risk factors and deduces relevant practical insights for strengthening varied aspects of organizational controls for reducing the likelihood of unwanted outcomes. It also provides valuable input for improving procurement activity through efficient material management practices. This concept of modelling and representation can is flexible and can be replicated in other situations ranging from analyzing failures in other fields like project failures and inefficiencies in new forms of organizations.

Chapter-IV elaborately discusses the characteristic features and practicalities of execution phase in large projects. Contract execution phase plays a critical role in achieving the desired level of contractual performance. Therefore, we use socio-technical system concepts to improve our understanding of the problem of execution phase and identify the factors influencing the performance. As learned from literature review, several harmful and counterproductive work practices, are affecting the project performance. These work practices are organized on the basis of their broad consequences which gave two important insights. Firstly, these harmful practices might result either in safety consequences or in non-safety consequence. Thus, a different penalty structure is introduced for safety and non-safety consequences in the analysis. Secondly, contractors may choose strategically to behave opportunistically or underperform without colluding with supervision units. Consequently, contractor's strategy space needs to be extended for comprehensive analysis otherwise it would lead to suboptimal solutions. Describing these practical considerations and empirical insights, a zero-sum finite game is developed by introducing the above factors and considering contractors' extended strategy space to assess the risk of underperformance, collusion and opportunism. The model identifies six important risk factors and facilitate effective conceptualization of underperformance risk scenarios. Inferences are also drawn for mitigating these risks by structuring organization policies and changing incentive structures in the organization.

Building on these findings in a sequential manner, we draw the knowledge from supply chain philosophy and find that contractor, supervisors and manager's behaviour is dynamic in nature and reflects limited rationality as they may learn the strategy that is more successful. To include the dynamic environment characterized by player's lack of complete information, Evolutionary Game model is developed to study the problem of underperformance and conditions of stability of evolutionarily stable strategies are derived and analyzed. Using this model, we simulate the effects of variables with the replicator diffusion equation to provide insights about the relationships between variables in these models and their impact on evolutionary outcomes. Further, control and monitoring functions during project execution are usually exercised through decisions and actions of multiple human actors rather than formal controls. Consequently, supply chain evolves with manager's decision making; the study therefore provides important insights for improved decision making for managing project supply chains. Several countermeasures are proposed which would help in improving the owner's strategies for handling the disruptions in the flow of work and creating the scope for improved performance potential. In addition, it also lays the foundation for more complex explanatory and predictive tools applicable to work execution phase in future studies. In essence, both EGT model and Game theory models complement each other to comprehensively analyze the execution phase.

Chapter-V extends the work by furthering the analysis on the policy conclusions drawn in Chapter IV and discusses the concept and types of wiener process and monitoring strategies. This chapter also outlines the unique nature of construction work and explains the need of appropriately modelling of costs of quality failures and project value. Enhancing the effectiveness and efficiency of project governance requires determining numerous parameters such as inspection frequency and rework penalty structure, assessing project worthiness and so on. Literature review reveals that existing project governance methods attempt to hedge the risk of performance failures by financial instruments like performance bonds and securities which can be forfeited in case of non performance. Project owner can respond to poor quality work by exercising various options like terminating the contract or deferring the acceptance depending upon cost of quality failures. However, exercising these options necessitates development of an economic basis for timely decision making and carrying out an efficient monitoring of quality failures in the project execution. This in-turn requires appropriate modelling of the quality failure costs and monitoring strategies.

Parameter uncertainty therefore remains a major issue in deciding monitoring system. In case of construction projects, performance uncertainties results from several factors such as risk of collusion and contractors' opportunism and capacity constraint in the project execution.

Contractual performance may either improve or deteriorate independently depending upon the work done and material used. Hence, quality cost variation over non-overlapping time interval are considered to be independent. It implies that if present value of the quality failure is high, asset value will be less. Future states depend on the Present state. i.e. quality failure cost to be Markovian in nature and follow GBM (Cui et al, 2004). Considering these aspects, costs of quality failures is modelled as Geometric Brownian Motion for analyzing various monitoring strategies. It begins with basic analysis of random inspection, continuous inspection and their combined inspection strategy which shows that owner can effectively reduce the risk of under-performance by employing the strategy combining continuous and random inspections and engaging internal and external supervision agency. Subsequently, it develops a model for quality failures and monitoring strategies by considering the interactions of monitoring, quality failure costs, and project value and characterizes the circumstances describing optimal monitoring. It also studies dynamic monitoring policy involving dynamic scheduling of inspections and deduces conditions for optimal monitoring. This analysis shows that dynamic policy would reduce the fluctuations in quality failure costs. The chapter presents a useful theoretical model that is expected to provide a consistent basis for timely decision making for improved project management and facilitate a richer assessment of risk of underperformance.

Chapter VI presents the summary of major findings and conclusion of the research work undertaken. It also lists the specific contribution of the research work in the area of assessment and mitigation of various risks in PP and project performance monitoring. It also includes the explicit areas where future research is to be carried out.

The thesis ends with a list of references and a set of appendices.

Chapter

2

REVIEW OF LITERATURE

2.1 Introduction

Public procurement (PP) remains an underutilized policy and business tool. Though governments and public procurement practitioners have worked for improving PP practices in the recent times, procurement outcomes still remain far from satisfactory. Factors contributing to suboptimal results are embedded in the complex web of organizational policies, procurement processes, vendors, and contractors, etc. Sometimes, these factors act in an inter-related manner as the PP is complex and multi-phased activity involving multiple stakeholders. The PP as business operation of the government generally impacts many different elements of society (Agbiboa, 2012). Despite its centrality to public service delivery, PP has remained on the periphery of management sciences (Flynn and Paul, 2014) and stayed as a neglected area in academic education and research (Thai, 2001).

Recognizing the importance of public procurement, researchers from different backgrounds have recently focused their attention on the subject. There are numerous lines of enquiry and diffuse nature of research in the public procurement (Flynn and Paul, 2014). Traditional view classifies public procurement as a routine and mundane function involving clerical means (Snider, 2006). Several scholars like Gordon et al. (2000); Thai (2001); Snider (2006); and Fernandez (2007) have considered it as a critical administrative function and underlined related unique issues and problems. For instance, Ni and Bretschneider (2007) have documented the increasing complexity of public procurement. Similarly, strategic nature and importance of public procurement have been effectively emphasized in the recent literature concerning with public policy (Thai, 2001; McCue and Gianakis, 2001; Lloyd and McCue, 2004; Matthews, 2005; Thai, 2005; Snider, 2006). Bolton, (2006) points out that it can be used as a policy tool to meet other secondary objectives. No agreed-upon success factors for PP are found available in the existing literature. Multiple goals and diverse notions of the public procurement are evident in literature. To sum up, there is a lack of conceptual and theoretic coherence within the understanding of PP (McCue and Prier, 2007). Further, clarity about the scope and breadth of activities encompassed in the public procurement activities is also lacking in the present body of literature. In fact, Lloyd and McCue (2004) record the inconsistencies in the body of existing knowledge and even in the terminology used to define Public procurement.

Essentially, challenges that are attempted to be addressed by recent procurement reforms are mainly concentrated in the procurement bidding and award phase. These measures are primarily concerned with institutional design challenges such as bringing transparency in tendering, competitive bidding and defining proper role for rules and discretion in the process. As a result, problems surrounding the post-award activities stayed unaddressed. Similarly, EU report records that while the control mechanisms pertaining to pre-tendering, tendering and award phases have improved, the implementation phase is less closely monitored (European Commission 2014). Compared to earlier phases of procurement cycle, the challenges of reinventing contract administration are mainly challenges related to human resources management and job design (Kelman, 2003) and understanding the harmful and counterproductive practices and efficient work monitoring.

Sufficient efforts are required for conceptual theorizing to aid researchers and professionals in making sense of its complexity, uses, and limitations (Snider and Rendon, 2008) so that effective remedies having practical relevance can be designed. This need of developing the theoretical understanding about its complexity becomes further essential for addressing the problem of unethical behaviour and practices in PP as it's one of the government activities that is most vulnerable to corruption (OECD, 2016). Contracting may occasion a whole range of corrupt practices, including nepotism, favouritism, and kickbacks (Rosenbloom and Gong, 2013). Public procurement corruption therefore emerges as another vital challenge for researchers. Many countries and international organizations are adopting coordinated measures to curb it (Petrou and Thanos, 2014). In general, despite extensive research attention and the numerous corrective efforts, effective and sustainable measures to reduce corruption have proved elusive (Misangyi et al., 2008). Judge et al. (2011) pointed out that this rather large and growing literature has failed to provide deeper insights and understanding because of the generally a-theoretical nature of the work and the failure to look beyond one's disciplinary lens. Therefore, this research adopts an interdisciplinary approach and reviews the literature on organizational viewpoint of corruption also to develop a comprehensive procurement risk perspective .

It is worth mentioning that recent emphasis on concept of value for money and efficiency, New Public Management (NPM) and its regulatory reinvention initiatives have impacted public procurement research arena. These aspects revised traditional buyer-seller relationships in the provisioning of public works, goods and services by adding the market orientation and shifting the concern from equity and scrutiny to efficiency. Accordingly, rules and discretion are also reviewed by scholars (Kelman, 1990; Schooner, 2001; Kelman, 2002; Bergman, 2013; Boulemia and Moore, 2014; Gutman, 2014) from the perspective of efficiency and flexibility of procurement managers. These developments are also affecting the way organizational processes are organized and various works are executed in the field. One of the main visible change is the projectification trend across all the industries that are affecting how the work is being carried out. Presently, across all the industries, organizations are realizing that traditional organizational structures are no longer adequate for ensuring high volumes of output of standard products and services (Davies, et al., 2006). In today's uncertain environment, organizations are finding that some form of project organization is better suited to the kind of their business requirement they face (Maylor et al, 2006). Miller and Lessard (2001) further suggest that projects are now getting more complex and widespread. It implies that there is need to understand the basic issues associated with project form of organization so that effective measures may be devised to improve the work execution phase.

The remainder of this chapter is structured as follows. First, it discusses the conceptual background of public procurement. Next section 2.3 presents literature review on the counter productive work practices, problems and difficulties associated with public procurement. Then, it highlight the relevance of good inventory management practices for improving procurement performance . Section 2.4 reviews the problem of unethical behaviour in public procurement in particular and draws the knowledge from the review of unethical behaviour in the organizations and related methodological issues. This section then summarizes the findings and inferences into unified themes and conceptualizes the vulnerability. Section 2.5 identifies the methods which can be applied in analyzing the risks in PP. Finally, we present conclusion and suggest fields for future research.

2.2 PUBLIC PROCUREMENT : MEANING AND CONCEPT

Public procurement is a complex activity. It concerns with providing required inputs for delivering different public works, and services. These goods and services are to be procured at appropriate cost with optimum levels of quality. In the private sector, the term purchasing was conventionally used (Lee and Dobler, 1977) for a set of widely ranging activities associated with procurement. Recently, it has acquired the broader term of supply management, which highlights the boundary-spanning roles of today’s private sector purchasing managers (Snider, 2012). Consequently, PP embraces wide ranging activities like determining price, delivery schedule, and quality standards. Considering the complexities involved in PP, Thai (2001) emphasizes that it should be viewed as a system of systems.

In general, multiple terms are used to refer to PP such as "purchasing,” “contracting”, “acquisition" and "buying" etc. It employs a wide range of means by which public agencies acquire works, supplies and services from outside sources (Snider, 2012). Consequently, there exist definitional ambiguities which become a concern (Llyod and McCue, 2004) especially as regard to which activities are encompassed by PP process. In this context it is necessary to review the literature dealing with concept and definition of PP and issues pertaining to procurement practices. PP is defined by American Bar Association’s (ABA) as buying, purchasing, renting, leasing, or otherwise acquiring any supplies, services, or construction. According to this, PP incorporates all the functions that are related to the acquiring any supply, service, and construction work. Stated simply, it embraces activities like defining the requirements, selection and solicitation of sources, preparation and award of contract, and also the contract administration. This definition resonates with usage of the term in the first issue of

Journal of Public Procurement, in which “procurement” includes acquisition, contracting, buying, renting, leasing, and purchasing, and also encompasses functions pertaining to requirements determination and all phases of contract administration (Thai, 2001).

As regards the above definitional ambiguities, Llyod and McCue (2004) note that some of the definitions include “before” actions such as (i) defining requirements, and (ii) participating in capital planning, while other definitions include “after” actions such as (i) inventory control (ii) warehousing, and (iii) surplus property sales. The debate regarding inclusion of certain before and after actions seem to be generated by the concern that these activities if included would make it mandatory for procurement officials to acquire the related knowledge and capabilities. However, it is worth noting that these actions surely affect the PP outcome. Therefore, study to improve PP practices cannot afford to ignore them in the analysis.

The above discussion highlights that public procurement system is a complex and dynamic system where procurement outcome depends upon interdependent decisions and behaviour of multiple entities. Realizing this aspect, Thai (2001) states that PP system cannot be understood either in terms of their elements or parts that make up an institution. Rather, it should be understood in terms of the emergent property of the combined parts of PP system i.e. when these parts are combined in a particular way to make a structured whole for PP. According to this systems view, a system in action is required to be understood (Checkland and Scholes, 1990). Thus PP process can be characterized as an abstract paradigm which outlines the conversion of various inputs like information about requirements, vendors and contractors, technology, technical expertise, and other organizational resources, etc., into desired procurement outcomes.

In this, it is worth referring to Thai’s study (2001) where he has defined the entire scope of PP as a combination of five core elements. These are policy making and management, PP regulations, procurement authorization and appropriations, PP functions in operation, and feedback. The PP regulations element provides the institutional framework to procurement professionals and program managers for implementing their procurement programs or delivering the projects. While doing so, they are accountable to policies and management executives. Procurement regulations specify (i) structure, roles and responsibilities of procurement organization; (ii) procurement process; and (iii) Code of conduct. Authorization and appropriations functions are related with approval of procurement requests and provisioning of fund for such approved purchases. The conceptual relationship among these elements are illustrated in Figure 2.1.

The core element - 'public procurement function in operations' actually will vary from organization to organization depending upon procurement arrangements and the procurement output itself i.e. whether it is required to procure a service or standard commercially available item or complicated IT system or a residential project. Code of conduct is another important aspect that governs the behaviour of employees but also affects the conduct of vendors and contractors. Various suggestions may come as feedback from internal members of the organization or audit agencies or external audit bodies. Feedback usually indicates the need of corrective adjustments or reforms in various procurement system elements (Thai, 2001). It would require to be considered while framing the procurement policies by the organizations.

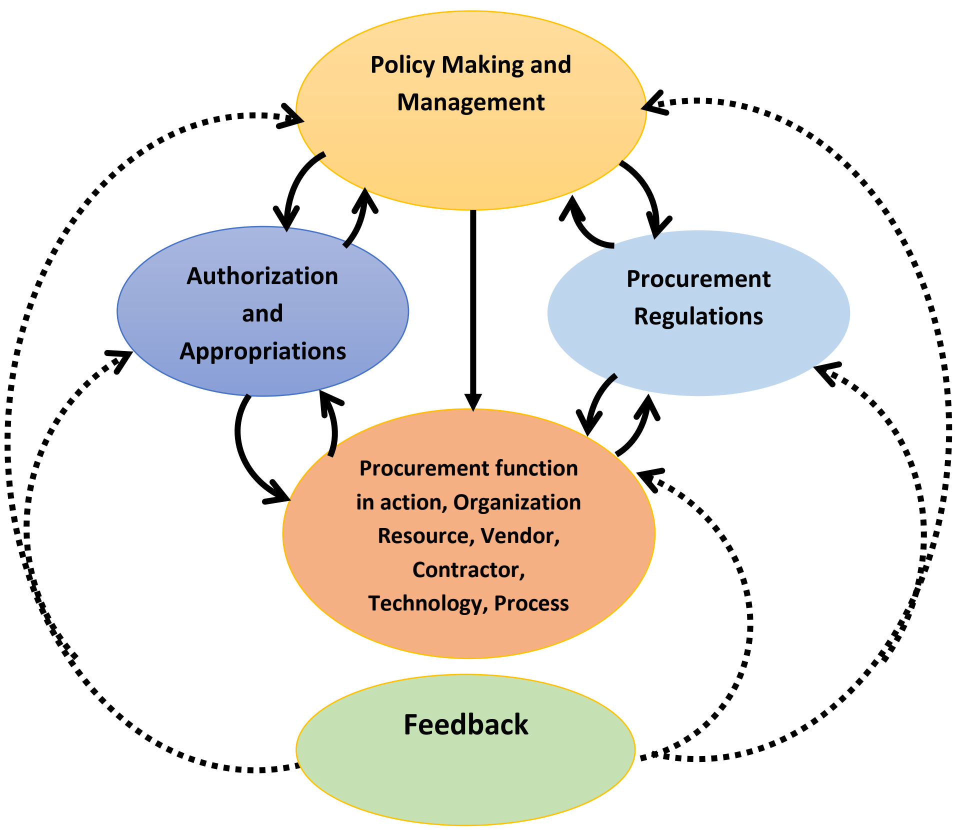


Figure 2.1: Public Procurement System (Adapted from Thai, 2001)

Llyod and McCue (2004) suggest that it might be possible that each of supply, warehousing, inventory management as a function does not justify separate existence. However, their incorporation into the analysis of PP risk would make the analysis more useful and relevant.

In addition to serving business functions, PP has also broader social, economic and political implications (Morris, 1998). A European Community study suggests that PP has been used to stimulate economic activities; shelter domestic industry; strengthen certain industrial sectors; and reduce regional disparities (Watermeyer, 2000). It has also been used for achieving certain more direct social objectives like fostering employment creation; supporting fair labour working conditions; preventing discrimination against minority groups; environment protection; encouraging gender equality; etc (Bolton, 2006). Outside academia, public procurement field has progressed upward and is now linked to strategic objectives such as economic growth and job (Murray, 2009) that has fostered research interests. However, despite these research efforts, there remain several areas which need to be fully addressed.

Initially, public procurement has focussed on the single contract or individual transaction, not on the purchase-aggregate. This transaction based perspective tends to consider each purchase in isolation. Consequently, contract solutions that emerge while working with this fragmented paradigm may not give optimal results. Several reasons like lack of information and capability might be supporting the continuance of such restricted view. More systematic approaches are required to be used to analyze the public procurement process which can bring economy and efficiency in the organizations. PP should, therefore, be strategic in its vision and purpose, and focus on acquisition processes and procurement outcomes rather than any individual transaction (Warren and Welch, 2004). As cited in Llyod and McCue (2004), National Association of State Procurement Officials (NASPO, 1999) have called for moving from "process-based to knowledge and/or accountability-based procurement organizations". In essence, this views SCM as the consummate strategic role for PP. Further, Canada's Procurement Review (Lacelle 2004) has emphasized the commodity management and collective purchasing as PP's main functions. Similarly, Gershon Review in the United Kingdom (Cabinet Office 2003) has echoed the same views. Therefore, any research effort aiming to improve the PP performance should entail the before and after action as has been emphasized in the preceding paragraphs highlighting the emergent property of procurement system in action.For bringing more clarity regarding public procurement cycle and its related activities, a process map is drawn which is represented in Figure 2.2. in this research. As the identification of how a process or the existing system

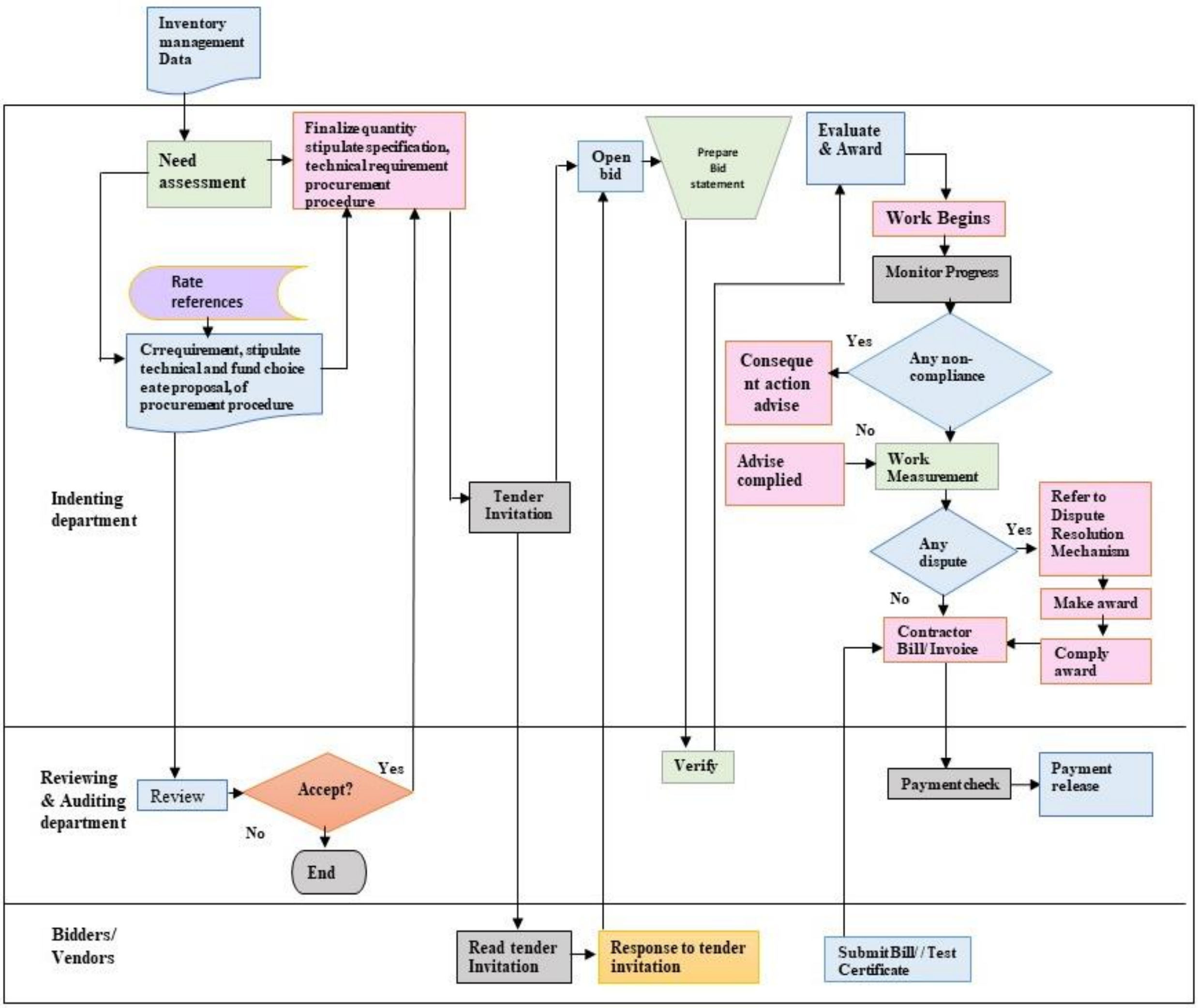


Figure 2.2: Procurement Process Map

functions is essential for uncovering the improvement opportunities, process mapping will improve the chances of a success of improvement efforts (Savory and Olson, 2001).

Mapping workflows is the first step that is quite useful in a broader organizational assessment (Savory and Olson, 2001).Actually, process mapping is an important. Actually, process mapping is an important analytical tool that attempts to reduce wastage of human, monetary, and physical resources in any business processes.

It can be defined as an exercise to uncover the major steps and decisions in a workflow in a diagrammatic form. Actually, it traces the flow of information, materials, and decisions associated with a process and elucidate various tasks, decisions, and actions which are required for translating the inputs to desired outcome. In essence, it not only provides a map of a current or conceived processes to enable organizations in finding their potential problems, but also facilitate an improved understanding about these processes, their successful flows. The process is appropriately scoped in terms of core elements as discussed above in Figure 2.1, and emphasis is placed on covering the activities that are associated with the public procurement process cycle and representing their interdependence in the work flow. It would help in enabling the research in two ways. Firstly, it would assist in uncovering the interrelationship between various risk factors while breaking down various procurement risks into risk factors during risk analysis. Secondly, it would also aid in devising preventive measures for risks which will be identified subsequently in this study.

2.3 REVIEW OF WORK PRACTICES IN PP

PP involves acquiring goods, services and works of appropriate quality at reasonable costs subject to the general principles of fairness, equity, economy and efficiency. Conceptually, it can also be referred to a set of procurement planning, contract placement and contract administration activities (Arrowsmith , 2010). It represents the translation of the agreed design or requirements into detailed specifications, leading to the contracting and implementation of works and goods (Gutman, 2014). The general dissatisfaction from the procurement outcome arises from cost overruns, time delays, benefit shortfalls and quality failures (Wells, 2014). One of the key characteristic features of PP is that it is expected to procure a wide variety of goods and products, services and works along with delivering broad range of socio-economic objectives. Therefore, challenges and problems faced may vary from organization to organization. Similarly, project execution phase will face different difficulties compared to bidding phase. Thus, risk analysis exercise requires to undertake the effort to ensure that whole PP process is well understood along with emphasis on key problems and their interrelationship. Actually, PP is often examined with a focus on process and procedure, and seldom discussed in terms of outcomes and effectiveness (Gutman, 2014). In the past reinventing government movement had mainly concentrated the front end of the procurement process like defining requirements, structuring the overall business arrangement, and selecting the right suppliers (Kelman, 1990).

PP is an information intensive function (Wittig, 2007). Suppliers possess better knowledge of their own processes and costs than the owner. This relative advantage to information can be utilized by suppliers and contractors to their advantage. Such situation creates an opportunity for suppliers for deceiving buyers by artificial cost hike, use of cheaper materials, withholding resources, and deliberate underperformance, (Handley and Benton, 2012). Šostar and Marukić (2017) also identify some of the risks in public procurements. These are namely; (i) unnecessary investment (ii) overestimated required amounts (iii) subdividing the value of procurement with intention of avoiding application of the procurement process (iv) discriminatory practices to favour a specific entity (v) change orders.

Efficiency and economy in the procurement activities may suffer from various factors such as lack of knowledge, large number of participants, fraud, corruption, opportunism and lack of control. For instance, causes of waste and problems in construction works may arise from the decisions that are made with the lack of understanding or information (Vrijhoef and Koskela 1999). Contractor-centered issues are mainly driven by contractors' endeavour to draw undue advantage from the use of sub-standard materials, poor workmanship, invoice fraud, and collusion between contractors and officials (Bowen et al. 2012). Other major issues concerning problems with suppliers are time delays, followed by non conformance with quality requirements (Serpell and Heredia 2004). In their study, Adnan et al. (2012) observed that illogical request for time extension happens quite often. Merrow (2011) studied megaprojects from several industrial sectors and found that as many as 65% of these projects can be considered as a failure.

Actually, construction is a productive process which includes a high degree of fragmentation among participants (Serpell et al., 2006). As a result, construction projects do not possess a unique, defining property. Consequently, this fact would give rise to many problems arising from lack of coordination of the participants. A study conducted by Albano (2013) shows that extent of contract mismanagement looks daunting i.e. 481 cases of purchase contract (out of 743 inspections) were collected but only in 2.49 % of these cases penalty clause were imposed by purchasing entities. The problem is more severe in case of procurement of infrastructure, such as highway, bridges, tunnels, etc. Poor quality resulting from non-conformance during project execution would lead to extra cost and time and subsequent costs of rectifying non-conformance can be high (Abdul-Rahman, 1995). In fact project performance outcome can be undermined by various factors such as complexity and capability limitation (Locatelli et al., 2014). The characteristics of uncertainty, transiency and non-repetitiveness associated with large projects may fragment the organization's ability to maintain coordination (Sjöblom et al 2015). Further, it also necessitate continuous strategy adjustment by the participants thereby make the project environment dynamic which necessitates choosing an appropriate method to model these project conditions to mitigate the risk of poor performance and unethical behaviour.

Public perception is that fraud and corruption is rife in PP which represents the Achilles' heel of public sector management in developed and developing countries (Gutman, 2013). Malpractice within PP is a government's major source of corruption and financial loss (Phillips et al., 2007).Corruption in public procurement undermines markets and welfare, and exerts a corrosive effect on society (OECD, 2007). Ethical aspects have, therefore come into research focus in the recent past. The issues highlighted include wrongdoing by vendors or public officials (Ferwerda et al., 2017; Schooner, 2003; Davis, 2004; Søreide, 2002; Rose-Ackerman, 1999; McCampbell and Rood, 1997; Badenhorst, 1994); emergency procurement (Schultz and Søreide, 2008), ground for exclusions for act of corruption (Arnáiz, 2006), integrity in procurement (Yukins, 2007) corruption collaborative governance (Rosenbloom et al., 2013) transparency of procurement processes and awards (Trepte, 2005) and incentives of officials for corrupt exchanges and bribes (Susan Rose-Ackerman and Søreide, 2011; Søreide, 2014). Mauro (1997) and Aidt (2009) have dealt with negative welfare consequences of corruption. These research efforts help in raising awareness of the damaging impact of corruption and understanding its phenomenon.

As corrupt activities involve certain forms of economic behaviour that leaves behind traces (Kenny and Musatova 2011) , indicators or red flags can be used to study corrupt procurements. OECD (2007), Ware et al. (2007), World Bank (2010) and Kenny and Musatova (2011) presented some of the corruption forms observed in procurement and suggested 'red flags' for identifying corruption. Wensink et al. (2013) identified red flags that could explain upto the extent of 55% as to whether a case is corrupt or not. Basheka (2011) and Ameyaw and Mensah (2013) used surveys and interviews to identify stages vulnerable to corruption and fraud risks in public procurement. Literature review reveals that various observable risk indicators have been used in past research as an attempt to develop objective measures of corruption in procurement. Golden and Picci (2005) developed missing infrastructure as proxy of corruption by comparing the difference in construction cost and infrastructure data of various regions of Italy. Fazekas et al. (2016) modelled procurement corruption risk by using multiple regressions linking likely corruption input such as 'tailored eligibility criteria' to likely outcomes like 'single received or winner share of contracts'. Several researchers had used various other indicators drawn from bidding data for instance the use of exceptional procedures (Auriol et al., 2011), explicit scoring rules (Hyytinen et al., 2008), number of bidders and same firm awarded contracts recurrently (Coviello and Gagliarducci, 2010) and difference in prices of standardized products (Tella and Schargrodsky, 2003). These objective approaches are quite helpful in monitoring the progress on one or multiple aspects indicating corruption. However, a broad list of factors is no substitute for a full understanding of the mechanisms underlying corruption schemes, of the interrelationships between risk factors and of how improved processes or risk mitigation measures would affect these interrelationships. For instance, corruption pertaining to exceptional procedures can be easily removed by simply deleting these procedure from the PP law. However, it is unlikely that this alone would address the underlying corrupt phenomena (Auriol et al., 2011). In fact, manager may tailor specification for doing the same or bidders may use shell companies to get the contracts. Terman and Yang (2016) show that procurement officials may give the image of heightened policy implementation without actually implementing them. Thus it is required to understand the full gamut of unethical practices that could be resorted to by corrupt officials. Actually, corruption is difficult to combat and control (Søreide, 2014). Officials entrusted for procurement functions may find alternate ways to circumvent the guidelines governing the thresholds for competitive bidding (Ntayi et al., 2012). Unethical behaviour among purchasers can be encouraged by circumstances within companies (Badenhorst, 1994). For instance, uncertain and variable rules create opportunities for corruption (Søreide , 2002). The reason for these problems might be that basic processes are not robust enough and remedial measures/actions are required in procurement processes, methods, monitoring mechanisms and human resources which cannot be addressed by procurement regulations and laws (Thai et al., 2005).

The above review shows that the problems in PP are diverse in nature in different phases of procurement such as pre tendering, tendering and work execution activities. As these problems and failures stem from various harmful and counterproductive practices, it would be useful to catalogue these practices showing their details so that they can be meaningfully organized to facilitate incorporating them into useful analysis. These details are discussed in table A.2. One interesting observation arising from this exercise is that there exists a large number of harmful and counterproductive practices, which are affecting the procurement outcome adversely resulting into two main consequences, in PP system. Tanzi and Davoodi (1998) studied the relationship between corruption in projects vs. quality and cost of infrastructure. Their results show that corruption is correlated with (a) higher public investment, (b) lesser revenue, (c) lower expenditure on operation maintenance, (d) lower quality. Whereas Shittu et al. (2013) highlights that poor quality and workmanship and substandard material may result into adverse safety consequences. Similarly, Olanitori et al. (2011) findings also indicate that one of the major factors causing compromise in structural integrity of the buildings is the low quality of concrete. Another useful distinction, revealed from the above review, pertains to the fact as to whether the poor consequence arises from the involvement of project official or a result of contractors' opportunism. It would be useful to categorize these harmful and counterproductive practices in these four dimensions i.e. collusive versus non collusive practices along with safety consequence and other than safety consequences. This framework would facilitate meaningful review of the earlier research and incorporate these two sets of contractor's strategy set in the analysis while studying the work execution phase.

2.3.1 PUBLIC PROCUREMENT AND INVENTORY MANAGEMENT PRACTICES

Procurement is all about organizing the purchasing of materials and issuing delivery schedules to suppliers and also following-up for ensuring timely supply by suppliers (Payne et al. 1996). According to Canter (1993), failures in either purchasing process or in overseeing and organizing procurement functions can lead to:

- Over-ordering that result in resource wastage;
- Over-payments due to inadequate administrative procedures;
- Loss of benefits or reduced benefit; and
- Lack of capacity or knowledge

As revealed from earlier discussion that certain 'before and after actions' are important for procurement process. Inventory management is one of them which is closely intertwined with need assessment phase and may affect in terms of over-ordering or wastage of resources. Inventory can be defined as a stock of items kept in hand by an organization to use in meeting demand (Russell and Taylor, 1995). The significance of inventory analysis arises from financial as well as operational requirement in the organization. Actually, inventory signifies a major capital investment for any organization. Investments in inventories may vary from 25 to 50 % of total assets of manufacturers and from 75 to 80 % of wholesalers and retailers (Johson, Newell and Vergin, 1974). From the operational perspective, inventories provide an operating flexibility. It has a financial value which can be considered as a floating asset for accounting purposes.

Even with supply disruptions, raw materials inventory would enable production operations to continue to produce for some time in case of construction projects. Inventory is equally important in project form of organizations as the proper quantity of inventory will ensure that all project activities will be smoothly carried out according to planned schedules. Based on the review of literature, it is found that inventories may be broadly classified into the following five categories:

(a) Raw materials' inventory which serves as an input for manufacturing or maintenance system or project work.

(b) Bought-out-parts (BOP) inventory which are either directly used in assembly of product. It may be consumed directly in the hospital by patients or used by employees for rendering different services.

(c) Work-in-progress (WIP) or pipeline inventory are the inputs and materials that are needed to make the complete product, assembly etc.

(d) Finished goods inventory are the items ready for use and distribution to the customers.

(e) Maintenance, repair, and operating (MRO) supplies. These include spare parts, indirect materials, and all other sundry items required for production/service systems.

Material costs contribute to more than 40% of the total construction cost. Therefore, material management is an important factor for the success of the construction project (Lee, 2004). Inadequate amount of inventory in construction might result in stoppage of work and wastage of manpower (Patel et al, 2015). The management of materials is a critical function that considerably contributes to the success of a project (Kasim, 2012). Materials management becomes increasingly difficult when projects complexities amplify. It is because materials tracking in large construction projects are also fraught with incomplete and lack of updated information about on-site material stock (Navon, 2006). Further, construction projects have many changes and alterations through the execution phase, therefore a certain level of material inventory is indispensable (Jung et al, 2007). Actually, large number of material transaction takes place with multiple stakeholders which are detailed in Table A.1 of Appendix A.

The inventory management problem is quite important in organizational management (Ziukov, 2015). Solving the procurement planning and inventory problems necessitate review of inventory models. Review reveals that current research analyzes the inventory problems by using rigorous mathematical analysis and developing mathematical decision models. Kumar et al (1997) developed optimization model for spare part and found that it was not easy to predict exact spares requirement which would ensure availability of required spares all the time. Walker (1997) estimated the base stock level for insurance type spares and highlighted that maintenance managers regularly face the problem determining the appropriate level of spare stock. Botter et al (2000) used Vital, Essential, and Desirable (VED) approach to determine the quantity of stock depending upon distinction of vital, essential, and desirable items. They found that service parts inventories were not managed by using standard inventory models as conditions of inventory models did not satisfy the real world requirement.

Githendu et al. (2010) suggested that firms having centralized stock holding do have an advantage as they could control their stocks and avoid stock duplication as well. Brigham and Gapenski, (2010) estimated that the savings on reduced inventories in terms of reduced storage fees, handling and waste would be in the range of 20 -30 percent (%) of profit realized. Razmi et al (2011) find that Vendor-managed inventory (VMI) systems work better than traditional order based replenishment practices. VMI system can be considered as a mechanism where supplier generates purchase orders based on the demand information provided by the retailers or customers.

Simultaneously, there has been research focusing on development of intelligent inventory management system. Hosseini et al (1988) introduced a knowledge-based system for inventory control to recommend optimal inventory control decisions. Do Young Jung (2007) developed the model for inventory management in the construction projects which involves fabrication on work-site. The study concludes that, inflow and outflow of iron-bars at the temporary on-site shop stabilized by applying the pull system to the phase in raw material inventory management and average inventory was reduced resulting in about 25% reduction in inventory costs. The available published literature provides a large variety of models and applications, with different methods, that seek optimal solutions, or, in their minority solving practical approaches (Bastos et al , 2017). Inventory control and management are, thus, found to be closely related with procurement planning as it provides valuable input for the procurement decisions. However, the problems with available inventory models, is that they are developed with specific requirements and may not provide readily available solutions for organizations which differs in terms of their varied procurement needs. Therefore, they cannot be thought of as a general panacea. However, improving inventory management practices have immense potential for implementation in procurement of goods, services and construction works. This can help in terms of making need assessment more objective, timely flow of material and information and reducing wastage such as excess procurement or unwanted procurement. This is equally relevant for procurement of construction works, as the material and work flow between the conversion activities is quite abstract in the execution phase and does not encourage clear identification of actual needs. In this regard, further research is required to identify the relevant and useful information and performance parameters that can be used to improve the efficiency and reduce the wastage in the procurement process. As flow of information, material, and work is quite essential for managing execution phase in an efficient manner, supply chain perspective can also be of significant help in organizing the construction process and analyzing associated risks.

2.4 UNETHICAL BEHAVIOUR RISK

Global initiatives, undertaken by international organizations such as Transparency International and World Bank have promulgated a perspective of corruption from the risk management angle (Hansen 2011). Most of the work with risk perspectives has been done at the macro level that has identified and prioritized corruption risks at national or sector level. But country level scan or sector indicators may be misleading at utility or service provider level as corruption involves specific individuals and organizations (Halpern et al., 2008). Developing an organizational perspective of corruption risks is important for undertaking comprehensive analysis of risks in public procurement. This section therefore underatkes a systematic reviews of academic literature published in research journals and studies published by international organizations like World Bank with an objective to present an overview of risk assessment of corruption in organization. (CRA). This section first provides theoretical foundation of corruption risk and organizes earlier research findings into meaningful themes which provide direction for improving effectiveness of risk assessment exercise. The study emphasizes contextual causality of procurement risk and suggests using qualitative analysis for contextualizing risk identification. This review also borrows knowledge from other established disciplines by adopting interdisciplinary approach and integrative perspective to posit a conceptual model for explaining the corruption vulnerabilities. As empirical knowledge of vulnerability helps in developing better understanding of procurement risk, and to integrate this knowledge to generate an effectual procurement risk map.

Why is corruption a risk? Corruption has been widely recognized as detrimental to society, institutions, and organizations. It is regarded as a significant contributor in restricting economic growth, inhibiting public service delivery, retarding human development and increasing inequality in societies. Existing findings (Golden et al 2005; Olken et al 2007) suggest that the public investment cost and the value of existing capital might differ considerably. Corruption can also threaten the humanitarian endeavor by preventing lifesaving assistance to those who are most in need (Maxwell et al 2012). Apart from financial loss, these risks may affect an organization's reputation, productivity, product and service quality in general and public safety in some cases. However, these impacts are kind of avoidable losses which can be prevented to a considerable extent, if organizations have knowledge about these risks.

What is Corruption Risk? Risk is generally defined as the possibility that an event will take place and adversely impact the realization of objectives. However, no universally accepted definition of Corruption risk is available in the literature. McDevitt (2011) pointed out that corruption risk generally takes institutional approach and is used to identify weakness but its conceptualization varies in various risk assessment tools. Georgiev (2013) refers corruption risk as the degree of probability that corruption might occur along with a reflection of the potential cost associated with the corruption. Buromensiky et al (2009) describe corruption risk as conditions favouring appearance, development, realization, and spreading of corruption practice in service and professional activity. For easy and better understanding, corruption risk may be defined as likelihood of corruption that might occur due to vulnerability or conditions present or practice prevalent in the system with reflection of potential impact associated with corruption. The potential impact would reflect a degree of monetary, social, or reputational cost or resource wastage which might occur due to corruption. CRAs basically involve identification of issues associated with, contributing to, or otherwise facilitating corruption in a particular setting (Williams 2014). CRA begins with data collection. Then risks are identified and risks are mapped in the activities or along financial flow in the organization. Next ranking criteria are developed for assessment of risks. Based on ranking criteria, risks are assessed and prioritized. Then responses to risk are determined in terms of policy correction and risk monitoring. CRA exercise is explained in Fig. 2.3.

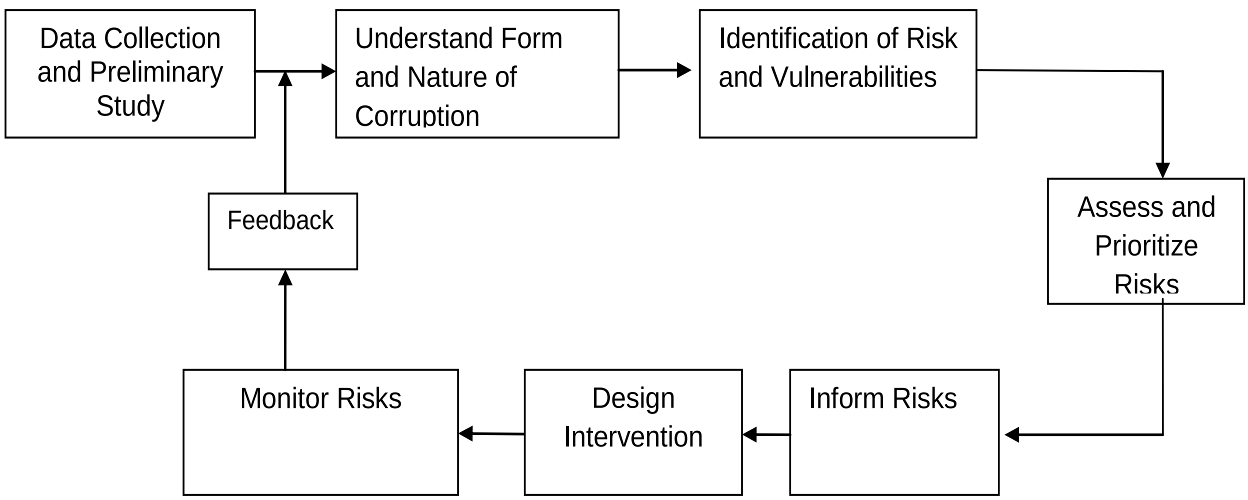


Figure. 2.3: Corruption Risk Assessment Exercise

(**Adapted from COSO, Risk Assessment in Practice: Through Leadership in ERM, 2012)**

CRA methods can be broadly categorized into surveys and interviews, indicator based methods, value chain analysis, Logic and probabilistic models, Audits, Data mining methods and Case study approach. Each of these methodological approaches is presented below:

2.4.1 SURVEYS AND INTERVIEWS

Surveys and Interviews have been used in research to identify corruption and fraud risks and find out vulnerable sectors at macro level or vulnerable stages in critical activities like public procurement (Gatti et al 2002, Ameyaw et al 2013, Olusegun et al 2011). However, they cannot give complete information to assemble risk map, especially on soft measures like values and norms, management attitude and integrity awareness (Bager 2011). If people respond on the basis of factors other than actual perception, survey results may give inaccurate results to that extent (DGHL, 2010). Moreover, surveys cannot provide information on those concealed acts which do not get revealed and their results may get affected by local understanding of terms. However, Reinikka et al. (2006) demonstrate that it is possible to collect quantitative micro data on corruption with appropriate survey methods and interview technique. Review of available literature suggests that targeted focus approach would be quite appropriate for risk assessment survey to obtain institution specific area of concern and prevalent unethical practices. However, surveys need to be coupled with other methods to develop a systemic perspective about corruption risks.

2.4.2 INDICATOR BASED APPROACH

Indicator based approach has gained acceptance because of difficulty in the direct measurement of corruption. They provide an easy method of quantifying the multi-dimensional concepts by combining a variety of statistical data to address. For the purpose of CRA, indicators representing various kinds of risks are identified and risk metrics is prepared to prioritize the identified risk. Indicators based risk approach can be catalogued into two broad groups -- subjective assessment and objective assessment methods. Objective methods are used for assessing risks in public procurement process. Wensink et al (2013) developed econometric model and identified red flags that could explain to the extent of 55% as to whether a case is corrupt or not. These models do not help in discovering the vulnerabilities in the system and applicable to procurement where objective data is available. Subjective methods (Blundell et al 2010, TI 21013 a, TI 2013 b, UNGCO 2013) use subjective ranking criteria and are used to parameterize the assessment of risks. These approaches do not optimally use objective data available in the organization and generally deal with economic aspects only. As many of the red flags have appeared in several investigations regardless of country or sectors (Ware et al 2007;), a generic set of indicators or red flag would be of considerable help in conducting CRA as a pre-identified external criteria. However review of earlier studies (Patrion et al 2007; Kenny et al 2010; UN 2010; Wensink et al 2013) reveal that there is a need to develop observable indicators at organizational level to capture systemic corruption as most of the indicators are either of macro level or of contract level and these indicators should be refined to avoid false negative or false positive indications.

2.4.3 VALUE CHAIN ANALYSIS

In this methodology, vulnerable points are identified along the value chain of translating inputs to output where situation/ conditions are diagnosed to understand the instance and intensity of corruption. It has been used to identify warning signals in various sectors like water and sanitation sectors (Halpern et al 2008), education sector (Patrion et al 2007) and revenue administration (Zuleta et al 2007). This approach has been used mostly in sector level assessment and would also be useful to generate risk map at organization level. However it needs to be combined with other methods for quantifying corruption risks.

2.4.4 SCENARIO LOGIC AND PROBABILISTIC RISK MODELS

Solojentsev (2006) suggests that concepts of probability of bribes and corruption are close to reliability and safety in engineering and similar to the notion of economic and business risk. He developed probabilistic model by using logic and probabilistic theory with a group of incompatible events for the purpose of quantitative estimation, and analysis of bribe probability. However, this model needs past information about events for estimation of bribe probability and require special software. It does not capture all aspects of corruption risks, nor does it provide information for risk mitigation and, therefore, has limited applicability.

2.4.5 DATA MINING METHODS

Several data mining models have been developed to assess the risk of fraudulent transactions. However, their reported utility is generally for fraud detection. Data availability is their main requirement for developing these models and, therefore, research body has grown in banking, insurance, etc. Risk indicators may be obtained through observation of phenomena that are assumed to be proxies of corruption such as difference between customs revenue and domestic sales figure of same items (DGHL 2010). Balaniuk et al (2012) had applied Naïve Bayers (probabilistic) classifiers to support risk assessment in public procurement. They evaluated risk by using classification rules and classified various units/area that are in high or low risk area. A review of various corruption risks identified in earlier research indicates that data mining can be helpful in discovering the variations in the price of goods/services or works procured, proportion of Single Sources or No bid contract awards, data inconsistencies in the manufactured output, material procurement and inventory etc,. This key information would serve as valuable input for assessing the risk of unethical behaviour.

2.4.6 AUDITS

Audit reports and investigations provide valuable inputs about corrupt and fraudulent practices. Bager (2011) reports that audit exercise taken by State Audit Office of Hungary for finding corruption risks in various ministries gave similar results and experience as obtained through self-assessments and surveys. Performance auditing can bring out corruption case indicated by lack of economy, efficiency, and ineffectiveness and participatory audit with user can expose the case of collusion and corruption (Khan et al 2006). Auditing can also contribute in detecting corruption opportunities by examining rules/regulations, procedures and standards. Bager (2011) points out that audit may not give reliable picture on soft measures. However audits may be conducted for detailed analysis of the observed corruption risk to find their nature and causes which will be useful input for risk of unethical behaviour.

2.4.7 CASE STUDIES

A few research studies have used case study method to find out the corruption risks. For instance, Maxwell et al (2012) have studied corruption in humanitarian assistance through case study along-with desk review and study of humanitarian agencies. They found that accurate targeting of those who need assistance pose significant corruption risk. Ekwo (2013) has undertaken case study for finding the corruption risk factors in public procurement in Nigeria. Hartley (2004) points out that a case study approach is useful as a research method for studying a problem in-depth, to understand the interplay of socio-economic forces and processes. Case studies can provide deep understanding of important procurement corruption mechanism and related vulnerabilities through rich details of actual cases. Case studies can involve either single or multiple cases, and numerous levels of analysis (Yin 1984). Darke et al (1998) point out that main criticism of the case study is that no standard approach exists for analyzing huge qualitative data. Graff and Huberts (2008) have pointed out that exploratory multiple case study methodology helps to expand our understanding of the way in which officials become corrupt. Graycar and Sidebottom (2012) analyzed past corruption cases to identify opportunity and control structure in order to devise preventive mechanism. Analyzing multiple cases would definitely bring out deficiency in control structure and existing opportunities for CRA. However, developing systematic methods for conducing such analysis need future research attention.

2.4.8 SYSTEMATIC REVIEW

The articles were searched electronically by using search term 'corruption risks', risk of corrupt practices, 'corruption vulnerability', 'identifying corruption risks', and 'assessing corruption risks. The articles which published in the time span of 2005 - 2015 were considered for our study as research on corruption risk from organization perspective is relatively new. Authors excluded studies and articles by following the concept of theoretical relevance as per the exclusion criteria noted in Table A.3 of Appendix A, systematic analysis procedure was followed with the application of analytical protocol (detailed in Table A.4 of Appendix A).

2.4.8.1 DISCUSSION AND DESCRIPTIVE ANALYSIS

This section summarizes and reflects on the findings inferred from the review of literature and assembles them into meaningful themes for improving the CRA. Firstly, a descriptive analysis of the review data set characteristics is presented. Secondly, it presents a broad overview of the theoretical field with several themes emerging from review. Thirdly, it provides input for conducting an improved risk identification approach by combining existing methods to facilitate comprehensive identification of corruption risks. In addition, it connects to the relevant findings of earlier research to conceptualizes vulnerability to corruption that would benefit the risk analysis in public procurement.

A total of 48 articles from journals and 34 publications of International Bodies pertaining to corruption risk studies were found to be relevant for studying risk of unethical behaviour. A wide range of methods have been employed by researchers as evident from review. The frequency details of various methods used in academic research and work of International Bodies is annexed in Table A.5 of Appendix A. Author- wise distribution of research methods is mapped in Table A.6 of Appendix A. The data set reveals that surveys, interviews and indicators are the most commonly used research methods. About 15 % of research articles were found to employ a variety of different methods such as case study, data mining, business game simulation, value chain, logic probabilistic models, and qualitative meta-analysis. It was further found that sixteen articles have used more than one method and survey was found to be one of the methods in these researches. However none of the methods have proposed methodological framework integrating variety of methods used in risk identification and assessment. A sizeable number of articles (about 36%) are found to be of theoretical in nature but these articles had not elaborated the concept of risk and vulnerability. This review therefore posits a conceptual model for explaining the corruption vulnerability. The theoretical nature of the majority of articles support the suggestion of Ashforth et al (2008) that there is much need for conceptual work that is integrative, interactionist, and processual in nature. This need is further confirmed by the fact that only 19 articles out of 48 have discussed about corruption risks. Most of articles published in top journals do bring out various factors affecting likelihood of corruption in the organization, however, several important issues pertaining to CRA are found to have remained unaddressed. The first issue is how to integrate various approaches to conduct comprehensive risk identification. The second issue concerns finding a suitable method for conduction systematic analysis of a variety of data gathered from multiple data and the third issue pertains to quantification of risk in assessment of risk of unethical behaviour.

2.4.8.2 SUMMING UP THEORETICAL FIELD

Unethical behaviour has been studied by placing emphasis on the individual's traits and behaviours, organizational parameters and process approach (Frost et al, 2014). Our review finds that recent research on organizational corruption has also taken in to account the factors governing interaction among different actors and external factors in explaining corruption. There are five major themes emerging from coded data of our consideration set. First major theme representing individual's traits and behaviours include unethical attitude and strive to gain benefit (Mackevicious and Kazlauskiene, 2009), disconnect between ethics and business in minds (Gopinath, 2008), level of moral meta-cognitive ability and information processing capacity (Hannah et al., 2011) and ethical decision frames (Tenbrunsel and Smith-Crowe, 2008). Their main focus is on individual predispositions for understanding corrupt behaviour and, therefore, omits more systemic causes. In the second theme, factors represent organizational parameters like weak procurement and control structure (Bowen et al., 2012), Entrepreneurial orientation (Karmann et al., 2014) and ambiguous rules (Martin, 2013). There remains empirical inconsistency in research body examining why some organizations are more prone to corruption (Frost et al 2014). It might be due to variety of factors including lack of systemic research perspective and contextual difference in corruption genesis in different organizations. There also exist a number of studies (Moore, 2008; Nieuwenboer and Kaptien, 2008; Pinto et al., 2008; Zyglidopoulos et al., 2009; Frost and Tischer, 2014) that have explained the prevalence of corruption through processes of institutionalization, rationalization and socialization as a result of interaction among different members within the organization. These studies focus on the group processes which lead to the normalization of unethical behaviour due to the incentives and tolerance of corrupt acts. There emerges the fourth theme which includes environmental factors like high taxes, convoluted licensing requirement and inefficient government service delivery (Wu, 2009), quasi monopoly over supply of public goods (Evernsel, 2010), social identity (Misangyi, 2008). This set of studies has highlighted the role of socio-political and economical factors embedded in external environment in explaining the corruption but these factors alone cannot explain organizational corruption. Fifth theme focuses on web of relations between internal and external actors. It includes social ties with the government officers (Collins, 2009), deployment of middleman (Biswas, 2015), and family and friend relationship (Bowen, 2012). These themes can be analyzed further from their theoretical perspectives. Misangayi (2008) notes that research and practice have been dominated by two alternative frameworks. The first perspective is based on an economic perspective and focuses on the roles of rational personal cost/benefit analysis, opportunities to exploit discretion for gain. Second one emphasizes on normative and cognitive aspects of corrupt behaviour and stresses the importance of the ways in which organizational settings can generate amoral reasoning and behaviour. In addition, this data set reveals the third perspective which examines illegal activities by focusing on interpersonal connections between public and private actors who profit from these associations. Jancsics (2014) has categorized these studies as relational model and explains that various advantages such as acquiring certificates, licenses, and contracts can be obtained through these connections. Mackevicius (2009) and Bowen et al. (2012) have employed Cresey's fraud triangle based model consisting of motivation, opportunity, and rationalization factors in their analysis. However present studies have not yet catalogued various opportunities and motivations in the context of organizational corruption. Further, there is lack of studies which systematically analyzes the simultaneous interaction of the these factors. Graycar (2012) had adopted situational crime framework which is close to Kiltgaard's (1988) approach for analyzing past cases to inventory control and opportunity structure by finding conditions having monopoly, discretion and insufficient accountability. These theoretical models and frameworks are effective conceptual model for explaining corrupt behaviour. However, they alone may not fully capture the complexities of corrupt acts from preventive perspective because opportunity does not capture capability factor and collusive behaviours especially concealment scheme which involve external elements and auditors. In sum, above themes highlight the need to adopt a systemic perspective to develop risk assessment framework to allow more comprehensive means to capture the various aspects of procurement corruption risk. These themes also illustrate that it would be necessary to obtain rich descriptions of 'real world' corrupt transactions and undertake qualitative analysis to find situational factors presenting opportunity and incentives within organization and understand the web of corrupt relationships for generating contextual information about procurement risks.

2.4.8.3 IDENTIFYING RISKS COMPREHENSIVELY

Risk identification is the most important part of CRA exercise. Therefore, methods used for identifying risk conditions and vulnerability warrant discussion. Bager (2011), UNGCO (2013) and TI (2013 a) categorize risk factors on the basis of motivation, opportunity, and rationalization/culture, incentives and opportunity. Blundell (2010) uses a generic heuristic to describe corruption scheme in assessing corruption risk in forestry sector. Cover et al. (2014) suggest developing sector specific corruption typologies to conceptualize corruption. TI (2013 a) recommends to consider external risk by correlating business proportion and CPI score of a country while assessing bribery risk for commercial organization. It is appropriate to consider external environment during CRA. Graycar et al. (2012) use case analysis to identify opportunity and control structure. ACLEI (2013) corruption risk framework identifies risks through various questions asked from multiple perspectives. Despite multiplicity of approaches and growing awareness about alternative theoretical explanations, risk identification exercise remains a complex issue and needs further clarity. With a view to provide a useful practical tool both for scholars and practitioners, the above approaches were meaningfully organized and it is deduced that risk identification can be operationalized in two ways. First, it can be undertaken by identifying risk events through surveys, workshops, desktop research and expert feedback and analyze backwards to pinpoint intermediate and root causes. Alternatively, risk identification may begin with discovering vulnerable areas and undertaking control reviews in these areas or analyzing qualitative data like corruption case, audit reports to uncover unanticipated vulnerabilities. It involves analysis in forward direction to proactively identify situations conducive to corruption. The first approach may not discover all potential corruption risk. Therefore, risk identification exercise should essentially identify potential risk scenarios – that is to find out what adverse could happen, how it can happen and where it would happen in the organization, it needs multiple level of analysis by using a variety of data to generate contextual information for assembling a meaningful corruption risk map. Vulnerability concept can facilitate multiple levels of analysis in the broader context embracing individual, organizations and environment. Therefore, this review develops conceptual understanding of vulnerability in the following sub-section so that understanding of vulnerability concepts can guide practitioners in carrying out risk analysis with systemic perspective to comprehensively identify procurement corruption risks.

2.4.8.4 CONCEPTUALIZING VULNERABILITY

Recent findings (Bager, 2011; Vian et al. , 2012; Johnston, 2012; Maxwell 2011) highlight the need to identify current vulnerabilities that may be sustaining corruption. Vulnerability analysis provides an idea of where corruption might be taking place (Vian et al., 2012) and help in vulnerability clarifying the concept of risk and identifying the areas of concern in the organization. Such an assessment can point to appropriate controls and incentives which are required to be considered for reducing corrupt dealings (Johnston, 2010). Bager (2008) states that vulnerabilities are defined at a higher level of abstraction which indicates areas where risks are more likely to occur. Johnston (2010) suggests the strategy of assessing the vulnerability by comparing government performance indicators to benchmark for example time or steps or fees needed for obtaining permits and registering a business. Vulnerability in the earlier research is being referred to as susceptible activities or certain characteristics assessed by abnormal value of indicators. Vulnerability usually occupies chief focus in risk assessment in fields like safety, disaster and security etc. Ernest and Young (2010) also suggests that corruption risk should be viewed in a way similar to health and safety risk because it has similar effect. It was, therefore, considered appropriate to grasp the understanding of vulnerability concept by borrowing and integrating knowledge from these disciplines. In the field of disaster and safety risk, vulnerability is considered a result of 'lack of capacity' or 'susceptibility to harm' (Brooks et al., 2005; Gallopin, 2006; Gaillard, 2010; Cardona et al., 2012). Similar definitional approach seems to be useful in conceptualizing vulnerability in the field of risk of unethical behaviour. However, it needs to be refined by taking findings of the review into consideration for vulnerability conceptualisation. The thematic analysis underscores the need of integrative approaches focusing on the relations between individual dispositions, organizational settings, collective actions and exchange with external environment. Ashforth et al.(2008) also suggested that measuring individual dispositions or organizational characteristics in a snapshot manner are not likely to tell much about the trajectory of systemic corruption. Authors, therefore, were guided by Turner's vulnerability framework (2003) which provides a template suitable for 'reduced form' analysis and yet inclusive of larger system character of the problem. Drawing on the theoretical explanations offered by the existing research and learning of thematic analysis, an attempt is made to synthesize vulnerability model with an empirical focus to find how different corrupt incidences can occur in the organizations and a theoretical focus on gaining a deeper understanding of the corruption. The model is depicted in Fig. 2.4 and presents the broad category of components which impact organization's vulnerability to unethical behaviour.

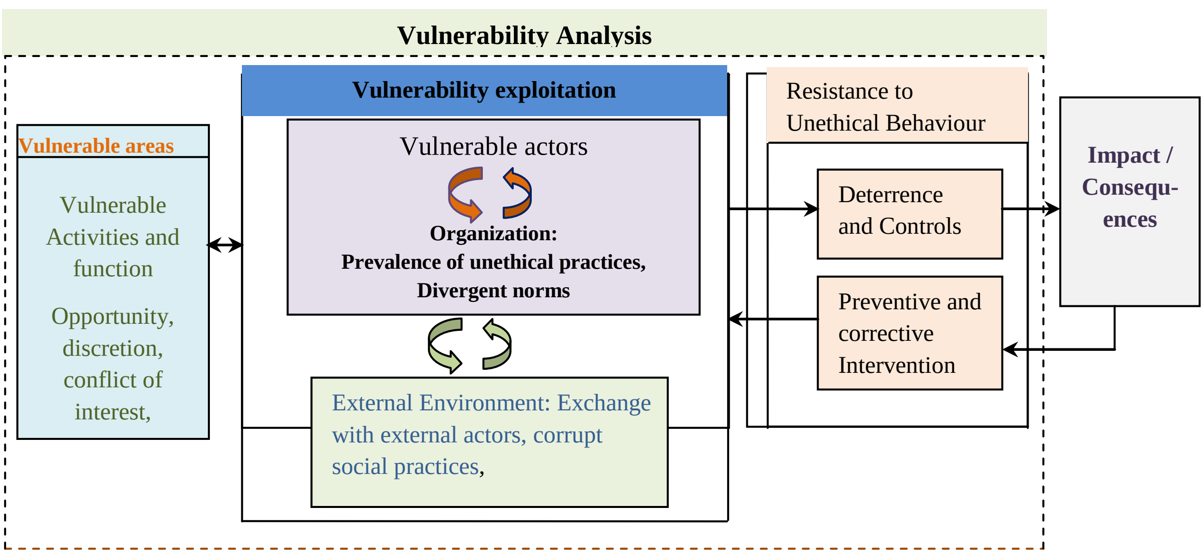


Figure 2.4: Details of Vulnerability Analysis Components

It shows that vulnerabilities are rooted in actions and factors embedded in organization and environment thus vulnerability is to be thought as a multidimensional concept. These components can be considered as risk elements which would be helpful in risk analysis while breaking down the procurement risk during risk analysis.

It also illustrates that vulnerabilities will not always lead to corruption unless they are exploited through corrupt actions (UNGCO 2013). It would, therefore, be useful to identify corrupt practice during CRA to understand how vulnerabilities are exploited. If corrupt exchanges are separated in time and the transfer and counter-transfer have different forms, one may easily blur the unethical nature of these transactions (Hipp et al 2010). In fact, it's possible that leaders can perfectly conform to the legal norms and yet abuse their position for drawing personal benefit (Aguilera et al 2008). These findings indicate that detection and prosecution is inherently difficult as corruption is secret and often consensual.

Vulnerability, therefore, also reflects 'unusual difficulties' in detecting and preventing corruption. A sub-set of organizational theme includes factors like absence of code of ethics, weak financial control, unregulated discretion etc., which together reflect lack of internal control. Internal control failures may results in opportunity for corruption and facilitate rationalization of corrupt practices (Pfister, 2009). Review of literature on internal controls (Merchant et al 2007, Hared et al 2013, Berry et al 2009, Nisiyama et al 2016, COSO 2012, Pfizer 2009) shows that these failures may arise due to weakness in the organizational structure, governance system, policy, procedure, processes and boundary systems. Thus vulnerability can arise due to lack of control in the organization. Changes in the internal control will reduce or increase the vulnerability hence vulnerability is to be considered as dynamic and can be described as a set of conditions arising out of interaction of various factors that increases the likelihood of corrupt practices and unethical behaviour.

As genesis and evolution of an emergent phenomenon like corruption will vary from organization to organization (Ashforth et al., 2008), an organization can be vulnerable to certain type of corrupt practices and not to others. Even within an organization not all activities and functions will be vulnerable to corruption. Vulnerable activities and functions need to be identified as control over them would reflect the 'characteristics' of vulnerability and reflect corruption risk exposure. The model recognizes importance of externalities in the corrupt exchanges and hypothesizes that individual, organization and external environment affect each other and should form an integral system for carrying out vulnerability analysis. It explains that vulnerability to corruption arises due to factors or conditions which are conducive to corruption that are being viewed as opportunity for organizational corruption and may facilitate rationalization of corrupt practices. It is to be noted that the above model is a descriptive one and does not explain the strength of impact of vulnerabilities nor does it show the interrelationship between various vulnerabilities. However, it can improve risk identification in the organization by facilitating systemic perspective about problem of unethical behaviour.

2.4.8.5 UNDERSTANDING VULNERABILITY LINKAGES AND PROCUREMENT MECHANISM

Very often corruption schemes are inter related and are used in complementary manner which reinforces the effect of each other and make their prevention more difficult (Ware et al 2007). However, most of the studies on the subject have tended to focus on the antecedents of organizational misbehaviour on non-compliances of procurement procedures (Tukuamuhabwa, 2012). Zimelis (2012) pointed up the observation that research on corruption should go beyond simplistic general conditions and need to better operationalize the elements of analysis and interconnectedness between various determining factors. This observation is significant in the light of fact highlighted by OECD (2009) that corrupt acts that will occur later can be planned at the stage of need identification and tenders' design and detection probabilities vary considerably according to procurement stages. Moreover, risk factor in broader procurement governance area may also facilitate corruption schemes in other activities. For example, corruption can skew incentives that may result in distorted decision making in respect of Budget and Project Prioritization. Earlier findings (Schliefer and Vishny 1993, OECD 2014, Kenny 2006) indicate that funds may be diverted to areas where corrupt actors can better extract bribes from new investment in PP. This review also indicates that only few studies have been undertaken for identifying risk arising from these procurement mechanisms.

2.5 RISK ANALYSIS: CONCEPTS AND METHODS

Risk analysis in public procurement is very important because it can contribute to effective handling of public outlays and help in achieving desired procurement outcome. Risk always conveys some consequences about a future activity. The concept of risk and risk assessments are quite old. In fact, the Athenians did assessment of risks before decision making more than 2400 years ago (Bernstein, 1996). However, risk analysis as a scientific endeavour is still evolving and consequently spreading to several new areas like supply chain management, procurement, human reliability, etc. Organizations can reap several benefits by extending the risk assessment to other important activities as it helps to build the defense against the possible adverse outcomes.

Risk usually encompasses impacts on finance, health, environment and human life. Risks faced by organizations may vary from simple to complex ones. Common example from procurement field includes resource wastage, time delays, financial loss, etc. These risks has different consequence and as pointed out by Koleczko (2012), the risk analysis excercise involves identifying, analyzing the different risks and responding to them. It enables the organizations to identify, assess, and manage to facilitate effective decision making. Aven and Zio (2014) and Society for Risk Analysis (2015) identify that the risk field has two key activities, viz. (i) using risk assessments and risk management for studying and addressing the risk in specific events or activities, and (ii) performing generic risk research and development, in relation to concepts, theories, frameworks, approaches, principles, methods and models for understanding, assessing, and characterizing. Simply stated, risk field pertains to developing our understanding about the world and finding how we can and should understand, assess and manage this world in reference to risk (Aven , 2016).

Risk assessment generally begins with data collection, then risks are identified and risks are mapped in the activities or along the financial flow in the organization. Next, risks are assessed and prioritized. Then responses to risk are determined in terms of policy correctional measures, process improvements, and risk monitoring. In general, risk assessment exercise contains well defined steps, viz. finding vulnerable areas, identifying causal risk factors, determining the frequency of occurrence, assessing the severity of consequences, estimating and prioritizing, risks, and mitigating risks. During risk analysis, risk identification and risk categorization are two most difficult but critical steps. There may be a number of ways to undertake this. For example, a risk assessment matrix is an example of one such easy and effective technique which can establish risk level by categorizing the combination of probability and severity. It would also provide input decision about allocating resources. The breadth of possibilities in drafting a risk assessment technique is quite extensive (Manuele, 2008). In many cases, knowledge gained by field staff, engineers, and procurement professional etc may provide valuable input to arriving at proper conclusions on risk mitigation. While in other cases, some information might be available like financial loss or down time, failure reports, accident investigation summary, etc., which can be used to attribute to certain causal factors. Here well established risk analysis techniques like FTA, FMEA, FMECA etc can be attempted. Though FTA is commonly used in industrial systems to study possibilities of technical failure, it can also be useful in economic risk assessments (Gatfaoui, 2008). Similarly, in a project kind of organizational setting, project outcome would greatly depend upon strategic interaction of involved stakeholders. Actually, human being behaviour also matter in risk analysis as they are an important and essential part of systems such as public procurement process which involve multiple stakeholders strategic interaction. Considering these behavioural dimension, Haunsen (2002) highlights that techniques like game theory became a natural tool in the risk analysis exercise. In sum and substance, probability is one of the common tool to express the uncertainty however, there exist other tools like imprecise probability and qualitative tools (Aven 2012, 2016). It is, therefore, essential to understand the context in which risk is to be understood and analyzed. In this regard, Aven (2016) offers the following qualitative definitions of risk which have been used by us in this study to build the conceptual understanding of the procurement risks:

(i) the possibility occurrence of an adverse event,

(ii) the potential for realization of undesired, negative consequences associated with the event,

(iii) exposure to a proposition (e.g. the occurrence of a loss) of which remains uncertain,

(iv) the consequences of the activity and associated uncertainties,

(v) uncertainty about and severity of the consequences of an activity in respect of something that humans value,

(vi) the occurrences of some specified consequences of the activity and related uncertainties,

(vii) the deviation from a reference value and associated uncertainties.

In essence, risk refers to the uncertainty that surrounds future events and outcomes. In other words, it implies the consequence covering an event and its effect. This concept is found to be relevant in case of functioning of public sector organization. For illustration, Australian and New Zealand Public Sector Guidelines for Managing Risk (HB 143:1999) define the risk as the "chance of something happening that will have an adverse impact on objectives. It is measured in terms of consequences and likelihood. It is the expression of the likelihood and impact of an event with the potential to influence the achievement of an organization's objectives (Treasury Board of Canada Secretariat , 2001). Basing on the above, we conceptualize procurement risk as potential loss in the procurement cycle in terms of objectives of fairness, economy and efficiency caused by uncertain developments in the procurement system which are triggered by procurement systems' core element. The procurement systems' core element has been described in detail in section 2.2, which has been further illustrated in process map in Figure 2.2.

Thus in case of public procurement, risk analysis exercise entails identifying risk factors associated with each procurement phase, analyzing their probability of occurrence and considering the potential impacts (Sorunke et al., 2016). Considering the fact the features of each phase of procurement would vary, any one of the tool may not suffice. This is in agreement with earlier findings (Aven, 2012, 2016) which highlight that every tool has certain limitations. Moreover, both strategically and operationally, identified risks and risk elements arise from diverse histories in diverse organizations (Lacey, 2011) which may necessitate development of specific approach applicable to specific activities or organization. Hence, the proposed risk approach concentrates on the procurement system characteristics and weakness, risk events and process stages as the constituent parts of risk analysis process to develop a comprehensive risk analysis approach by integrating various risk analysis techniques. These are described in the following sections.

2.5.1 FAULT TREE ANALYSIS

Fault Tree Analysis (FTA) is a risk analysis method used in investigating the failure behaviour. FTA adopts top-down deductive analysis to trace various failure paths. FTA is an event oriented analysis which makes it more versatile compared to other reliability techniques which allows only hardware failure considerations (Misra, 1992). As a result, it can identify the contribution of human errors, software failures, deficient process states and environmental influences into potential risk event and help in analyzing their influence . Fault tree analysis, far from being an artefact of engineering process alone, provides a structured and systematic mechanism for identifying risk factors in human service system (Lacey, 2011). While highlighting the utility of FTA as risk analysis method, Paul (2012) highlights that it is quite useful to identify those errors or defect which are not easy to detect. It is a systematic method that is used for analyzing the risks by adopting a deductive approach where a specific risk that is only qualitatively recognized from a relevant primary system under study is placed as the top event for deductive reasoning (Hyun et al. , 2012).

It is considered quite useful as risk analysis because it can show how an undesired event can happen in different ways and systematically identify the probable sequence of risk events leading to failures. FTA also permits the theoretical relation between the risk categories (top events), the risks and the risk factors (Hyun et al. , 2012) that can facilitate subsequent qualitative and quantitative analysis.

To develop FT, faults can be thought as non-conformities, weakness in system or a business enterprise. Therefore, approaches like FTA which helps in their mitigation assume relevance as risk management techniques enable effective planning of remedial measures. Conforti et al., (2013) used fault tree analysis to identify risk conditions in all phases of logistics business process model for real-time monitoring of risks. The approach specifies risk conditions by developing risk template on the basis of negative process states (faults) for detection of risks during process execution. The analysis starts with the top undesirable event and then failure is decomposed by finding all the potential ways in which it can happen. The failure process is summarized graphically in the form of a fault tree. This graphic representation demonstrates all potential parallel and sequential combinations of faults which may lead to the top event. In essence, a fault tree shows the logical interrelationships of basic events which can lead to the failure. Stated simply, FT is a logic diagram that represents the relationships between a failure event and its causes. As it is a graphical method, it gives a visual model of how equipment failure, human error and external factors contribute to an undesired event (Baig, 2013). Yu et al. (2011) developed a mixed approach in which the FMEA is guided by a FTA. Their analysis begins with defining the failure event and then fault tree is constructed as a whole for a particular system (Peeters et al, 2017).

2.5.2 FMECA

The purpose of FMECA is an important risk analysis technique which analyze the system characteristics in respect of the requirements to make the system design fulfil the reliability requirements (Cetin et al, 2015). In fact, FMECA helps in resolving potential problems in a system before they occur (Sematech, 1992). FMECA is performed by defining all the potential failure modes and considering their effects on the system functioning. Essentially, it is an inductive and bottom-up approach used to identify failure pathways (modes) and system weaknesses. After identifying these modes, they are prioritised or classified according to their levels of criticality (Dinmohammadi et al 2016). Finally, preventive measures are also suggested to improve the system reliability. It is worth noting that this analysis can also be performed at the individual process step or at the functional level which can help us in identifying the functional level defects or vulnerabilities and addressing them.

FTA does lack a method for assessment of criticality (Peeters et al, 2018). It begins with a specific failure event and then identifies all potential failure modes which can lead to this event, whereas a FMECA aims at identifying all possible failure modes and their effects. FMECA being a non structured approach, it is difficult to apply to a complex system for identifying all possible failure modes. Thus, analyzing risk with FTA in combination with FMECA would make the analysis more reliable and make it possible to quantify the results. FMECA is preferred over FMEA if it is required to quantify the criticality of effects of risk factors for prioritizing mitigation effort. The 'C' in FMECA refers to the criticality or severity of the various failure effects that are analyzed and ranked (Rusand, 2004). Criticality Analysis relates failure rate and severity of the effect of failure (DA, 2006). One of the methods for obtaining criticality is to find Risk Priority Number (RPN) using the ranking of severity, occurrence and detectability (Rusand, 2004). However, its most criticized considerations refer to the fact that RPN have same value for many items (Ungureanu et al, 2016). Moreover, it is difficult to properly weigh the detectability. Further, some S, O, D (severity, occurrence and detectability) scenarios give RPN values that are lower than in other combinations, but potentially more dangerous (Ungureanu et al, 2016). Considering the nature of phenomenon of procurement risks, it is found difficult to spell out a perfect mechanism for weighing detectability in this research. Another alternative method for assigning criticality score is, therefore, found from the literature.

2.5.3 GAME THEORY

The game theory, which emerged in the middle of the twentieth century, provided new insights that have been applied successfully in various fields. It enabled researchers to analyze the issues of cooperation and conflict with mathematical rigour. Major development in game theory work began with Émile Borel, John von Neumann and John F. Nash. The first known discussion of game theory occurred in a letter written by Waldegrave wherein he describes a solution concept using minimax mixed strategy to a two-person version of a card game. Thereafter, Émile Borel provided a minimax theorem proof zero-sum matrix games for two-person by conjecturing symmetric pay-offs and non-existence of mixed-strategy equilibria. Actually, the foundations of game theory were laid out in 1944 when John von Neumann and Oscar Morgenstern published their book "The Theory of Games and Economic Behavior". Since then a lot of work has been done. In the 1950s, John F. Nash developed the concept of Nash Equilibrium which made it possible to use game theoretic models in various areas. It mainly provides us tools for analyzing important economic phenomena. It also offers mechanism to analyze complex interactions involving multiple decision makers. In addition, it enables us to compare different resource allocation mechanisms.

Actually, Game theory abstracts the real world setting ito a quantitative model by formulating mathematical expressions for involved entities' strategies. Such situations usually can not be modelled by other single decision maker models which makes it a quite useful analytical tool. There are four main elements in a game, viz. players, information, strategies and payoffs. In this regard, von Neumann and Morgenstern (1944) provide a vivid description to the game and its constituents.

Consequent upon the work of Maynard Smith involving evolutionarily stable strategy, game theory began to be extensively applied in biology. Subsequently, it has been established as a useful and important research tool in many other fields and developed sound mathematical theory. Game theory is quite general and its simple tools and intuition can be used in a wide variety of decision-making contexts (Horowitz, 1996). It is most immediately applicable to problems involving contracts, cooperation, and public goods (Karp and McCalla, 1983). Considering the fact that it can provide more conceptual way of analyzing problem of counterproductive work strategies and consequent contractual under-performance, several scholars have applied game theory to study construction projects. Actually, mitigation of risks present in supply chain for improving the control requires that owners' strategy is made efficiently. Game theory helps in achieving this objective. As a result, it has been applied to analyze and hedge various risks in supply chain. For, instance, Zhai et al. (2016) have used game theory for production lead-time hedging in SCM of prefabricated construction. Hao (2011) studied collusive behaviour in bidding stage of procurement and suggests for centralized procurement and open bidding. Howbeit, open bidding with low cost bid selection may itself sometime prompt bidders to take contract at low rate and subsequently compromise with quality. Shurong and Miao (2012) analyzed rent seeking in supervision by using game theory and suggests for improving the monitoring efficiency to restrain rent seeking. As game theory provides a mathematical framework to analyze the interactive decision situations, it is considered appropriate for application in the work execution phase in the public procurement to analyze the risk of various counterproductive work practices that would result in underperformance. However, one of the limitations of game theory is that it cannot incorporate the strategy adjustments i.e. dynamic changes in the analysis and in such situations it can be complemented by EGT.

2.5.4 EVOLUTIONARY GAME THEORY

Evolutionary game theory (EGT), developed a game theory application in biological evolution contexts, has been applied in several other fields such as economics, business, and supply chain (Cai and Ned, 2009). The first EGT application can be traced back to 1973 when Smith and Price came out with their paper “The Logic of Animal Conflict”. The EGT’s main insight is that the success of any strategy involving interdependent interactions of multiple organisms depends on how this strategy interacts with that of others. It implies that success of any individual player has to be evaluated in the context of the full population of participants. Here, evolution does not necessarily mean biological evolution. It might be the changes in beliefs, strategies and norms over time. A social or organizational interaction involving dynamic changes can be easily modelled with EGT by defining the strategies of the interacting agents. EGT achieves equilibrium as a result of outcome of adaptation and selection of more successful strategies rather than strategic reasoning. This dynamic approach is closely linked to the study of the complex adaptive systems (Santos et al, 2016). As a result; it would be quite useful in designing measures to promote the change from undesirable state to other alternative desirable equilibrium states.

EGT can be applied to a wide variety of systems, viz. projects, supply chain, cooperation in technology sharing, supervision, etc. Recently it has been used to study the construction projects. However, Wen et al. (2014) has reviewed the literature in game theory application on collusive behaviour found that there exists few research which explore the phenomenon of collusion in construction project by applying EGT. However, analyzing collusive behaviour with EGT will simulate construction projects' characteristics more practically as the central insight of EGT is that many behaviours involve the interaction of multiple actors where the success of any of these actors depends on how its behaviour interacts with that of others. In fact, EGT does not require the assumption of all players being intelligent and rational. Here, the rationality notion is replaced with the concept of reproductive success. Strategies yielding high payoff would spread and replicated more often through learning, copying or inheriting strategies of others. Put simply, the success of any given strategy would depend on the ecology of behaviours present (Santos et al, 2016). This is true for unethical strategies or counterproductive opportunistic behaviour which would spread if not controlled in the organizations. However, the players' payoffs will depend on the actions of the co-players which in turn depend on the frequencies of the strategies. Detailed theoretical background of EGT and mathematical explanations of related solution concepts have been provided in section 4.2.3.

2.5.5 GROUNDED THEORY

Grounded Theory (GT) is developed by Glaser and Strauss (1967) and has proved an extremely useful research approach (Stol, 2016). It is now being used in various other fields like disaster studies (Turner, 1976), innovation (Lowe, 1995); hospitality management; medical studies (Connell and Lowe, 1997); mergers of businesses (Lowe, 1998), management action (Partington, 2000); building and testing TQM theories (McAdam et al, 2008), audit detection risk assessment (Chang et al, 2008) operation management research (Binder, 2008); supply chain management (Ambe et al, 2011); disaster risk reduction (Roth et al, 2011); information system (Halaweh, 2012), supplier sustainability risk (Harilainen, 2014), Human resource planning (Pourander et al, 2015), Software engineering (Stol, 2016). GT's particular value lies in its ability to present a conceptual overview of the phenomenon under study (Holton, 2008). Halaweh (2012) suggests that grounded theory can be applied for systematic procedures for analyzing the data collected from various data sources including case study. Fernández (2004) has applied GT as an overarching methodology to analyze the data in an exploratory study and to guide data collection within and outside the case study. Grounded Theory Method (GTM) provides a "compromise between extreme empiricism and complete relativism" by positioning a middle range stance where systematic data collection is used to develop theories which take into account the interpretive realities of actors in social settings (Suddaby, 2006). Although procurement transactions are socially constructed phenomena, they are very much part of objective reality of various activities in which organizations are engaged which are driven by objectives and rules. Therefore GTM offers a potent alternative for studying procurement risk.

GTM provides a systematic approach for data analysis. Its systematic procedures of simultaneous collection and analysis of data and the constant comparison provide the required rigour to qualitative analysis (Charmaz, 2006). GT is general research method and is useful when studying a relatively little explored area. As field of corruption risk management is a relatively new research field where an inductive approach like GTM would enable researchers to understand the underlying organizational and environmental features that can lead to corruption in an organizational setting. Further, it facilitates generation of concepts and categories which offer immense "grab" for practitioners (Hoda, 2011), therefore, research outcome offers practical value.

Binder et al. (2008) stress that GT is useful when research and theory are at their early, formative stage and not enough is known. As field of procurement risk analysis is a relatively new research field where an inductive approach like GTM would enable researchers to understand the underlying organizational and environmental features that can lead to corruption in an organizational setting. GT is particularly appropriate when main research objectives pertain to identification and categorization of elements and the exploration of their connection (Auerbach and Silverstein, 2003). It would, therefore, be appropriate and quite useful to apply GT in qualitative analysis and data collection in PP risk study. A variety of data can be analyzed through systematic procedures of Grounded Theory can provide the input to construct Fault Tree.

2.5.6 Project Governance And Stochastic Process

Several commentators have observed the current surge of interest in project organizing which has spread beyond construction and engineering sectors (Sha, 2006). Even supply type of contract are now being treated as new type of projects called 'integrated solutions' projects (Davies, 2003). These projects extend backwards into pre-bid or pre-offer stages and forward beyond the handover stage (Brady et al, 2005) by incorporating the activities into operational phase of the use of procured goods. This trend also accompanied the organizational changes i.e.

projectification of firms. This increasing trend of "projectification" of society signifies that today's business environment has turned into a more project-based economy (Lundin and Söderholm 1998; Turner and Keegan 2001). The responsibility for delivery of intended objectives is divided among a large number of entities that result into several problems and challenges. In this regard, project governance is considered as a essential tool for ensuring successful delivery of projects.

Project governance can be conceptualized as a pivotal tool for controlling the risk exposure of individual projects. Turner(1999) defines that the role of project governance is to set strategic direction, set and monitor performance levels, especially profitability, control financial returns. It also incorporates offering technical expertise, providing an auditing function, and controlling the risk exposure. The central issue in the governance study pertains to identification, explication, and mitigation of all contractual hazards (Williamson, 1996) and linked to ensuring order of these transactions. However, this may be disrupted by random risks or opportunism-induced behavioural uncertainty in the project implementation phase (Chang, 2015). Project governance as summarized by Le et al (2014) is one of the main strategy to counter unethical behaviour in the project settings.

Project governance is defined in different ways by different scholars. For instance, it is considered as a set of principles, structures, and processes for undertaking the management of projects by Crawford and Cooke-Davies (2009), whereas, Turner and Keegan (2001) defines it as a central tool to control the risk exposure in every project. Turner (2009) consider it as a set of inter-relationships among the project's management, sponsor, owner and other stakeholders. What all the different definitions emphasize as conceptualized by PMI (2013) is that it's an overarching business function which provides a framework for supporting organizational processes, decision models and project management tools for facilitating successful project delivery. In this regard it becomes necessary to clarify the difference between project management and project governance.

Actually, project management and governance are closely related to each other. For instance, both project management and governance assist in achieving organizational effectiveness and efficiency. While, management is generally linked to the execution of daily work and operational control through hierarchical coordination at tactical level (Sha, 2016), governance is mainly concerned with project's strategic objectives (Biesenthal and Wilden 2014). These objectives pertain to collective interests and the consent of people which leads them to voluntarily do the right things (Müller et al. 2014). Thus, project governance concerns with aligning the project objectives with the strategy of the organization by the project sponsor and project team (PMI 2013).

Williamson (1996) emphasized that governance design should also examine arrangements for addressing moral hazard problems. For instance, Kenny (2009) argued that the separation of functions in the projects can effectively mitigate corruption. Some of the common mechanisms used in project governance are namely; compensation in the form of engineering change, claim, and counterclaim), insurance as financial aid and protection and security in the form of guarantee, mortgage, lien and bond deposit. A performance bond is a kind of bond that is used to provide security for executing the contract. The bond is a deed by which one person commits himself to other person to perform something or refrain from doing something (Martin 2003). Performance bond can be in the form of bank guarantee. They are usually of two types, viz. conditional bond and unconditional bond. The conditional bond makes the guarantor liable upon proof of a breach of the contract terms by the owner and the beneficiary sustains loss as a result of such breach. An unconditional bond is also called 'on demand' performance bond. In case of unconditional bond, the guarantor becomes liable merely when demand is made upon him by the beneficiary and there is no necessity of proving any default by the beneficiary in the contract performance. In construction contracts, a 'performance bond' is submitted by the contractor, usually from a bank or insurance company in a stipulated maximum sum of liability and time validity. This performance bond is enforceable by the owner in the event of the contractor's default, repudiation or insolvency (Robinson et al. 1996). As a precaution, contractor is usually not allowed to execute the contract unless and until the performance bond is given (Azizan et. al, 2009).

Chang (2015) also notes that three type of means; choice of procurement systems, type of contracts forms and financial instruments are commonly used to manage the risk in the projects. Theoretically, these three lines of defence can be effectively used to prevent opportunistic behaviours in the project execution (Sha, 2016). However, due to asymmetric information and complexity, it is difficult for the owner to know the agent's performance. Further, good performance might result from flukes whereas deficient performance may generate from some uncontrollable risk. Given that effort” is not contractible, the agent's best effort can only be elicited (Chang, 2015). Financial instruments like performance bonds, guarantees, and collateral warranties can help to some extent in addressing these risks. In the fixed price contract, contractor would retain all the cost savings. Therefore, if the scope of work can be clearly defined, this type of contract would provide high-powered incentives to improve efficiency (Tadelis, 2012). However, this would not help, if the contractor behaves opportunistically to maximize his saving. Consequently, financial protections are more relied upon as safeguard against the poor performance or quality failures. Greater project complexity generally consequences in more often use of financial protection (Chang, 2015). In the projects, work of regulating the participants’ behaviour can be catalogued into three main categories (Sha and Wu 2016):

- To increase incentives by means of more reasonable allocation of responsibilities, rights, and interests for making participants unwilling to behave opportunistically.
- To increase the difficulty of wrongdoing by using stricter supervision and restrictions, and adopting check and balance mechanisms.
- To increase the risk and cost of wrongdoing which would prevent participants from behaving opportunistically.

However, finding monitoring methods and control system to properly use these means for mitigating underperformance risks still remains an unaddressed issue. Earlier researches (ICAC, 1998; Serpell and Heredia, 2004; Stansbury, 2005; Pryke, 2009; Brockmann, 2011; Adnan et al., 2012) brings out that quality failure, time and cost overruns, safety issues and poor returns are the major challenges faced by the construction industry. These factors not only cause financial loss and induce performance uncertainties but also adversely affect social and economic benefits from them. Real options are now commonly recognized in the literature for valuing and selecting the projects with strategic issues and operational flexibilities (Dixit and Pindyck, 1994). Real option modelling has become quite popular approach for the valuation of both the large infrastructural projects and innovative projects in technology intensive industries (Engelena et al. 2016). Recently, strategic flexibility for managing dynamic uncertainty has been accepted as a vital and useful value-adding part of project management (Ford et al, 2002). Real options allow strategy changes in the future based on how some uncertainty has been resolved (Johnson et al, 2006). Therefore, it can be an effective method of managing the risks of collusion, opportunism and underperformance in construction project. An option is usually a security giving the right but not an obligation to take an action in the future subject to certain conditions. Most common types of options are of two types, viz. call option and put option. While a call option provides the owner a right to buy the stock at a predetermined exercise price on a specified point of time. The option is exercised only when the stock price exceeds the exercise price on that time. A put option can therefore be considered as the reverse of a call option. The put option confers its owner the right to sell the stock at a fixed exercise price. An option provides its owner an opportunity to exercise it and earn if a positive uncertainty unfolds.

The payoff to an option is considered non-linear that will change with the decision taken (Mbuthia, 2000). Mason and Merton (1985:32) view project flexibility as a "description of options made available to management as part of a project". Growth option provides an option to expand the clause. Short closure option is exercised by developers and contractors mutually when it remains no more viable to execute a contract. The exit option provides the option to abandon a project. The option to abandon can be defined as the right to walk away from poor and adverse circumstances. Similarly, termination option provides an option to terminate the contract by the owner or developer when value of project falls below acceptable standards. An important insight is the recognition that well-developed financial theory of real option applies to engineering systems. In case of procurement, General Motors Company has used the theory as material switching options with different vendors in producing new cars. Similarly, Sprint Corporation applied growth option to validate the enormous investments into telecommunication infrastructure for which the technology was yet to exist at the time. It has been used in high-speed rail development in Taiwan by (Bowe and Lee, 2004). It can be considered as a means of capturing the flexibility in the project management to address the uncertainties. Actually, those who are involved in engineering economics, industrial organization, or related disciplines might not be aware of this theory but it should be high on their reading list (Trigeorgis, 1996). The need for real options is increasingly gaining attention within the engineering community (de Neufville, 2004). Actually, options thinking can lead to fundamental changes in the way engineers do system planning and design and handle the uncertainties and shape the management of projects. The essence of a real option, therefore, lies in the value of optimal utilization of all its operating options. The value of the asset underlying the option is assumed to follow a stochastic process. The main difficulty is in quantifying the costs associated with various options, however, it enables the management to analyze the situation with more clarity.Detailed mathematical explanation and fundamentals underlying various stochastic processes used in option analysis can be found in Dixit and Pindyck (1994). However, the most common process used in financial options is the Wiener or Brownian motion process. In these processes, change in value from non overlapping time intervals is assumed to follow a normal or log-normal distribution. A wiener process is the stochastic process which is the scaling limit of random walk in several directions. What it implies is that if one takes a random walk with very small step, one would get an approximation to wiener process. This convergence of random walk towards wiener process is actually controlled by central limit theorem. The central limit theorem establishes that when independent random variables are added, their normalized sum tends to follow a normal distribution. Put simply, it means that the sampling distribution of the sample-means approaches a normal distribution when sample size becomes larger.

As the evolution of the underlying project asset value would depend on work performance of the contractor which itself follows a random walk behaviour or stochastic process, Geometric Brownian Motion (GBM) can successfully be considered in the modelling of project performance. A convenient way for modelling the project performance uncertainty is by treating it as a stochastic process. In this regard, GBM is described by Chou et al. (2007) as a mathematical tool having the capability of calibrating demand volatility quite reasonably and accurately. Actually, GBM is a renowned model that has been frequently employed in diverse fields, like SCM, biology, physics, economics, and financial engineering (Hsu and Wu, 2011). Because of normal distribution of random variable and its application capabilities, GBM can be applied universally (Valis, 2014). Marathe and Ryan (2005) analyzed four data-sets from the energy, transportation, and telecommunication sectors. They found that GBM model a good fit. Qin, and Nembhard (2012) used GBM to generate sample paths of demand forecasting diffusion. Behlaj and klimenko (2011) have used GBM process to study the problem of optimal supervision in banking industry. In the supply chain management area also, GBM has been successfully applied. Park and Padgett (2005) have developed several new models for degradation and failure data using geometric Brownian motion. Chou et al. (2014) has applied GBM in capacity planning. Elsayed and Liao (2004) have applied a Geometric Brownian Motion Degradation Model by utilizing field degradation data of a civil engineering structure for modeeling field reliability. Cui et al. (2004) have argued that project failure cost varies according to the contractor's performance on the work site and applied GBM to model quality failure costs for deciding to buy warranty provisions in highway projects. Following Cui et al. (2004) and Livenh (1996) and considering the fact that quality degradation increments in an infinitesimal time interval of the construction project cycle are independent and additive superposition of multiple factors, GBM can be successfully applied for modelling of quality failure costs. Therefore, what happens at a given time in terms of quality degradation during the execution phase of the project has an effect on the evolving risk profile of projects value.

2.6 CONCLUSION

The chapter begins with reviewing the PP literature with a view to develop an in-depth understanding of the public procurement, identify associated research challenges and develop an organizational perspective of PP risks. Review reveals that procurement subject has been approached from different lines of enquiry and recent research has emphasized the strategic nature of PP. The review also highlights the immediate research attention in PP for reaping significant potential benefits. At the conceptual level, past research has acknowledged some definitional ambiguity. An in depth discussion has, therefore, been presented in the section 2.2 clarifying the core elements of the public procurement along with their role. Keeping the PP complexity in view, process map is also developed to identify the major steps and decisions and understand the interrelationship between various activities in a workflow of PP. In simple terms, public procurement can be considered as a purchase of goods, works and services by governments. However, in reality, it is a very complex function of government involving multiple stakeholders and incurring large public expenditure. One of the main objective of public procurement is to obtain the best possible combination of high quality and appropriate prices. Other policy objectives are social development, employment generation, infrastructure creation, protection of national industry, environment protection etc. Presently, there are several issues and unaddressed problems in PP which are contributing to general discontentment with procurement outcomes.

As the risk perspective helps organizations in adopting a proactive approach, risk analysis may be undertaken to improve the important organizational activities such as public procurement, expenditure management, inventory and supply chain management and other business functions. The risk analysis is specifically crucial in the context of PP because procurement has remained an underutilized tool. In fact, significant advantages in several socio-economic areas can be achieved by improving the procurement outcomes through analyzing the risk present in the PP system and drawing policy correctional measures and other organizational interventions for mitigating the identified risks. PP is often treated by policy-makers and practitioners as an administrative "plumbing and wiring" issue, and best left to procurement technicians (Gutman, 2014) and managers without giving required attention to causal risk factors. Therefore, undertaking risk analysis in public procurement is the prime necessity for aligning the procurement system in the desired direction. As procurement corruption remains one of the major unaddressed issue in PP , earlier research dealing with organizational corruption was also systematically reviewed. These findings were combined into meaningful themes leading to a conceptual model of vulnerability to unethical behaviour in the organization and suggesting the potential methods for risk identification in the procurement. The risk assessment techniques found useful in this context can be considered for integration in future research to build a systematic risk analysis approach for analyzing PP risks.

Most of the present methods of analyzing problems in PP do not help in operationalizing the interrelationship between various elements of PP risk and their identification. As seen from the review, the identification of procurement risk specially to uncover the factors embedded in the procurement process is needed for effective risk mitigation. Therefore, it is required to develop an integrated risk analysis method by considering various risk analysis techniques to facilitate effective procurement risk identification, and conceptualization of their interrelationship. It is essential to capture the interrelations because the PP failures or suboptimal results might be arising from a combination of risk factors embedded in the complex web of organizational policies, processes, vendors, and contractors, etc. It is expected that such an analysis can help in finding the suggestions for designing better monitoring method, clear standards, and changes in the organizational policies that can lead to the improved decision making for timely intervention, evolution of effective organization of procurement work and less performance risk.

Earlier research (Sohail et al., 2008; Heredia 2004; Adnan et al., 2012; Handley and Benton, 2012; Locatelli et al., 2014) have revealed the effect of lack of oversight of contract execution in poor procurement outcomes. As a part of risk assessment, researchers are not only worried about how much one factor affects the outcome, but they are also concerned with how this factor affect that matters. It is therefore necessary to understand the work practices that are resulting in poor performance or undesired outcomes. While reviewing the past research pertaining to work execution phase, it is revealed that a large number of counterproductive and harmful practices are adversely affecting the procurement process in terms of quality, time and cost parameters. These practices need to be organized in a meaningful framework so that they can be incorporated in the mathematical analysis. Game theory and EGT can be effective techniques for analyzing the risk of underperformance arising from these harmful practices so that effective policy correctional measures can be designed.

Recent reforms and initiatives like e- procurement, transparency in tendering procedures, open tendering, etc., have been adopted by many organizations in numerous countries. Similarly, some efforts are being made to develop more effective methods of selecting the vendor for improving the purchase process. Though several initiatives like these have been taken to improve the procurement processes, these efforts have been mainly confined to the front end of the procurement process. Hence, the back end of procurement process i.e. post award phase involving management of contract execution needs urgent research attention. Actually work execution phase is already fraught with several kind of problems which make monitoring of performance a difficult exercise. Coupled with this, the change in the way work is being organized in today's time i.e. projectification, is also making the work setting more dynamic and difficult to manage. Most of the work is presently being done in the form of projects which fragment the capability of even the permanent organization to monitor. Monitoring can, therefore, play a larger role in improving the procurement outcomes because, if poor quality or deficient work remained unattended, it would go on to stay and affect the asset value and its performance in the future. The use of substandard materials shortening the useful life of a road can seriously impact the economic benefits more substantially (Gutman, 2014). Several researchers (ICAC, 1998; Serpell and Heredia, 2004; Stansbury, 2005; Pryke, 2009; Brockmann, 2011; Adnan et al., 2012) have already pointed out the quality failures, time and cost overruns, safety issues and poor returns as major challenges in the projects. Apart from financial loss, these problems induce performance uncertainties and mechanism available in project governance cannot be effectively used because of several reasons. As a result, these problems have still remained unaddressed. In this regard, this review brings out potentially applicable stochastic processes to appropriately model the cost of quality failures which can provide a consistent basis for risk mitigation decisions. In the background of the above mentioned set of diverse and varying problems, risk assessment and management research literature was reviewed to develop the understanding of the concept of procurement risk. Risk literature review also suggests that any one tool or technique may not suffice for analyzing the risks of the multi-phased procurement cycle, thus potentially useful methods were identified in this study for risk analysis and modelling in public procurement process.

CHAPTER

3

RISK IDENTIFICATION AND ASSESSMENT IN PUBLIC PROCUREMENT

3.1 INTRODUCTION

Public procurement(PP) is a very vital policy instrument and an important business operation of government. It provides the required inputs to the delivery of different public services and works; at appropriate cost with optimum levels of quality. At the same time, it is used as a policy tool to meet many other objectives (Bolton, 2006) such as employment generation, social development, infrastructure creation, improving health facility, etc. PP encompasses acquisition, contracting, buying, renting, leasing, and purchasing (Thai, 2001). As a result, it includes functions such as need determination, defining requirement in terms of quantity, quality and time parameters, and administering various phases of contract.

In spite of its centrality, PP is traditionally viewed as a routine and mundane function involving clerical means (Snider, 2006),until recently it has drawn the attention of the scholars. Some scholars consider it as a critical administrative function and highlight its associated unique challenges (e.g., Thai, 2001; Snider, 2006), and some identifies its strategic nature and importance in public policy (Thai, 2005; Rosenbloom et al., 2013; Soliño and Santos, 2016). PP represents significant portion of state's economy in almost all the countries and therefore plays a critical role in achieving various policy objectives. While on the other hand, many problems and issues like poor quality, complexities, poor procurement planning, prevalence of unethical practices, and deficient work, etc. are still continue to remain unaddressed. These issues and problem give rise to various risks in public procurement. Some of the critical concerns are risks of resource waste, and underperformance in procurement process. Therefore, there is an urgent need of understanding these issues and vulnerabilities in the PP processes in the organizations which are contributing to various risks and unwanted outcomes .Actually, PP embraces the active involvement of multiple stakeholders. Intricacies of procurement process, close interactions between public officials and businesses and multitude of stakeholders make PP process analysis and modelling of procurement risks a complex exercise.

Moreover, there exists a lack of conceptual and theoretic coherence within the understanding of public procurement (McCue and Prier, 2007) which makes mapping of procurement risks further difficult. Thus, sufficient research efforts are required in respect of conceptual and integrative work to assist researchers and professionals in making sense of its complexity, uses, and limitations (Snider and Rendon, 2008).Moreover, existing PP literature lacks empirical research apart from a few descriptive studies (Diggs and Roman, 2012).As a result, risk mapping needs to be undertaken with an evidence-based approach to build empirical insights about potential cause and preventive measures. Literature review further reveals that existing literature does not provide systematic methods in discovering the vulnerabilities in the procurement system. A few studies(Golden et al., 2005; Hyytinen et al., 2008; Coviello et al., 2010; Auriol et al., 2011; Basheka, 2011; Wensink et al., 2013; Fazekas et al., 2016) have focussed on procurement vulnerabilities. These studies generally use red flag or risk indicator approach. However, risk identification in this kind of check-list format would not assist in developing the holistic perspective and understanding the interrelationship between various risk factors. Further, quantifications cannot account for all perspectives and thus provide partial insight. Moreover, these models don’t help in uncovering the vulnerabilities present in the organization. Hence, it becomes necessary to develop a systemic view of the procurement risks by combining quantitative and qualitative methods. Therefore, this research endeavour attempts to address this gap by mapping the risks embedded in PP processes using a novel and a robust interdisciplinary approach of integrating inductive and deductive methods. It is expected to be of help to organization in understanding where checks and controls to be implemented for enabling increased prediction and explanation. It also makes methodological contribution as this integrated approach can be used for risk mapping in other activities, and areas.

The notion of risk is quite congruent with an interdisciplinary research. It has been successfully applied in diverse fields such as social, physical, and medical sciences. Moreover, risk-based approach facilitate examining PP processes from multiple perspectives in an integrated framework that would help in identifying procurement risks and proactively designing preventive strategies and actions. The proposed method uses an interdisciplinary approach that combines risk management approach of fault tree analysis (FTA) and Failure Mode Effects and Criticality Analysis (FMECA) with the grounded theory (GT) method for mapping risks in the public procurement. FTA is a well established risk management approach and being used in various fields. It is based on deductive logic and begins with analyzing an event of system failure and then aims to deduct potential contributors to failures. Savage (2007) suggested use of techniques like FTA for breaking down of corruption risks into causal risk factors.

Procurement risks can be considered among other things a result of incidence of failure of control and deterrence and weakness in the procurement structure of the organization. Accordingly, system weakness or deficient control or prevalent improper practices may be considered as negative states or faults. These negative states can be easily described in terms of multiple aspects such as, tasks occurrences, decisions, process vulnerabilities and other organizational factors like, policy, practices, control inadequacies, and resource deficits, etc. These states and/or circumstances are the interrelated risk factors and risk events that contribute to the likelihood of corrupt behaviour. Fault tree offers an easy and reliable way of conceptualizing their inter-relationships to show how the existing vulnerabilities can be exploited. FMECA is also a very useful risk analysis technique (Cetin, 2015). It is anchored in inductive logic and applied to identify failures that have significant effects. Actually, deduction logic alone cannot comprehensively identify risk and decompose it into causal risk factors or preconditions. Saud et al. (2014) suggests that concept of cause consequence analysis involves combining the inductive and deductive reasoning. PP being a complex function and serving multiple functional and policy objectives, combining induction and deduction logic would help in comprehensive identification of PP risks. Earlier studies (Najib et al., 2013; Sallam, 2015) had integrated failure analysis techniques successfully. In this regard, Grounded theory (GT) is considered to be appropriate for integration with FTA and FMECA to reach the desired valid results as it is a general methodology and been applied to understand the social context through systematic qualitative analysis of data. Actually, GT approach is well suited to the study the complex entities and phenomenon as it is able to produce a multifaceted account of organizational action in context (Locke, 2001), therefore GT is considered as appropriate in this research.

The regulatory and monitoring objectives for PP are considered in terms of equity, integrity, and economy and efficiency (Kelman, 1990). As a result, issues pertaining to inefficiency, corruption, and value for money become important for mapping of procurement risks. Actually, many of the performance failures and poor outcome arise from unethical practices prevalent in the procurement process. For illustration, delays and cost overruns in projects often are the consequences of corrupt practices (Sohail et al., 2009). Corruption also causes a lot of setbacks to projects such as abandonment of such project and/or below standard completion (Oyewobi et al., 2011). It may manifest in various forms of unethical practices in public procurement. Corruption is usually viewed as misuse of public office for private gain and may lead to distorted prices, inflated procurement costs and may place the honest businesses in disadvantageous position. It also acts like a tax adding to the cost of providing public services and conducting business (Olken, 2007) and jeopardizes the public sector's ability to provide adequate levels of public goods for facilitating development of private sector (OECD,2013). Consequently, it has become a prominent issue all over the world, intensified by the globalization of commerce and encountered in different degrees in all countries (Petrou et al., 2014).Actually, public procurement functions involve repeated interactions with external entities and possess inherent opportunities for corruption that may enable procurement managers to take undue advantage, of their expertise and position. It would take long time for sociological and political communities to undertake long term processes of cultural and policy changes to handle the corruption(Locatelli et al, 2017), organizations should focus on vulnerabilities embedded in the PP processes, also.

Three broad perspectives, viz. economic oriented, fraud triangle, and organizational behaviour have been used to study various unethical practices. Each perspective employs a different diagnostic toolkit which would recommend a different kind of response (Larmour 2006).Economic theory-based approaches view unethical behaviour as abuse of opportunities as rational and self-interested behaviour and recommend for restructuring the organization settings to make consequences of unethical behaviour un-profitable. Empirical evidence regarding success of this approach is not encouraging (Misangyi et al., 2008). Organizational behaviour perspective focuses on regulative i.e. organizational controls, normative and cognitive aspects to understand the normalization of unethical practices. This approach focuses on cultural changes and internal factors in the organization. Fraud triangle is quite effective conceptual model for explaining the unethical behaviour but it does not capture collusive behaviours and concealment schemes which involve external elements and auditors.The establishment of mechanism of auditing, oversight and control can be costly and time consuming therefore an appropriate system for identifying risk factors that lead to corrupt practice must be devised (Anderson et al., 2012). The difficulty of stopping corrupt activities that have become embedded within daily routines leads some researchers to suggest that corruption is best handled through prevention (Ashforth et al.,2003). An understanding of the causes of corrupt exchange is a useful way to anticipate and prevent its re-occurrence. Considering the significance of PP corruption consequences as discussed in the aforementioned paragraph, risk-based approach developed here in this chapter is applied to identify the procurement risk in general and then specifically used to find the criticality of risk factors in respect of corrupt practices in PP.

In the present risk analysis, past procurement cases are selected on the basis of theoretical sampling from multiple organizations. Firstly, it triangulates data sources in our qualitative analysis which improves the congruence of findings with the reality. Secondly, such an analysis would instantiate common corrupt practices and provides a general pattern of corruption risk which is expected to improve the transferability of the findings to different social settings. Thirdly it provides varied insights and rich information about wide spectrum of possible manipulations in procurement process which help in improved understanding of interrelationship between various elements of analysis. This in turn facilitate the generation of the findings of academic and practical relevance.

The remainder of this chapter is organized as follows. First, it presents literature review and theoretical background of fault tree method and grounded theory. Next section 3.2 outlines the methodical design of the integrated model. Then, it illustrates the application of proposed model to procurement activities and present data analysis by analyzing earlier published corruption case reports. This section also demonstrates qualitative analysis of fault tree model by using minimum cut set method. Section 3.4 brings forwards the managerial implications and limitations of our study. Finally, we present conclusion and suggest fields for future research.

3.2 METHODOLOGY

Public procurement is used for multiple goals and objectives. It need to be responsive to aspirations, expectations and needs of the society (Amemba et al, 2015).The good procurement process include various effective mechanisms which enable careful spending of the resources, facilitate competitive supply, efficient monitoring and embracing best practices for inventory storage and need assessment. Therefore, treating it a simple clerical formality would be detrimental to efforts for developing a useful body of theoretical and practical knowledge (Diggs and Roman, 2012).Several measures like forecasting, value engineering, value analysis, requirements consolidation, inventory management, and material standardization have been used to reduce procurement cost. Ensuring fairness in contract awarding phaseis also considered crucial to ensure efficiency and accountability. However, existing methods do not help in discovering the process level vulnerabilities and nor they provide information about their interrelationships. Risk analysis in the PP is required to facilitate developing the understanding about the problems in PP and associated contributing factors. This entails undertaking a comprehensive analysis of these factors and devising preventive measures. Risk analysis methodology is developed for finding various procurement risks and developing preventive measures. Considering the significance of impact of unethical behaviour in PP, it has then been applied for analyzing severity of various risk factors in reference to procurement corruption. In this regard, Basheka (2011) points out that PP corruption studies are more difficult to carry out because of the variety of causal factors. It becomes further difficult due to hidden nature of corrupt exchanges. Sometimes, procurement corruption schemes are inter-related and used in a complementary manner. For example, corrupt acts can be planned at the stage of need identification and design of tenders. Moreover, basic procurement processes are not robust enough and procurement regulations and laws are unable to offer remedial measures (Thai et al., 2005). Therefore, it is necessary to revisit the PP system considering the real world organizational transactions and undertake their qualitative analysis (Sharma et al., 2016). Additionally, this approach will provide empirical base for more robust and systematic risk mapping in public procurement process.

Considering the difficulties in getting access to research site and participants, researchers choose the cases where topic of interest is available as recommended by Eisenhardt (1989). Multiple cases create more robust theory as resultant findings are very well grounded in the diverse empirical evidence (Graff & Huberts, 2008; Eisenhardt & Graebner, 2007). GT has been used recently successfully for qualitative analysis in corruption studies (Kihl et al., 2008; Pfister 2009; Jancsics, 2015). Charmaz (2006) points out that it can be modified and applied to suit the nature of the research problem. Graycar et al. (2012) also used past cases in the analysis to develop an inventory control and opportunity structure. At the same time, earlier research (Savage, 2007; COSO, 2012) has recommended for use of risk assessment techniques like FTA and cause effect analysis for breaking complex structure of corruption risk.

FMECA is one of widely used risk analysis technique. Its key application is to rank potential failures according to the combined influence of their severity and probability of occurrence. By determining the criticality, it is possible to prioritize remedial measures for risk mitigation. While studying a complex system with FMECA alone, it is difficult to identify all possible failure modes. Whereas combination of more than one fault or factor can be better considered by FTA (Birolin, 1999), but it does lack a method for assessment of criticality (Peeters et al., 2018). Thus, analyzing risk with FTA in combination with FMECA would make analysis more reliable and make it possible to quantify the results. Combination of FMECA or Failure Mode Effect Analysis (FMEA) and FTA can provide better assurance for completeness of analysis (Birolin, 1999). FTA has been successfully combined with FMECA by Cheng et al. (2005) and FMEA by Yu et al. (2011), Han et al. (2013) and Peeters et al. (2018). FMECA extends FMEA by incorporating a criticality analysis by considering the probability of failures against the severity of their consequences. Authors have therefore preferred FMECA over FMEA as this research aims to quantify the criticality of effects of risk factors for ranking them.

In view of above facts, this research employs a holistic design for risk analysis and draws on publicly available data to provide input for conducting risk analysis. The method uses inductive grounded theory approach to analyze case reports to develop Fault Tree for corrupt actions. By integration of FTA, FMECA, and GT, this research uses triangulation as an attempt to reach valid research result as suggested by earlier research (Denzin, 1978; Silverman, 2001).It is reiterated that FTA uses deductive process whereas GT and FMECA embrace an inductive approach. In fact, the concept of cause-consequence analysis is a combination of the inductive and deductive reasoning of logic diagrams (Yaneira, 2013). Therefore inductive and deductive processes are not mutually exclusive in our research enquiry and form an integrated approach. Some of the consequences or causes that are not the most undesirable but occur frequently may be omitted while constructing Fault tree focus with deductive method (Qinghe et al., 2012). Such a situation would be avoided by combining inductive and deductive reasoning in undertaking systematic analysis of sample data. Moreover, the application of GT is appropriate when the research focus is explanatory, contextual, and process oriented (Eisenhardt, 1989). The main objective of choosing GT based coding paradigm is to provide a data sampling method suiting to procurement study, and facilitate a structured qualitative analysis fordeveloping interconnection between risk factors, and identifying risk consequences. Before presenting the risk analysis method, theoretical background of FTA, GT and FMECA is presented in following subsections.

3.2.1 Grounded Theory

Initially, GT was applied in sociology. Decoding a large sized qualitative data and deriving a theory from therein is indeed a great challenge to the social science researchers. To address this issue, Glaser and Strauss (1967) developed the GT which discovers a relationship amongst certain categories such as structural conditions, consequences, norms, processes, patterns, and systems, etc., based on inquiry from the data.

A GT is one that is discovered, developed, and provisionally verified through systematic data collection and analysis of data pertaining to a phenomenon under study (Strauss and Corbin, 1990).In fact, GT is now considered to be one of the important qualitative inquiries in social science research. It can be considered as a general style of doing analysis which is not dependent upon any particular disciplinary perspectives (Strauss 1987). As GT is a general methodology a way of thinking about and conceptualising data, it has been adopted to studies of diverse phenomenon. For instance, the GT approach had been applied in the studies of operation and quality management, and organization behaviour. In fact, it has been one of, if not the most, prevalent methodological citations appearing in the published qualitative studies (Locke, 2001). GT embraces specific data analysis procedures which, when applied appropriately, would result in rigorous and well grounded theory (Lawrence, 2013). The essential concept, techniques and procedures of grounded theory that will be used in this study are discussed below:

3.2.1.1 Theoretical Sampling

Theoretical sampling means checking emerging theory against reality by sampling incidents that are relevant to study and may challenge or elaborate its developing claims. It can be considered as a unique process of data collection where researcher simultaneously collects, codes and analyze the data and decides what data is required to be collected and where to find them. Grounded theory uses all data that is available i.e. interview case reports, case study etc. In fact, it considers even existing literature as a source of data which need to be integrated into constant comparison process. It implies that researchers enter into data gathering exercise with the idea that this will be an open ended and flexible process which is likely be modified during the study when researcher compose, and work to clarify, elaborate and refine the conceptual categories and conceptual scheme (Locke, 2001).

3.2.1.2 THEORETICAL SENSITIVITY

Theoretical sensitivity entails the ability to generate concept from data and relate the data to research enquiry and questions. It requires the ability to develop theoretical insights and conceptualize data for which it is recommended that researcher should familiarize himself with the research subject.

3.2.1.3 THEORETICAL SATURATION

The researcher continues data collection process until no new categories can be identified, or when new instances of variation cease to emerge i.e. theoretical saturation has been achieved. It implies that just enough data has been gathered in the process and subsequent data that are examined provide no new meaningful information. GT analytical process is completed when core categories are theoretically saturated and continued as iterative process as shown in Figure 3.1.

3.2.1.4 CODING

Data analysis process begins with the coding as shown in Figure 3.1. Charmaz (2006) defined coding as "naming segments of data with a label that simultaneously categorizes, summarize,

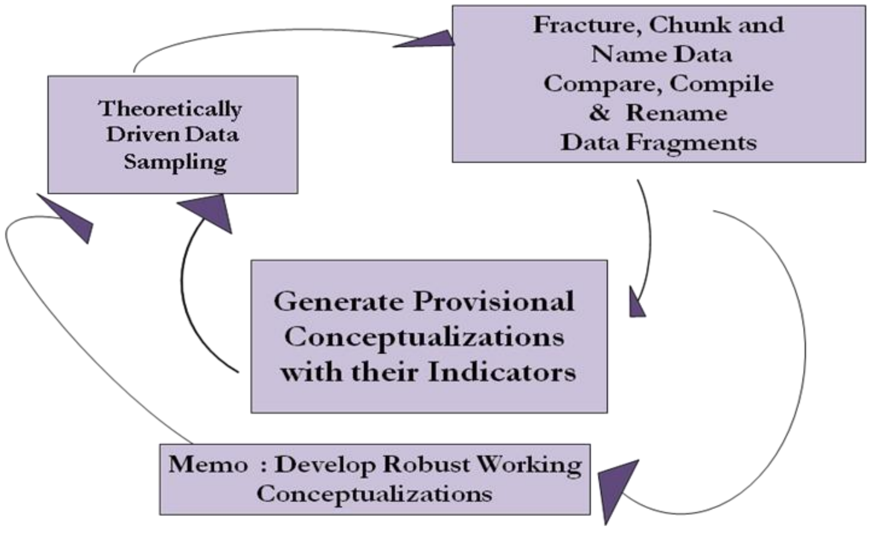


Figure 3.1: Analytical Process in Grounded Theory Research

and accounts for each piece of data. Coding leads to making analytic interpretations. The coding paradigm span over the three forms of analytic activity which focus on the slightly different aspects of naming and comparing different levels of conceptual perspective (Locke, 2001). In simple words, coding procedures are theoretical schemes or conceptual templates which enable researcher thinking about possible theoretical categories and their interrelationship. Coding is undertaken at three different levels; open coding, axial coding and selective coding. These three types of coding are detailed below:

3.2.1.4.1 Open coding - Categorising strategy

The focus of open coding is on finding the similarities that could be used to sort data into categories (Maxwell 2005). During open coding transcripts are compared, conceptualized and categorised (Ambe et al, 2011). It pertains to the naming and categorising of phenomena through close examination of the data (Lawrence, 2013). The process begins with line by line coding of data by researcher for identifying and naming each phenomenon (incident, idea or event) which capture its essence which in turn generates concepts. This process of grouping concepts at a higher and abstract level is known as categorising.

3.2.1.4.2 Axial coding- Pattern matching

The open coding fractures the data into concepts or categories and followed by axial coding. The axial coding process puts those data back together in new ways by making connections between a category and its subcategories (Strauss and Corbin, 1998). It therefore enables researchers to identify patterns within the established categories through the process of constant comparison of the texts analyzed. After identification of categories researchers is required to refocus on instances of differences within a category so that subcategories can also be identified to capture full complexity of the process. Constant comparison enables researcher to connect and integrate categories in such a way that all instances of variations can be explained by the developed model. Strauss introduced the term ‘axial coding’ for formalizing the naming and comparing activity which is essential for fully developing their properties and finding their possible relationships to each other. The Figure 3.2 explains the framework for moving from open coding to axial coding.

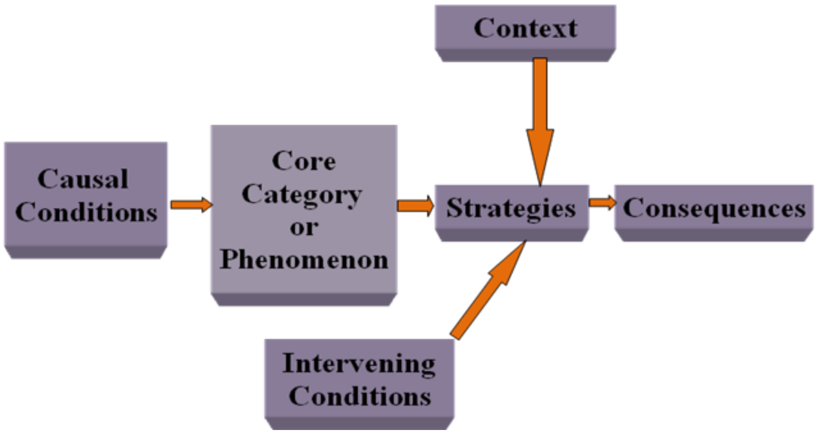


Figure 3.2: Framework for Axial Coding

3.2.1.4.3 SELECTIVE CODING

Selective coding is the final stage of data analysis. During the selective coding process, concepts and categories identified through preceding stages are further developed, and refined and brought together to identify central or core concepts which represents central phenomenon. These core concepts are then systematically related to other categories. The essential idea is to summarise all the data incidents by developing core categories which explain the central phenomenon completely.

3.2.1.4.4 MEMO WRITING

This is an important part of the GTM which involves theorizing and commenting about codes. Memo writing is undertaken throughout the research process. Memos may be either observational note or methodological note or theoretical note. Theoretical memos are essentially coding summaries, questions and discussion about concepts and emergent relationships. Memos are used to define each code or category by it's analytical property and in making comparison between data and data, data and code, codes and codes. Memos help in keeping a written record of progressive integration of higher- and lower-level categories and subsequent theory development.

3.2.1.4.5 CONSTANT COMPARISON

During entire course of study, the researcher constantly compares data, memos, codes and categories and is shown in Figure 3.3. Glaser (1978) names this process as the constant comparative method. In constant comparative method, parts of data are compared with other and codes are constantly confronted with new data for the purpose of verification.

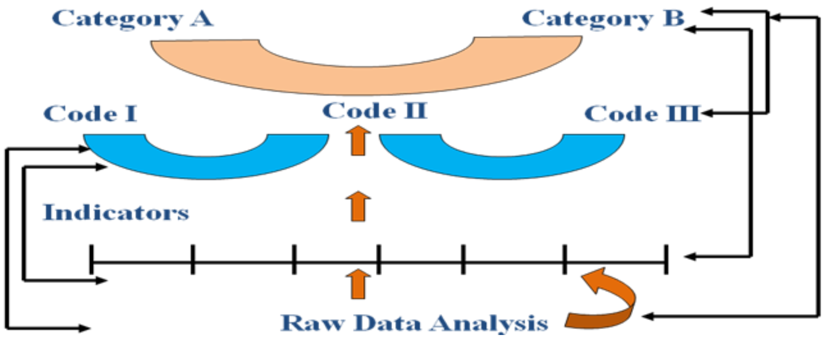


Figure 3.3: Constant Comparison Processes

Actually, constant comparative is central part of the data analysis in the GT. Its basic purpose is to develop and elaborate a category by examining all the data it covers and variations from it (Lawrence, 2013). Comparative analysis compels the researcher to full develop an emerging category by finding its structure, temporality, causal factors, contextual conditions, consequences and its relationship to other categories. As discussed above, data interpretations and categories evolve saturate until they 'fit' the data (Glaser 1978).

3.2.2 FAULT TREE

FTA was initially developed by H. A. Watson at Bell Telephone Laboratories in 1961. It was developed as a result of efforts put in the safety program for the Minuteman Launch Control System. Subsequently, it was refined at Bell Telephone Laboratories and at Boeing Company (Haasl, 1965). Thereafter it got widely accepted in the aerospace and nuclear industries, and later on in the chemical process industry also (Fussell et al, 1974). Fault Tree Analysis is now one of the well- established techniques used in a wide range of industries (Ruiters et al, 2015). It is a top-down deductive analysis that traces failure paths. It is essentially a graphical method that works on the principle of multi-causality and models how failures can occur in a system. It can also be considered as a logical tree where events are linked nodes represented by gate symbols, tracing all branches of events which could contribute to system failure. In essence, it is a technique used to enhance the success probability in any system by analyzing the all potential failure modes (Witkin, 1972). Deductive analysis involves reasoning from the general to the specific. In a deductive analysis, we hypothesize that the system has failed in a certain way and then attempt is made to observe what factors have contributed to this failure. As a result, FTA connects a specific failure to its potential causes (lower-level events) through logic gates. Typical real life examples are accident investigations where deductive analysis is used to find out which processes, instrument, and human fault contributed in causing accident. The top event is generally a complete or catastrophic failure in the system. Alternatively, it may be the failure of a mission or some subsystem or components also.

Starting with the top undesirable event and then finding all the potential ways it can happen is summarised graphically in a fault tree. The graphic model shows various parallel and sequential combinations of faults which can result into occurrence of the undesired top event. A fault tree thus illustrates the logical interrelationships of basic events which result in the undesired top event.

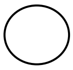
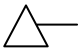
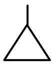
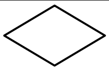
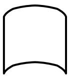
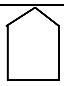
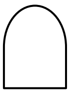
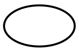
3.2.2.1 THE BUILDING BLOCKS OF THE FAULT TREE

As discussed above, fault tree is a graphical representation. It consists of two types of nodes; events and gates. Table 3.1, introduces different type of gates and events symbols used in FTA. The primary events of a fault tree are those events, that have not been developed any further. These are four types of primary events which are as under;

(a) Basic Events
(b) Conditioning Event
(c) Undeveloped Event
(d) External Event

In addition there is an intermediate event. It is actually a fault event that takes place due to one or more antecedent causes acting through logic gates. Circle denotes a basic event that needs no further development. Stated simply, it signifies that the appropriate limit of breaking down the risk analysis has been reached. In the case of fault tree developed for a procurement related irregularity, it may represent either any corruption risk factor or vulnerability embedded in tasks associated with public procurement. The diamond denotes a specific fault event which is not further developed, either because it is of insufficient consequence or because relevant information is not available. Rectangle represents intermediate event that results from a combination of less general fault events. It is main building block for the analytical tree. It is the only symbol which would be having a logic gate and other input events below it. House identifies as an external event which is normally expected to occur in a system. It is also referred as initiating event. However, these events those are not, of themselves, faults. An oval symbol represents conditioning event i.e. a special situation which can occur only when if certain circumstances happen. The details of the symbols can be seen in Misra (1992).

Table 3.1: Gates and Events' Symbols used in FTA

Symbol	**Event/ Gate**	**Symbol**	**Event/ Gate**
	Basic event		Transferring out point
	Intermediate event		Transferring in point
	Underdeveloped event		OR Gate
	External event		AND Gate
	Conditioning event		

3.2.2.2 MINIMAL CUT SET ANALYSIS

Minimal Cut Set (MCS) is one of the qualitative methods used for analyzing fault tree. The concept of MCS is relatively new and applicable to all fault trees. It is still being explored and developed for effective application as the initial concept was developed in generalized form (Clark et al, 2012). It is a mathematical technique applied for utilizing the logic relationship of a FT to identify all those combinations of basic events which lead to the occurrence of the top event.

A cut set in a fault tree is a combination of those Basic events whose concurrent occurrence ensures that the TOP event takes place. A cut set is called MCS if this set cannot be reduced any further. Actually, it rearranges the fault tree in a way that none of the basic event which appears in various parts of a FT is "double counted" during the quantitative evaluation. In essence, MCS analysis reproduces a new FT which is logically equivalent to the original FT. The new equivalent FT consists of an OR gate below the top event, whose inputs are the

MCS. The symbol "+" is used to represent the logical OR operator whereas the symbol "." is used to represent the logical AND operator. Therefore, MCS can be expressed as follows;

$T = M_1 + M_2 + M_3 +... + M_k$

T represent top event and M_1, M_2,......&M_k symbolize minimum cut sets. In minimal cut set analysis, we actually reduce basic event combinations i.e. cut sets to find the minimal sets of events necessary and sufficient to cause the occurrence of the top event. In other words, MCS is an AND gate that contains a set of basic inputs which are necessary and sufficient for occurrence of the top event.

In this process, we first mathematically express fault trees by using Boolean logic for defining the relationship between events of a fault tree. Accordingly, a FT is expressed into an equivalent set of Boolean equations. Now, we find the MCS by identifying the combination of minimum events from the equation. The Boolean equations representing cut sets is mathematically and logically equivalent to the original FT. However, the MCS form is more amenable to quantification. This process ensures that any single event that emerges repeatedly in different parts of the fault tree is counted only once. Following are the import defining properties of minimum cut sets:

a) MCS are the failure pathways involving those minimum no of components which are sufficient for the occurrence of top event. •
b) In a MCS, the occurrence of all events is necessary for the top event to take place.
c) There exists finite number of distinct MCS for the top undesired event in every fault tree.

A fault tree can be evaluated to yield its qualitative and quantitative characteristics. However, these characteristics cannot be directly derived from the FT itself. Rather, they are extracted by finding equivalent Boolean equations. The relevant details pertaining to basics of Boolean algebra are explained in Appendix A.

3.2.3 FAILURE MODE EFFECT AND CRITICALITY ANALYSIS

FMECA is a technique to address the potential problems in a system at the design stage (Sematech, 1992). Subsequently it has been adopted in operation stage. Simply stated, it is an inductive approach and uses method of process analysis that identifies and prioritizes potential failures. It was initially developed by the National Aeronautics and Space Administration (NASA) to improve and verify the reliability of space program hardware

(Carlson, 2012). It is performed by defining all the possible functional failure modes and their effects on the system (Cetin et al., 2015). Potential failure modes and their consequences are first identified. Failure mode is the way in which a failure is observed in meeting the requirements. A criticality measure is then calculated for each potential failure on the basis of occurrence rate and severity of the possible consequences. Finally, these failure modes are prioritised as per their criticality levels for prioritizing the effort. FMECA also highlights single point failures (Cetin et al., 2015), therefore analysis can be performed at the piece-part level like individual component, process step or task or functions. This study focuses on component level while applying FMECA i.e. risk factor level as failure modes have already been identified by using FTA and MCS analysis.

3.2.4 METHODOLOGY DETAILS

The proposed approach examines the PP process from a micro-perspective. It uses triangulation as an attempt to reach valid research result as suggested by earlier research (Denzin 1978, Silverman 2001). This approach allows triangulation at the level of data sources by allowing a variety of data for analysis and methods as well by combining grounded theory and fault trees. A similar approach was adopted by Turner (1976) in disaster by relying on the detailed accounts of action that was available in the public inquiry records of three disasters from which constituted his data source. The first disasters resulted from a slide of a portion of a colliery tip onto the Welsh village of Aberfan that led to death of about 150 people, most of whom were children. Second incidence was of a collision between a slow moving transporter with an express train on an automatically controlled railroad crossing. Third disaster was of a fire incidence in a holiday leisure centre. The three incidents were sampled on the basis of theoretical sampling as they provided different instances of serious disasters having common features; informational complexities and failures of foresight.

3.2.4.1 PROCEDURE

As per the Grounded theory procedure, three types of coding were computed – initial coding, axial coding, and final coding – along with memo in order to identify the relationships between phenomenon of the study, causal conditions, context and intervening conditions, action strategies, and consequences (adapted from Strauss & Corbin, 1990). The detailed analytical procedure is depicted in Figure 3.4 and mentioned below:

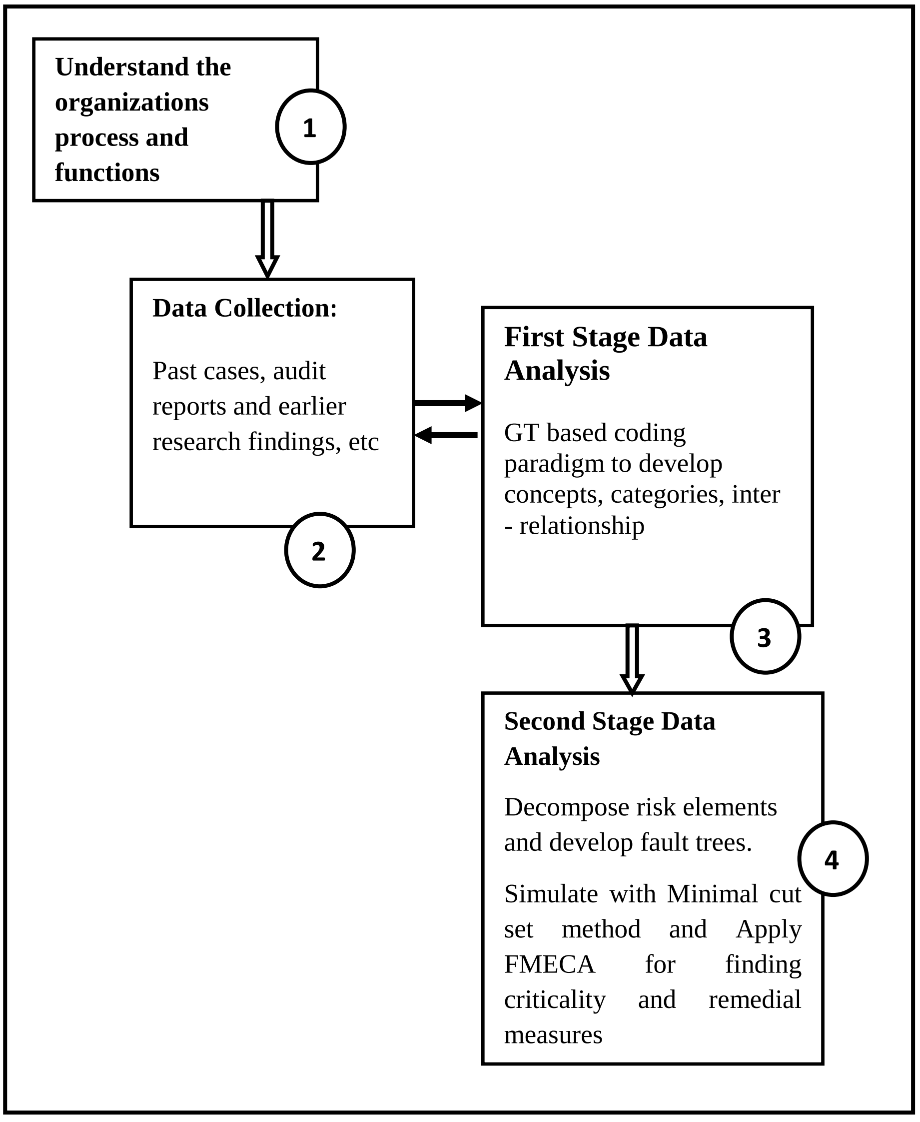


Figure 3.4: Methodology of Risk Identification and Assessment

- Codification and analysis were done by using cases, reports and other data as key building blocks. Then categories were developed by clustering codes and document the process through memos.
- Next level coding was the axial coding. Here, data were re-organized in new ways by finding interconnections between categories developed from earlier step through constant comparison to refine and integrate categories.
- Core categories that included integration of categories and formation of theoretical narratives were developed to identify relationship between potential causes and corruption outcomes.

- Then emerged relationships were analyzed with backward deductive logic to trace back the corruption outcomes to the potential first level contributors /causes, examine them to determine its subordinate causal factors, and describe their logical interrelationship.
    - (a) Identify potential first level contributors and examine each of them to determine its subordinate causal factors;
    - (b) Examine the relationship between contributors to ascertain the nature of logical connectors to link them; and
    - (c) Continue (a) and (b) until basic events can't be separated further.
- Thereafter the possible multiple corruption pathways were simulated by using minimal cut set method (MCS).
- Finally, FMECA was applied for finding out the criticality score for risk factors involved in basic events and finding mitigation measures.

3.2.4.2 SAMPLE DATA

Data were collected from the procurement corruption case studies on the basis of theoretical sampling and theoretical saturation. It offers three advantages. Firstly, it triangulates data sources in our qualitative analysis which improves the congruence of findings with the reality. Secondly, it provides a general pattern of procurement corruption risk which is expected to improve the transferability of the findings to different social settings. Thirdly, it provides varied insights and rich information about wide spectrum of possible manipulations which help in improved understanding of interrelationship between various elements of analysis. As it is essential to ascertain 'just enough level' in data collection exercise in the qualitative research without compromising the validity of research, theoretical sampling and theoretical saturation were used in this research to optimize data collection. Theoretical sampling means checking emerging theory against reality by sampling incidents that are relevant to study. As research progresses, researcher develops an understanding and concepts which direct his/her further data search. In this sense, it is purposeful sampling but purposeful according to concepts and categories developed from one's analysis (Charmaz, 2006). When no new categories can be identified, and new instances of variation for existing categories have ceased to emerge, theoretical saturation is said to have been achieved.

Data collection began with the theoretical sampling and researchers iteratively moved back and forth in case selection and coding analysis. Owing to the difficulty in access to research cites, data search was made from the publicly available resources by selecting the case studies where topic of interest was observable. It continued with the research objective of studying various prevalent unethical practices schemes in public procurement by following principle of theoretical saturation. A total of 69 case studies were selected for grounded analysis. The cases were picked from the construction, infrastructure, health, power, oil, gas and port, and goods and services sectors. Out of these 69 cases, 27 were taken from 26 countries and remaining 47 cases were based on real occurrences but did not contain country names and taken from multiple organizations. Eleven case studies were taken from construction sector, 28 from infrastructure, 11 from service, 7 from health, and 5 were from 'Power oil and Gas'. The data references details are given in Table B.1 of appendix B.

3.3 Data Analysis

The analysis began with coding exercise. The coding paradigm involves three forms of analytic activities that focus on the slightly different aspects of naming and comparing different levels of conceptual perspective (Locke, 2001). Initially, transcripts were broken down into discrete parts, examined them closely by comparing for similarities and differences to understand the underlying phenomena. The cases were therefore coded line by line for capturing the key points of data i.e. identifying and naming each phenomenon (incident, idea or event) which captured its essence that in turn generated concepts. For illustration, several concepts like copied specification, tailor-made specification, specification rigging, framing specification in a biased manner, lock-out specifications, etc., emerged. They represented one common phenomenon, i.e., specification suiting to one bidder. Initial coding was followed by axial coding and selective coding. Initially coding fractured the data into concepts or categories, however axial coding process puts those data back together in new ways by finding inter-connections between various category (Strauss & Corbin, 1990).

This coding paradigm was actually iterative and codes titles and descriptions were changed and refined as researchers became more familiar with data and interrelationships emerged. Each identified code was briefly commented and defined through the analytical description in Memos.

In order to increase the reliability of coding and analysis, three measures were taken. The provisional codes were reviewed by the second coder. The results were compared and led to minor changes in refinement of coding and categories and emergence of new codes. Secondly, literature was referred to find whether the observed phenomena were coded and named earlier. It helped in removing the potential ambiguity and facilitated enfolding existing body of knowledge in this research effort. For example, some cases described the incidence of a favoured bidder being supplied with confidential information needed to bid according to the requirements. This increased the likelihood of winning the contract. Such a phenomenon was already described as unbalanced bidding in OECD (2010, p.10) and therefore it was taken as one of axial code. Thirdly process maps were developed to increase the understanding about functions analyzed.

For axial coding, data were reorganized in new ways by relating the codes to each other through the process of constant comparison. Observations from the case studies were compared with other data incidents for developing a common name or code for multiple observations. For instance, several initial codes signifying ambiguity in contract documents were developed. These were namely; incomplete contract details, incomplete work details, the bid document did not mention the quantity requirement that allowed them to make profit and incomplete price details. From these comparisons of codes, axial code of bid obscuration emerged. Thus, it enabled researcher to explain all instances of variations by capturing full complexity of the process. A sample of initial and axial coding is shown in Table 3.2.

Table 3.2: A sample of Identification of Concept during Initial and Axial Coding

Sl. No	Initial codes	Axial Codes	Operational definition
1.	Adopt negotiation on the ground of unjustified urgency; Frequent and unjustified use of a negotiated procedure for additional procurement; frequent and unjustified use of the negotiated procedure for reasons of urgency.	Abuse negotiated procedure	Abusing discretionary negotiated procedures in the procurement activity.
2.	Defining the items in such a way that only a particular bidder is able to execute the contract; bid document contained unrelated diversified products; intentionally altered the material	Unjust item description	Defining the items in a way that can be met by a particular bidder.

	requirements in the tender to favour a supplier		
3.	specifications included in bids had been such that adequate furniture could only be offered by an exclusive representative; measurements were set without any tolerance of possible even minimal variations; nominates a particular brand of air conditioning plant for use in project; volume indicated in the specifications is smaller than the estimated volume; tailored tender specifications for computer software; Consultant wrote the tender specification by relying almost entirely on input from Company	Tailored specification	Unreasonable specification that are tailored to favour a particular bidder
4	Incomplete contract details; incomplete work details; bid proposal did not mention the labour rates that allowed them to make profit.	Bid documents obscuration	Intentional incompleteness of bid documents regarding certain items having financial significance.
5	Corruptly obtain payments by supplying confidential information about a series of high-value engineering projects; information leak to favoured contractor.	Information leakage	Supplying confidential information with the favoured bidder that is not shared with others.
6	Supply of false expert evidence in dispute resolution proceedings; claimant offers witness a percentage of any future award to give false evidence to support claimant in arbitration; concealment of documents in dispute resolution proceedings; supply of false witness evidence in dispute resolution proceedings; a witness giving evidence on behalf of claimant; witness confirming that supporting documents are genuine though he knows that they are false.	Manipulating dispute resolution	Influencing the dispute resolution proceedings by manipulating the expert advice and other evidences.
7	A favoured bidder is supplied with confidential	Unbalanced	Bids containing high

	information which is not shared with other bidders. This information enables the favoured bidder to customize its bid according to requirement and thus increases its likelihood of winning the contract	bidding	prices for the items that the contractor knows or anticipates will be increased and low price for the items that are not likely to be executed.

After axial coding, final or selective coding was undertaken to identify central concepts which represented central phenomenon and explained most of the variation in a pattern.The final coding involved systematic approach towards development of core categories (key characteristics) that included integration of categories developed during axial coding into theoretical framework and identifying any redundancy or inadequacy in the coding.

Following the initial coding approach along with the constant comparison method, 866 useful codes emerged. These codes were subsequently aggregated, and clustered into 274 axial codes which finally led to the emergence of seven core categories (selective coding). A conceptual overview of the relationship developed from the analysis is presented in Figure 3.5. The analytical process of coding and memo writing resulted into seven core categories of risk consequences at organization level; financial loss, reputation loss, wastage, undue private gain, potential safety hazards, unfair contract awards and sub optimal performance (due to substandard products and reduced access to public services). It has other indirect impacts also like impeding social and economic growth which were not developed in our model. Safety hazard; unfair contract award and wastage are important risks present in the PP.

Risk of wastage needs special mention because of lack of conceptual clarity about it. One of the common public notions about waste is associated with the debris generated in the construction work. However, wastage has a specific connotation in reference to public procurement. Actually, it indicates the non value adding activity resulting into loss of efficiency. For construction projects, Skoyles (1976) categorises waste as direct and indirect material waste. Direct waste includes instances of complete loss of materials either due to irreparably damaged or simply lost. Whereas, indirect waste takes places when materials are not physically lost but causes financial loss. For instance, waste due to concrete slab not conforming to dimension specified in the structural design.

Figure 3.5: Conceptual Relationship

Similarly, Bandiera et al (2008) distinguish waste as active and passive waste in case of public procurement. Active waste entails direct or indirect benefit for a public official which in-turn indicates presence of corruption. On the other hand, passive waste does not provide benefits to the public official. It may arise from the multiple risk factors. One of the potential causes is excessive regulatory burden that make procurement cumbersome and increase the average price that the public body pay (Kelman; 1990, 2003). Another one is that public officials don't have knowledge to optimize the cost or procurement process is poorly planned. PP process is found to be closely interlaced with inventory control and management. As seen from the study, poor inventory control practices may lead to three major kind of waste, (a) Excess materials, (b) Out-of-date, expired, or out-of-specification materials and (c) Materials that are no longer needed or used. These instances of waste might also arise from unethical practices adopted by procurement officials while planning the procurement. Such practices are not only easier to adopt but difficult also to be detected if inventory control is not properly exercised. For illustration, when inventory –on hand is not known, it would not be difficult to inflate the item requirement. In case of construction projects, waste can arise at any stage of the construction process starting from from inception, and design, execution till operation of the developed asset or built facility (Faniran and Caban, 1998). Construction activity generally generates a significant amount of waste (Teo and Loosemore, 2001).Such wastes are required to be minimised for avoiding the loss of efficiency. Formoso et al (2002) identified various managerial problems that can lead to resource waste. At the same time, the conversion process contributes to the lack of transparency to some extent in the project, as it abstracts away the flows between various interdependent activities which does not facilitate a clear identification of internal and external entities in the execution process (Koskela 1992). Greif(1991) also highlights lack of transparency as a cause of waste in the process. Therefore, it is required to review inventory management literature and suggest good inventory management practices that can help in ensuring efficient material planning for reduce the wastage and understanding the factors that can compromise the transparency in contract awarding.

3.3.1 APPLICATION OF FTA

These identified risk consequences are considered as 'critical failure effects' that need to be eliminated or reduced. As discussed above, several procurement irregularities emerged, research focused on the irregularity pertaining to awarding the work to a preferred bidder. The detailed information gathered from the grounded analysis of cases is used to discover how the risk of possible failures representing corruption incidences occurred during procurement processes and how different causal factors contribute towards them by using above steps.

3.3.1.1 DEVELOPING FAULT TREE

Analysis started with unfair contract award as a top event and each branch in successive level was explored using information gathered from grounded analysis by following the procedure given in section 3.2. Two important rules; viz Complete-the-Gate and No Gate-to-Gate Rule, recommended by Stamatelatos & Vesley (2002), were followed for avoiding the errors in developing FT. According to the first rule, all inputs to a particular gate should be completely defined before further analysis of any one of them was undertaken. The second rule states that Gate inputs should be properly defined fault events, and gates should not be directly connected to other gates. From the grounded analysis, 17 codes reflecting risk factors and conditions along-with 16 codes representing intermediate risk events, which portrayed mediating corrupt strategies for unfair contract award, were identified. Following above procedure, relevant risk elements i.e. risk factors and intermediate risk events were developed into FT by deductive reasoning. Deductive analysis revealed that incidences of unfair contract awards (T) were usually associated with manipulation in the bidding process (G1) and corrupt relationships (G2). Thus, top event (T) was considered as an outcome of simultaneous occurrence of both the intermediate events G1 and G2. Therefore, T was connected with G1 and G2 through an AND gate as shown in Figure 3.6. Further, it was observed from the analysis that bidding process was manipulated by adopting either of the strategy of avoiding public call (G3), unbalanced bidding (G4), choosing subjective evaluation (G5), making tender documents suiting to one bidder (G6) or limiting participation (G7). Thus G1 (bidding process manipulation) can be linked to G4, G5, G6 & G7 through an OR gate as shown in the Figure 3.7. The codes for top, intermediate and basic events used in fault tree are presented in Table 3.3.

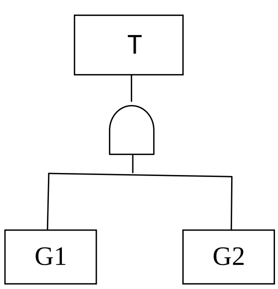


Figure 3.6: Initial Fault Tree with AND Gate

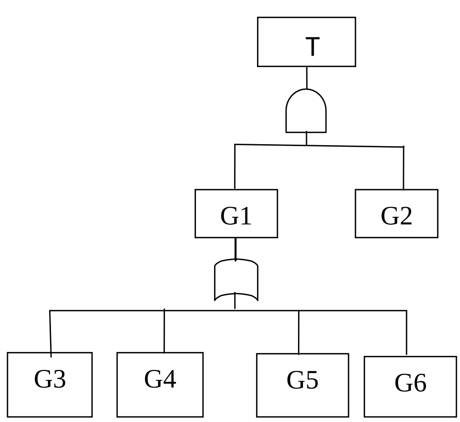


Figure 3.7: Intermediate Fault Tree

Table 3.3: Events Codes Used in Fault Tree.

Event codes	Events description	Event codes	Events description
T1	Work awarded to preferred bidder	X_1	No open bidding norms
G1	Manipulate bidding process	X_2	Discretion abuse
G2	Corrupt relationship	X_3	Poor procurement plan
G3	Avoid public Call	X_4	Low decision monitoring
G4	Unbalanced bidding	X_5	Change order abuse
G5	Subjective evaluation	X_6	False urgency
G6	Tender documents suiting to one bidder	X_7	Abusing cost estimation
G7	Limit participation	X_8	Share confidential information
G8	Contract splitting	X_9	Absence of standard code and criteria
G9	Unjustified additional work	X_{10}	Absence of verification
G10	Urgency Abuse	X_{11}	Staff Capacity deficit
G11	Undervalue the estimate	X_{12}	Complexity
G12	Specifications suiting to one bidder	X_{13}	Abuse in choice of procurement procedure
G13	Arbitrary delivery/eligibility conditions	X_{14}	Obscure the bid
G14	Accelerate the procedures	X_{15}	Conflict of interest
G15	Bid obscuration	X_{16}	Intermediary/ Agent/ Consultant
G16	Vendor driven specification	X_{17}	Corrupt exchanges

NB: Symbol T denotes top event which is broken down into intermediate events represented by G which in-turn further broken into basic events shown by X

In a similar manner, fault tree is developed by uncovering the interrelationship between various risk elements and expressing through logical gates. The Figure 3.8 presents a fault tree diagram that shows the sequence of events in the undesired corrupt activity of bidding process manipulation leading to unfair contract award.

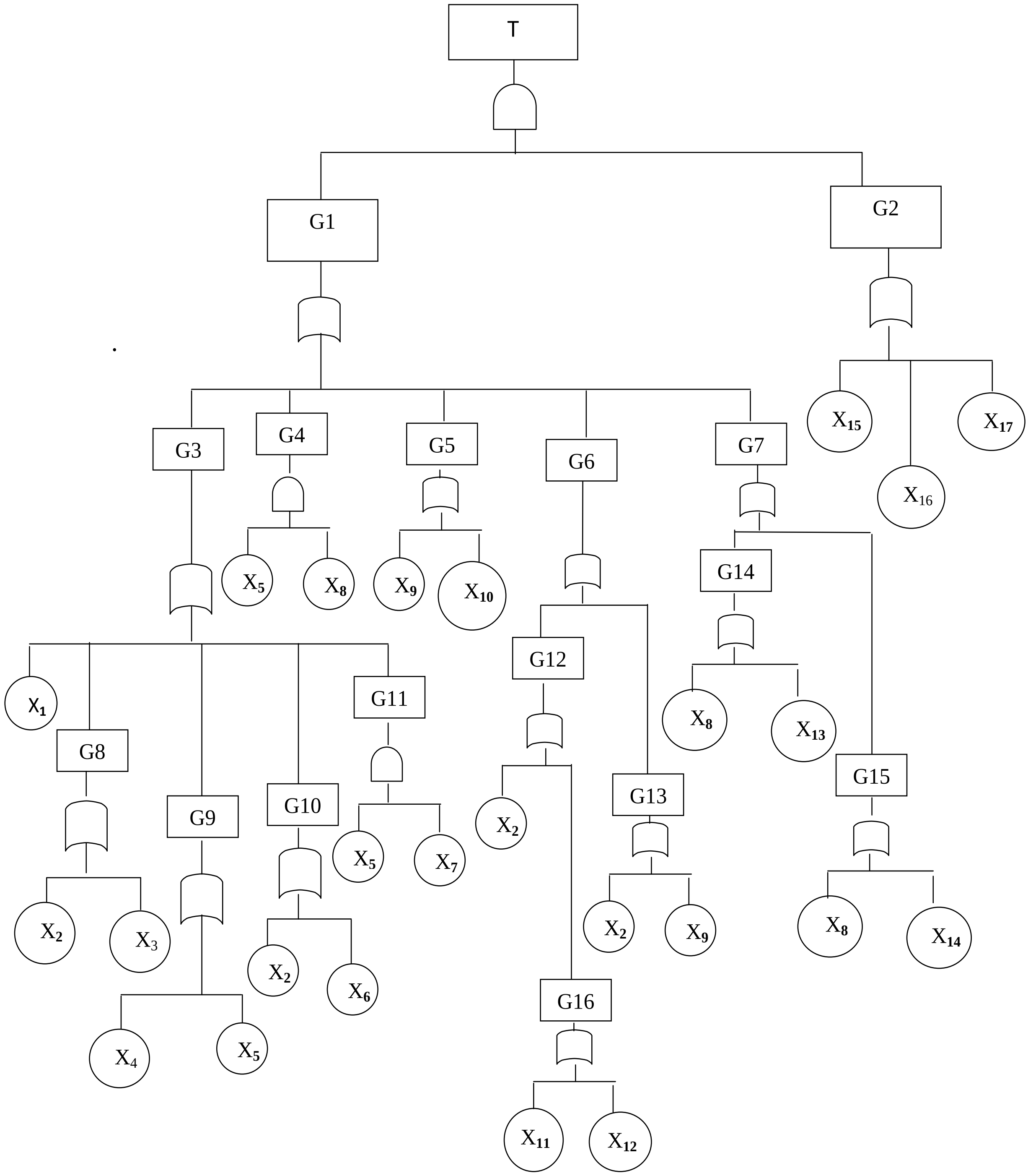


Figure 3.8: FTA for unfair contract award

The FT was validated by obtaining MCSs, identifying the smallest order cut sets and checking their validity (Stamatelatos and Vesley, 2002).A fault tree represents the risk model containing various risk elements. It is worth mentioning that a fault tree itself is not a quantitative model. However, it can be evaluated quantitatively. Qualitative techniques provide insight about failure pathways and are used to detect system vulnerabilities. Cut sets and minimal cut sets provide important information about the vulnerabilities of a system (Ruijters et al 2015). After developing the FT, it was simulated by finding MCSs.MCS is one of the qualitative methods used for analyzing FT in following section.

3.3.1.2 Analysis with Minimal Cut Set Method

A cut set is a combination of basic events whose occurrence ensures the top event happens. A MCS is a minimum set of events necessary and sufficient to cause the occurrence of the top event. MCS can thus be considered as a particular risk scenario that leads to the undesired top event. To find MCS, we first mathematically expressed fault trees by using Boolean logic defining each gate as a Boolean expression of basic events. Accordingly, a FT is expressed as an equivalent set of Boolean equations. MCS was, then, found by identifying the combination of minimum events from the equation.The occurrence of all events in a MCS is necessary for the top event to take place. There exists a finite number of distinct minimal cut sets for the top event in every fault tree. More is the number of MCS, higher is the risk of failure.Following the above, 45 MCSs were found which is explained in Appendix A.

Two element minimum cut sets: $\{X_1, X_{15}\}$, $\{X_1, X_{16}\}$, $\{X_1, X_{17}\}$, $\{X_2, X_{15}\}$, $\{X_2, X_{16}\}$, $\{X_2, X_{17}\}$, $\{X_3, X_{15}\}$, $\{X_3, X_{16}\}$, $\{X_3, X_{17}\}$, $\{X_4, X_{15}\}$, $\{X_4, X_{16}\}$, $\{X_4, X_{17}\}$, $\{X_5, X_{15}\}$, $\{X_5, X_{16}\}$, $\{X_5, X_{17}\}$, $\{X_6, X_{15}\}$,$\{X_6, X_{16}\}$,$\{X_6, X_{17}\}$,$\{X_8, X_{15}\}$,$\{X_8, X_{16}\}$,$\{X_8, X_{17}\}$,$\{X_9, X_{15}\}$,$\{X_9, X_{16}\}$,$\{X_9, X_{17}\}$,$\{X_{10}, X_{15}\}$,$\{X_{10}, X_{16}\}$,$\{X_{10}, X_{17}\}$,$\{X_{11}, X_{15}\}$,$\{X_{11}, X_{16}\}$, $\{X_{11}, X_{17}\}$, $\{X_{12}, X_{15}\}$,$\{X_{12}, X_{16}\}$,$\{X_{12}, X_{17}\}$,$\{X_{13}, X_{15}\}$,$\{X_{13}, X_{16}\}$,$\{X_{13}, X_{17}\}$,$\{X_{14}, X_{15}\}$,$\{X_{14}, X_{16}\}$&$\{X_{14}, X_{17}\}$

Three element minimum cut sets: $\{X_5, X_7, X_{15}\}$,$\{X_5, X_7, X_{16}\}$,$\{X_5, X_7, X_{17}\}$, $\{X_5, X_8, X_{15}\}$,$\{X_5, X_8, X_{16}\}$&$\{X_5, X_8, X_{17}\}$

As seen from above some of the examples of MCSs are: {X2, X15}, {X2, X16}, {X3, X17}, {X5, X7, X12}.To illustrate, $\{X_5, X_7, X_{17}\}$ implied that officials abused his discretion in omitting an item to undervalue the estimate (G11) for avoiding public call (G3) and subsequently involved in change order abuse (X_5) to include the omitted item for awarding the work to a favoured bidder in lieu of the corrupt exchange (X_{17}). Truly, any of the 45 MCSs may lead to the top event. It implied that there exists at least 45 combinations of risk factors and intermediate risk events that could lead to unfair contract awards which in-turn reflected the complexity of the problem of corruption. The large inventory of MCSs indicates that the process is not exposed to the single point of manipulation i.e. the corruption would occur in a variety of ways. Next it is seen that frequency of X_5, X_6, X_7, X_8,X_{15}, X_{16} and X_{17} are higher therefore these events need more attention and resources. However it's relative importance will be discussed in next section. Various risk factors identified from the analysis which may lead to various risk consequences are described in details in the Table-B.2 given in the Appendix B.

3.3.1.3 DEVELOPING VULNERABILITY SCORE

In this study, we are interested in finding out the importance of individual risk factor and their combined effect. Importance of risk factor can be supposedly measured in terms of its' contribution to vulnerability of the procurement system in respect of any particular undesired consequence like unfair contract award. In other words, vulnerability index can be defined as a fraction of system vulnerability contributed by a particular factor. Fault-tree analysis has been used a quantitative and qualitative assessment of the failure characteristics of various systems. The system is modelled as a logic diagram composed of a directed graph with a superimposed Boolean algebra.

The minimal cut sets for a fault tree is used to identify the most critical basic events leading to occurrence of top events and has following important characteristics:

a) MCS can be considered as a particular risk scenario that leads to the undesired situation i.e. top event.
b) the significance of a risk factor can be based on its relative contribution to the occurrence of the top event. •
c) Event which features in large number of MCS is more important as it would contribute to the undesired top event in the more number of risk scenarios.

A static fault tree FT is a finite DAG where its leaves represented by B, are called basic events. Its inner nodes, designated by G, are termed as gates. Each set $C \subseteq B$ of basic events characterizes a whole class of those risk scenarios in which all events from set C occurs.

A scenario ξ is a set of basic events that represents the circumstances where all basic events from ξ occur and the remaining other basic events does not occur. These scenarios can be inductively extended to undesired top event. It is stated that event O takes place by a scenario ξ if and only if the type of the top gate G is

a) AND along with all input events of this gate occur by ξ, or
b) OR and at least one input event of this gate occurs by ξ.

Further, it is noted that ξ is a failure scenario if it leads to occurrence of top event. It is also stated that C represents ξ if $C \subseteq \xi$. It is also said that C is a cutset if all represented scenarios are risk scenarios. It implies that the top event takes place in scenarios defined by C. In continuation, we define C_m as MCS if there is no smaller cutset $C_i \subset C_{\mathbf{m}}$. MCSs represent precisely all risk scenarios. In fact, every failure scenario is a superset of some MCS and every superset of a MCS is a failure scenario (Krcˇál et al, 2015).

For a given FT, one can easily compute the total number of all risk scenarios ΣC_m, it characterizes which in turn reflect the number of possible failure scenario in which a system can fail. An organization can be vulnerable to certain type of corrupt practices and not to others and vulnerability to corruption arises due to factors or conditions which are conducive to corruption that are being viewed as opportunity for organizational corruption (Sharma et al, 2016).Vulnerability therefore corresponds to presence of risk factors in the system and resultant failure risk scenario. The importance of each event can therefore be measured on the basis of the number of risk scenarios (minimal cut sets) to which the basic event contributes compared to total number of risk scenarios in the fault tree.

Thus, we can characterize vulnerability of system V_s as a set of collection of all minimal cut sets C_m. In this regard, quantification of vulnerability contribution of primary events i.e. risk factors or causal factors in the system is of critical importance to design preventive measures. Vulnerability contribution of a risk factor is derived on the basis of Minimal cut set theorem.

> ***Theorem 3.1 (Minimal Cut set Theorem)*** *If all conditions of a fault tee are verified and if for each minimal cut set at least one of the basic events is prevented from happening, then the top level event will never happen.*

Theorem shows that it is sufficient to prevent only one primary event of each MCS, to prevent system failure (Ortmeier et al, 2007). The theorem is proved by using structural induction in the FT by Balser et al (2000). By following the theorem, one can obtain the numeric evaluation of overall system vulnerability to a hazard caused by the occurrence of a particular fault. Let us say risk factor $X_{\mathbf{i}}$is eliminated then fault tree T is transformed to another fault tree $T_1$where V_s also changes to V'_s i.e. vulnerability reduces by quantity δV_i. It can be easily seen that, δV_i is itself a set of collection of all those C_m which contain X_i .Vulnerability contribution of a risk factor X_i, therefore, can be reflected by δV_i (reduction in risk scenarios) if risk factor X_i is eliminated from the system. Thus relative vulnerability score V_{Xi} can be measured by finding ratio of δV_i and V_s. Mathematically we express

$V_{Xi}= \delta V_i / V_s$

Since, procurement system can be manipulated by corrupt official even if there remain a possible corruption way (not all primary causal factors are eliminated), it is natural to assume that V_s can be expressed as a number of Minimal cute sets i.e. total number of all risk scenarios. Thus above equation simplifies

$V_{X i}$= (Number of minimal cut sets containing X_i)/ Total No of MCSs

Similarly we can find out thee combine vulnerability effect of two risk factors X_i and X_j as $V_{Xij} = \delta V_{ij} / V_s$, Where, δV_{ij} represents reduction in number of risk scenarios if risk factor X_i and X_j are eliminated from the system. Following the above we calculate the vulnerability score of various risk factors present in the risk model which is tabulated in Table 3.4.

Table 3.4: Relative Vulnerability Score

Sl No	Risk Factor	δV_i	Vulnerability Score (V_{Xi})
1	X_1	3	0.067
2	X_2	3	0.067
3	X_3	3	0.067
4	X_4	3	0.067
5	X_5	9	0.20
6	X_6	3	0.067
7	X_7	3	0.067
8	X_8	6	0.133
9	X_9	3	0.067
10	X_{10}	3	0.067
11	X_{11}	3	0.067
12	X_{12}	3	0.067
13	X_{13}	3	0.067
14	X_{14}	3	0.067
15	X_{15}	15	0.333
16	X_{16}	15	0.333
17	X_{17}	15	0.333

The factor featuring high in the list of importance of relative contribution towards vulnerability of system found to be are namely; X_{15},X_{16},X_{17} ,X_8 andX_5 . Organizations dealing with public procurement should therefore focus their attention and give resource to contain these factors. The score signifies very important meaning in respect of preventing unethical behaviour i.e. vulnerability Score (V_{Xi}) for risk factor $X_5$is 0.20, it shows that relative contribution of X_5 is about 20 % in making system vulnerable to unfair contract award. However the vulnerability Score is a kind of relative ranking and provide important insight for prioritizing the risk mitigation efforts.

3.3.2 FMECA APPLICATION FOR RANKING RISK FACTORS

The risk factors involved in basic events are analyzed further with FMECA to rank them in reference to already identified corruption pathways (failure modes). As discussed in section 2.3, criticality analysis computes criticality numbers (C_r) for each item (risk factor) criticality numbers by using the formula (Borgovini et al., 1993; Misra, 1992):

$$C_r = \sum_{j=1}^{m} (\alpha\beta\lambda_p t)_j \quad ; \quad j=1, 2, \ldots ,m$$

where $C_r$is the component critically number for item r, j is the component failure modes, m is the last component failure mode in severity classification, λ_p is the basic failure rate of an item, t is the time duration or the operating time. Thus $\lambda_p t$ denotes the number of failures in the given time. In our study, it represented the number of corruption cases or occurrences involving particular risk factor. α is the failure mode ratio which is probability and expressed as a decimal fraction that the component will fail in an identified mode. Sum of α for all components adds to unity. One way of assigning the probability of failure for an item would be the proportion of corruption cases attributable to a particular risk factor to the total corruption occurrences. It can therefore be approximated as $(\lambda_p t)_r$ / $\sum\lambda_p t$ = (No of occurrences involving particular risk factor 'r'/ total occurrences) for a particular risk factor. β is "the conditional probability that the failure effect will result in the identified criticality classification. Following above explanation, we can rewrite as

$$C_r = (\alpha\lambda_p t) \sum_{j=1}^{m} (\beta)_j$$

Further, values of β are based on analyst's judgement of conditional probability that the loss would occur. One such quantification recommended by (Misra, 1992). According to this criteria, value of $\beta$is considered as one and zero for actual loss and no loss respectively. The range of β is specified as $0.1<\beta\leq1$ for probable loss and $0<\beta\leq0.1$for possible loss respectively. Earlier corruption research (Moody-Stuart, 1997, Rose-Ackerman, 1999;

Søreide, 2014; Ochrana et al., 2015) has considered the amount of undue personal benefit as a key parameter. Size of personal gain increases with bribe amount involved in the contract awards. At the same time, they represent significant costs of doing businesses (Cole & Ahn, 2011). It also reflects circumstances for extending undue favour and willingness of contractor to pay the bribe. Bribes are often calculated as percentages of the total sum (Moody-Stuart, 1997). Size of bribes is positively correlated with corruption frequency (Andvig & Moene, 1990). Hence, the distinction between size and frequency would not matter much for the construction and understanding of the risk index. Therefore, size of the bribe in reference to contract value is considered appropriate to estimate the criticality of corruption effect. A similar concept was applied by Ochrana et al. (2015) for estimating corruption risk. They have considered benefit of officials (the amount of benefit like bribe, commission etc) and impact on budget as loss for estimating the impact of corruption. We have extended this basic logic, followed the standard MIL-HDBK-217C which is a handbook for guidance on prediction of electronic component failures, to conceptualize the failure probability, and applied above criteria to quantify the effect of corrupt actions more objectively. Actually, failure of electronic components are non repairable and may be catastrophic. Likewise, corrupt actions, once take place, their affects can't be erased unless the causal risk fctors are identified and addressed beforehand.

In continuation, Tella and Schargrodsky (2003) finds well defined negative effect of standardized products of the measures used to capture corruption on the prices. As firms cannot deduct the cost of bribes from their account books, amount of inflation in costs would provide meaningful guidance on tackling corruption (Cole and Ahn, 2011). Further, sample cases contain the information pertaining to the inflated margin in price, relative inflated margin in price was also used to estimate the probable loss. We have considered false contracts and unutilized assets as actual loss. Whenever cases involving unfair contract award or acceptance of substandard and defective material, do not reveal any objective information about bribery, cost inflation, these actions were assumed to occasion possible loss. The value of β for possible loss lies in between 0 and 0.1. When contracts are awarded unfairly without open tendering, the value of β is taken as 0.1 i.e. highest value of the range. It seems to be in conformity with earlier findings. For instance, on an average, bribes equalled 10.9% of the transaction value and 34.5% of the profits (OECD, 2012). An estimate of the total corruption cost varies between 6.65% to 20.02% of the total procurement spending (Auriol, 2006). Tella and Schargrodsky (2003) estimate that procurement overprice in Argentinean hospitals is about 10%. Similarly, the value of β is taken as 0.1 for cases involving substandard and defective material being accepted. Actually, estimates of 20-30% of project value lost through corruption are widespread (Wells, 2014), 24% of missing expenditures in Indonesian road construction were observed by Olken (2007). However, when contracts are awarded unfairly with competitive tendering, the value of β is approximated as middle value of the range i.e. 0.05. The middle value is taken for estimation as it provides a good approximation. Moreover, it is plausible to imagine significant financial savings from contract publication in terms of reduced prices as greater threat of scrutiny can lead to significant reductions in corruption (Kenny and Musatova, 2011). Based on above discussions, we have used following quantification criteria for quantification of different case scenarios by using transaction-level data which is described in Table 3.5.

Table 3.5: Value of β and Nature of Loss for FMECA Application

S.N.	Basic norm/ Criteria	Nature of Loss	Value of β
1	If bribe and contract value is given	Probable Loss	Ratio of bribe and contract value
2	If value of inflated price is specified	Probable Loss	Percentage of inflated margin in price*
3	False contract, asset remain unused	Actual Loss	1
4	If contracts are awarded unfairly without publicity or open tendering.	Possible Loss	0.1
5	If contracts are awarded unfairly with open tendering through abuse.	Possible Loss	0.05
6	Substandard material or defective work or unnecessary procurement	Possible Loss	0.1

Applying above criteria for finding the value of β and using the data from the sample cases, we performed analysis for finding criticality scores for each risk factor. The results are summarised in Table 3.6, which shows the values of α, $\lambda_p t$, β and C_r. Based on the values of β, the risk factors are ranked also for grasping their relative importance. The first two top ranked risk factors are X2 and X17 with the respective C_{xi} score of 16.5355 and 15.8087. Similarly, X10 , X16 and X15 emerges as third, fourth and fifth ranked factors respectively.

Other factors ranked from sixth onward can be seen from the Table 3.6. Their practical significance and related remedial measures are discussed in the following section.

Table 3.6: FMECA Results and Rank of Risk factors

Sl. No.	Factors	Description	α	λpt	Σβ	C_{xi}	Rank
1	X_1	No open Bidding Norm	0.011695906	2	0.174	0.004070175	17
2	X_2	Discretion abuse	0.198830409	34	2.446	16.53553216	1
3	X_3	Poor procurement plan	0.023391813	4	0.737	0.068959064	12
4	X_4	Low decision monitoring	0.058479532	10	0.756	0.442105263	7
5	X_5	Change order abuse	0.052631579	9	0.612	0.289894737	8
6	X_6	False urgency	0.011695906	2	0.393	0.009192982	16
7	X_7	Abusing cost estimation	0.023391813	4	0.228	0.021333333	14
8	X_8	Share confidential information	0.052631579	9	1.273	0.603	6
9	X_9	Absence of standard code and criteria	0.035087719	6	0.566	0.119157895	9
10	X_{10}	Absence of verification	0.099415205	17	2.008	3.393637427	3
11	X11	Staff Capacity deficit	0.01754386	3	0.2475	0.013026316	15
12	X_{12}	Complexity	0.029239766	5	0.498	0.072807018	11
13	X_{13}	Abuse in choice of procurement procedure	0.029239766	5	0.513	0.075	10
14	X_{14}	Obscure the bid	0.01754386	3	0.433	0.022789474	13
15	X_{15}	Conflict of interest	0.070175439	12	1.516	1.276631579	5
16	X_{16}	Intermediary/ Agent/ Consultant	0.087719298	15	1.9015	2.501973684	4
17	X_{17}	Corrupt exchanges	0.18128655	31	2.813	15.80873099	2

3.4 PRACTICAL IMPLICATIONS AND LIMITATIONS

There are several practical implications yielded from this research. It facilitated the development of a comprehensive list of influencing factors from the entire procurement cycle which are facilitating corrupt behaviour. It contributes to developing an understanding of the interrelationships among various risk elements. The fault tree developed in Figure 3.8 shows an overall view of potential multiple corruption pathways. It elaborates as to how the procurement manager may use different mediating strategies to exploit different set of vulnerabilities which would vary organization to organization like setting arbitrary criteria, tailoring specifications, abusing urgency provisions, information leak, change orders, bid document obscuration, etc, to reach the same intended outcome. Hence, corrupt officials may change their strategy to nullify prevention effort depending on wide array of existing weaknesses. Consequently, preventive measures which have worked in one organization might not be effective in others. As seen from the results of FMECA in Table 3.6, two most critical risk factors emerged are X_{2} and X_{17} i.e. discretion abuse and corrupt exchanges. Absence of verification, presence of the intermediary and conflict of interest are next three top-ranked factors. Poor procurement plan, low decision monitoring, change order abuse, sharing confidential information, the absence of standard codes & criteria, complexity and abusing choice of procurement procedures feature as sixth to twelfth ranked risk factors.

The analysis findings regarding most critical factors seem to be quite relevant as validated from the seemingly irreconcilable ongoing debate on the issue of discretion of procurement officials in the context of public procurement reforms. Some scholars (Kelman, 1990; Anechiarico and Jacobs, 1996; Kelman, 2002) point out that limiting discretion would hinder in acquiring best-value. However, other scholars (Schooner, 2001; Schooner, 2003; Henderson et al., 2017) have raised concern regarding greater discretion for procurement officials. The answer is therefore not so easy and needs to be found by considering the specific corrupt practices prevalent in the organization and where greater discretion would be useful. Actually, efficiency coupled with meaningful oversight seems a prudent approach (Schooner, 2001). In this regard, our model uncovers various risks associated in procurement process and provides a kind of heuristic to find how the existing weakness can be exploited with current policy or proposed changes.

The difficulty in detect-ability of corrupt exchanges seems to be a logical explanation for the significance of X_{15}, X_{16} and X_{17}. Actually, one of major difficulty faced by organizations is that internal investigative agencies of any public organization find it difficult to trace and detect corrupt payments wrapped beneath the cascade of multiple intermediary and consultancy or marketing agreements having offices located in multiple countries. Regarding this aspect, FT risk model shows that risk factors are embedded into various phases of the procurement system. It implies that efforts in addressing procurement corruption should include wide-ranging measures i.e. reforms in procurement process, methods and streamlining organizational policies and controls. Earlier research (Yang, 2016; Terman and Yang, 2016) shows difficulty in enforcing the accountability as procurement officials may give the image of heightened policy implementation without actually implementing them. Actually, procurement activities are usually structured through various phases and controls are independently designed for each stage; pre tendering, tendering, execution. However, there exists interdependence in these activities which weaken the control. It is, therefore, suggested that controls be rationalised and correspond to multiple vulnerable points in the entire procurement cycle.

First, it necessitates regulating the interaction between procurement officials and suppliers and contractors. Rotation of public officials responsible for procurement could be an important measure (Søreide, 2002) for de-establishing corrupt relationships. Organization may introduce the obligation to sign a "confidentiality and impartiality and conflict of interest statement" for all employees to address X_8 and X_{15} and specify the measures that will be taken for violating these standards. However, such managerial interventions alone cannot address corruption risks. Several scholars (Kelman, 1990; Schooner, 2001; OECD,2012) recommend making the penalties more stringent to address these corruption risks. Criminalising the bribery and its enforcement also complements to prevent and detect corrupt behaviour (OECD, 2012). However, more stringent penalties and criminal prosecution could not be productive because of low detection rates (Williams-Elegbe, 2011). It highlights the need of refining various process aspects to improve detectabilty. At the same time, organization may consider provisioning of administrative methods like Transparency International's integrity pact as a part of corruption controls.

No open bidding norm i.e. X_1 emerges as relatively lower ranked risk factor. The most acceptable explanation seems to be the fact that officials are adopting various corrupt practices even with following open bidding norms. However, if an organization does not mandate open bidding and corrupt practices are its results, it might turns out to be more critical risk factor. This indicates that corruption risk profile may change with time and therefore require continuous monitoring effort. In this context, corruption control merits further deliberation. Actually, control structures are the arrangements that defines the mode in which , managers or other officials are directed, evaluated, and rewarded (Aldrich, 1999). Organizational control literature review reveals that organizational leaders target controls either outcomes or the antecedent behaviours associated with those outcomes (Merchant, 1985). Outcome-oriented controls involve influencing the behaviour through its consequences like rewards or punishments. Process-oriented method would involve ongoing monitoring of the trend like repeatedly awarding the contract to certain vendors (Lange, 2008). However, outcome-oriented controls are preferred because of cost considerations (Zajac, 2002). Anechiaric & Jacobs (1995) raised concern that focus on corruption control can detract from achieving the competition and efficiency goals. It is therefore recommended that organizations can now easily monitor procurement process without much cost implications because of increasing use of computerization. Various intermediate risk events/ risk factors like the extent of use of urgency and accelerated procedures and difference in prices of standardized products, etc, highlighted in this study can serve as risk indicators for facilitating monitoring. Secondly, procurement procedures can be refined for improving objectivity and facilitating traceable records. For instance, organizations may define intended outcomes such as timelines and value for money while designing urgency and accelerated procurement procedures. The incidences of timeline failures in procurements made through urgency can be audited to find out abuse as well as correcting deficiencies in procedures. As regards complexity X_{12}, it is suggested that specific standards like higher levels of monitoring and review may be adopted for complex projects. Similarly, discretion in the adoption of technical solution/standard for complex projects can be disciplined through making informed choices by obtaining information from other organizations who have already implemented technical solutions under consideration.

As the bribe payments are expected to be associated with quality compromise and/or inflated price, organizations should focus on these two aspects also. Non availability of rate reference might be used by officials to conceal price inflation. Organization may standardise products and their benchmark prices (Søreide, 2002) and build rate references. Goods procured should be “simplified (Rose-Ackerman, 1999) for making decisions efficiently. Similarly, adopting Standard bid document and criteria would limit the opportunities of manipulation through bid obscuration, unclear selection and award criteria.

As revealed from the FTA, changes order abuse X_5 is associated with unbalanced bidding, undervaluing the estimate to avoid the public call, unjustified additional work and sharing the confidential information. Organizations may mandate that decision involving post tender changes should bring out its rationale and financial implication. Change orders involving inconsistent justification or severe financial implications may be considered for the audit. A lack of review and verification i.e. X_{10} may facilitate normalization of unethical practices. For instance, if contracts are being usually awarded without verifying capability and securities, it would become a routine and officials would not consider it inappropriate to award the work to contractors submitting forged certificates. Managers and supervisors' knowledge deficit would not only make them unable to detect corrupt behaviour but also lead to unusual excessive reliance on consultants and vendors. Thus, an organization may focus on building technical expertise of the staff to address risk arising from capacity deficit.

Poor procurement planning might stem from the difficulties in estimation of needs or requirement especially in large organization which often deal with different kind of works and services. In fact, large number of material transaction takes place with multiple stakeholders. Actually, standard inventory models do not satisfy real world conditions (Botter et al, 2000). A specific inventory model addresses specific problems, therefore, a large number of inventory models have been proposed. Consequently, there does not exist any standard solution as the conditions in each organization are unique and include many different features (Ziukov, 2015).Even expert system based tools, which are highly valued by the academic community often fail to provide practical solutions to real problems (Kobbacy and Liang, 1999).However, recent research results hint that inventory management software applications has now become a valuable tool for organizations to upgrade their stock control system (Gordon et al, 2016) and to improve their procurement process. A variety of such capabilities of applications is available today (Akindipe, 2014). Organizations are required to develop their inventory data base as a mandatory first step. The efficient inventory management would not only be helpful in undertaking material planning appropriately but also facilitate streamlining the controls in procurement process by generating traceable records and making need estimation more objective. In addition, it can timely provide updated and objective information about material on-hand and requirement along with its correct description which will reduce the chances of passive waste such as excess material or arising from poor procurement planning. Managing inventory data base is also equally important for effective material management in the projects. As projects complexity increases, materials management becomes more difficult and problematic. Presently, project organization largely uses manual methods for inventory records (Liwan et al, 2013).Traditional materials tracking methods are labour intensive, inaccurate and error prone that can result into waste and surplus of materials, delays, and productivity loss (Navon, 2006). A clear plan to manage materials on-site is lacking among the respondents, creating common inventory problems (Dakhli et al, 2018).The proper material plan can achieve the timely flow of materials and equipment and facilitate improved productivity, better schedules, and lower project costs (Soni et al. 2016). It is therefore recommended that a material management team may co-ordinate various entities in the project every stakeholder and asset for time, material, machinery and location. Likewise, the inventory management system would be useful for healthcare organizations. It would provide interface for patients, clinician, care provider, medical supply, medication, and chemicals. Using the real-time information from interconnected sub-systems, itcan make managing inventory seamless and provide valuable input for procurement activity.

With the invent of ICT, it is easy to maintain an updated data base of inventory status of various items which are lying in various stages in the organization. The data base or inventory system can be customised with particular characteristics and features to provide with a focus to provide required information and generating records of material transactions that can be traced later on. FMECA of various risk factors leading to waste reveals that some important information and performance parameters that can be quite useful for developing data base to reduce the wastage. These details are described in Annexure 2 which can be taken up in the future research.

As regards limitation of the study, we acknowledge that it did not capture the full complexity of the procurement system. It is pointed out that the case reports analyzed here do not provide many opportunities for examining causes attributable to individual’s traits or organizational processes like rationalization or justification. These factors have not yet been fully developed in this study and need further research. Moreover, some cases might not have been reported or somehow escaped during the sampling. Consequently, all potential risk factors might not have been included. However, future study with the proposed method, if undertaken, would help in generating more detailed risk scenario modeling.

3.5 CONCLUSION

The key contributions of this study to the existing literature are four folds; first it uncovers activity or function level vulnerabilities embedded in public procurement and sheds light on their interconnectedness. Secondly, it provides empirical foundation based insights about prevalence of multiple corruption pathways in public institutions and suggests measures for improving organizational controls and procurement processes. Thirdly, risk factors were identified and ranked according to their criticality scores. Fourthly, it methodizes a systematic approach of risk analysis.

As a part of an interdisciplinary research effort, FTA, GT, and FMECA are introduced and reasons for their integration were presented in this study. The integrated approach is successfully applied for identifying risk elements and analyzing their relationship. Coding and constant comparison of data was undertaken for finding the causal conditions, context and intervening conditions, action strategies, and consequences of various corrupt actions. It is found that there are many critical risk factors which have not yet got researchers attention as evident from procurement corruption literature though some of them appear in some of the practice oriented reports. These are namely; knowledge deficit, procurement bid obscuration, normalization of improper practices, corrupt inducements, complexity, absence of rate reference and need analysis and weak dispute resolution mechanisms. Similarly, reputation damage, wastage, potential safety hazards emerged as corruption risk consequences but they are yet to be included as element of analysis in future studies. An interesting area of research may be to analyze as to how knowledge deficit and complexities affect the monitoring costs and likelihood of collusion between supervision and contractors. It is worth-noting that all of these factors and consequence are not amenable to quantitative analysis as observable data might not be readily available. However, further qualitative analysis would definitely help in comprehensive risk identification by uncovering underlying strategies of abusing vulnerabilities.

Several procurement irregularities emerged, however this study develops fault tree for the irregularity pertaining to awarding the work to a preferred bidder. Then mathematical technique of minimal cut set was used for simulating the possible combinations of risk elements that may lead to the unfair contract award. It was found that procurement managers can pick any strategy from large inventory of corrupt pathways to favour a bidder of their choice. This study found 45 combinations of various risk elements that could lead to awarding of the work to a favoured bidder and this list may expand with time as new opportunity may arise or discovered. This interesting finding actually hints at the complexity of the phenomenon under study. The criticality analysis of risk factors provided several important insights for strengthening relevant aspects of organizational controls and improving the processes. It also suggests several good inventory management practices and provides relevant information and performance parameters that can be quite useful for developing data base for ensuring proper procurement planning. These process improvements can bring several benefits other than corruption risk reduction. As our findings are supported by accepted theoretical explanations and draw on interdisciplinary approach based on well established qualitative analytical techniques, it can provide important qualitative input for analyzing the risks of underperformance in the contract execution phase of PP. It is essential to develop a suitable framework to analyze the various practices which lead to risk of poor procurement performance and quality failures for finding suitable mitigation measures. Such an analysis would contribute in enhancing our understanding about problems of execution phase and conducting richer assessment of risk of underperformance.

The study embraces triangulation of data sources and methods to improve the transferability of the findings to different organizational settings and relevance of the findings to academic and practitioners.It should also be useful to researchers and managers to study and analyze important issues in other fields like organizational and contractual underperformance, project failures, corruption and inefficiencies in new form of governance structure of organization like Joint Venture, PPP or activities like concession and licensing. Future research in this direction may yield significant results for the organizations.

CHAPTER

4

RISK OF UNDERPERFORMANCE IN WORK EXECUTION

4.1 INTRODUCTION

Public organizations have developed risk based approaches to PP based on three primary pillars, viz. procurement plan, contract award, and management (Pennington, 2007). Public procurement (PP) concerns with administering these three phases of contract. Risk identification and assessment exercise undertaken in this research reveals that execution phase is fraught with several problems and difficulties that lead to poor procurement outcome. Despite presence of these problems and consequent risk of underperformance, execution phase has attracted researcher attention only in the recent past. As a result, execution phase remains under-researched, though it is critically important for ensuring successful procurement of projects and works. Developing countries, where majority of the world's population reside, undertake various projects to achieve their socio-economic and other developmental objectives (Human Development Report, 2011; Zeybek and Kaynak, 2008). These objectives are achieved by constructing infrastructural, industrial, transportation, educational, medical, and residential projects which enable these countries to fulfill their various needs and objectives (Othman, 2013). The large projects are actually significant undertakings which are characterized by multi-organizations and impacting different socio-economical objectives. Researchers use different terms like giant projects, major projects, new animals, complex projects, and megaprojects for describing large projects (Ruuska et al., 2009). Brockmann (2009) describe megaprojects as unique construction projects which are known for their complexity, enormous size, huge cost, and long time period in comparison to conventional construction projects. Their size and complexity are represented by a price mark which surpasses one billion dollar (Fiori et al. 2005) and by a time period exceeding the five-year limit (Zidanea et al, 2013). Thus, these projects, usually involving construction work plays a vital role in the global economy and socio-economic development through creation and expansion of infrastructure. However, generally, there remains discontentment with the performance outcome of the projects.

Major challenges plaguing the construction projects often include low quality, time overruns, excessively high cost, unsafe conditions, and poor returns. These problems in turn adversely impact social development and poverty alleviation which leads to a search for ways to obtain a better ‘value for money’ (Wells, 2014). Actually, these large projects possess uniqueness and differentiation mainly due to two characteristics; “fixed position manufacturing” and rootedness of activities-in-the place. Further, the presence of a large number of players and resultant fragmentation tends to weaken the integration force in the supply chain of the construction project. Most of the large projects are either get delayed or over budget by the time when they are transferred to the project operators or owners (Ambsisi, 2011). Everybody knows that if projects are not delayed and over budget, there is a compromise on content or quality” (Goldratt, 1997). The explanation for poor construction outcomes is partly related to mismanagement, but corruption is also one of the reasons in low-income countries (Locatelli et al. 2017).

Several authors (Zhou, 2006, Olken, 2007, Pryke, 2009, Adnan, 2012, Bowen et al. 2012, Osei-Tutu et al. 2014, Moodley, 2014) highlighted the effects of corruption and provided empirical account of various events where newly built bridges and dams collapsed, just completed highways showing signs of failure, delay in completion, poor quality, missing quantity and unjustified variations. Further, suppliers better know their own processes and related costs compared to owner, creating in turn an opportunity for them to deceive buyers by artificially increasing unit costs, using cheaper materials, withholding resources and deliberately underperforming (Handley and Benton, 2012). Such opportunistic behaviour emanates from the motive of maximization of one’s own profit and lack of trust (Carson et al., 2006; Jagtap & Kamble, 2015). It is these kind of harmful and counterproductive work practices that instantiates the use of inferior materials and poor workmanship as a common norm. However, most of the studies (Lo et al. 1999, Ray et al.1999, Zarkada-Fraser and Skitmore, 2000, Vee and Skitmore, 2003, Bowen et al., 2007, Sohail and Cavill, 2008, Alutu and Udhawuve, 2009, Hartley, 2009, Ma and Xu, 2009, Ameh and Odusami, 2010, Hao, 2011, Auriol et al. 2011, Olusegun et al. 2011, Tabish and Jha, 2011, Goldman et al. 2013) have focussed on bidding and tendering stage.

Normally, consultants become accomplices and approve fraudulent payments for defective or non-existent goods, work or services. They also tend to approve artificial claims, unjust variations and time extensions (Osei-Tutu et al., 2014). Thus there exists various kinds of counterproductive and unethical work practices causing under-performance. To build the conceptual basis for understanding the differences and similarities among various harmful and counterproductive practices for a comprehensive analysis, it is considered helpful to categorize and distinguish between harmful and counterproductive practices and their broad consequences. We find that these practices may stem from collusion between project officials and contractor, or be manifested in the form of a non-collusive practice like contractor's opportunistic behaviour. These practices may result in either safety consequences or poor quality outcomes. This categorization enabled us to infer two important practical implications. First, organizational control should include different penalty structures for collusive behaviour resulting in safety consequences and those with no safety consequences. More severe penalty can be conceptualized for the first category. Secondly, contractors' opportunistic behaviour also impacts the performance outcome and therefore it should be considered along with collusion for effective monitoring.

However, one of the major recurring unethical practices in the literature pertains to collusion between bidders and officials either during bidding in the execution phase. In this context, failure to consider the non-collusive practices would lead to an inadequate consideration of the problems and issues, which are causing underperformance, and consequently, the analytical results remain suboptimal. Risks like lack of control, fraud, and corruption, quality counterfeiting, financial risks etc., in a business environment can cause huge work disruption (Tiwari et al., 2015). Thus, monitoring of contractual performance becomes significantly important. However, it remains a difficult taskbecause formal control cannot be completely observed due to large number of participants and fragmentation of activities (Wells, 2014).

In this regard, several scholars (Smith, 2011, Norman et al. 2016, Upadyhay, 2016) advocate treating the project management process as a socio-technical system. While others (O'Brien, 1999; Vrijhoef & Koskela, 1999; McDermott & Khalfan, 2006; Adnan et al., 2012) have advocated the use of supply chain perspective to improve the project performance. Actually, projects' evolution is characterized by an increasing complexity (Laufer et al. 1996). Fundamentally, major projects can be perceived as a system composed of socio-technical subsystems (Smith, 2011). Socio-technical systems consist of four components, viz. structure, task, people and technology (Leavitt, 1964). Structure includes organizations forms, and responsibility, incentive and penalty structure. Task represents various activities like planning, need assessment, supervision and monitoring. Complexity and uncertainty, surrounding the project management tasks, reflect the task's key characteristics and would affect their outcome. Actors include all stakeholders, viz. project owner, mangers supervisors, contractors and end users. Organizations usually monitor contractual performance through supervision unit. Consequently, supervision is considered to have significant impact on value for money achieved. The quality of supervision is dependent upon the supervisor's skill (Alwi et al. 2001). As complex societal systems have many components, viz. technical and otherwise, their interactions are critical to the system's overall behaviour (Norman et al. 2016). Hence, failure to consider these criteria leads to an inadequate scrutiny of the socio-technical system elements and ineffective solutions (Robertson, 2001).

Similarly, main reason behind the adoption of SCM philosophy in the construction industry is its successes within other industries (McDermott & Khalfan, 2006). Though the construction process is different, SCM can be valuable and effective in construction projects (O'Brien, 1999) as it helps in developing a holistic view of the fragmented process and facilitates effective ways for creating the value. Here, it is pertinent to note that most of the problems do not arise in the conversion process but generated in the different interfaces of the Construction Supply Chain (CSC) (Serpell & Heredia, 2004). Therefore, quality must be integrated into the processes, instead of quality checks of each final product (Oakland & Marosszeky, 2006). Supply chain (SC) efforts help in ensuring the focus on quality in the transformation processes by developing a clearer and broader view of the situation.

Therefore, this research adopts both socio-technical viewpoint and supply chain perspective for conducting a comprehensive analysis. It first uses socio-technical viewpoint of the projects and find that complexity, capability limitation and work practices emerge as important influencing factors which would affect the project performance outcomes. In a decentralized and fragmented system like that of construction projects, central coordination and control are replaced by decisions and actions by multiple players. Game theory provides a tool that models interactions between multiple rational agents by providing a general framework for structuring and analyzing strategic choices for making improved decisions. In this context, Game theory can facilitate useful concepts and mathematical tools for assessing the risks and allocating resources for preventing unethical practices (Sharma et al, 2017). Because, game theory models can most effectively explain the basis for decisions of reasonable men to be corrupt (Macre, 1982). Game theory has been used to study construction projects and moral hazards (Yuan et al. 2016). Based on socio-technical viewpoint, a game-theoretical model can be developed that would provide useful policy conclusions and mitigation measures to prevent collusion and resultant contractual underperformance.

Subsequently, this study uses supply chain perspective to analyze construction project performance by applying evolutionary game theory. Supply chain perspective is expected to be of great help in developing a systemic view of the problems pertaining to project underperformance by observing the entire scope of project activities and their practical characteristics. This systemic view is essential for conducting a comprehensive analysis and finding measures for improving the project performance. The contractor behavior in the construction project is dynamic in nature and reflects limited rationality as the contractor may learn from others or through trial and error to opt the strategy that is more successful. These strategy adjustments are largely driven by additional information and knowledge acquired during the process. Game theory assumes that all players are rational, which becomes unrealistic in case of CSC. Evolutional Game Theory (EGT) is therefore quite appropriate to analyze the problems of CSC as both the fields deal with dynamic environment and are characterized by the player's lack of complete information. A very few studies have analyzed the problem of collusion by applying EGT. Earlier research have studied knowledge sharing in the supply chain (Zong et al., 2014) and safety management in construction project (Wen et al., 2014) by using EGT. Actually, the difference in the extent of prevalence of unethical practices can be attributed to the fact that different construction project organizations can get trapped in different equilibria. This study identifies different situations where it becomes optimal to engage in collusion or opportunistic behaviour despite strict monitoring and having provisions of cost recovery and penalty. Therefore, supply chain performance risks are to be controlled through simulating efficient choices for possible adjustment actions in order to mitigate the risks.

The rest of the chapter is organized as follows. Section 4.2 presents relevant literature, provides theoretical foundations of supply chain perspective, Game theory and EGT. It also reviews the unethical practices and categorizes them in an organizing framework. Next section 4.3 outlines the assumptions and formulates the game model for analyzing the problem of project underperformance. It also formulates an evolutionary game model of construction supply chain. The game is then solved in for establishing and analyzing the stability of evolutionarily stable strategies. Comparative discussion on game theory and evolutionary game modelling is presented in section 4.4. Finally, section 4.5 presents conclusions, summarizes the managerial implications and charts the opportunity for future research.

4.2 RELATED LITERATURE

Procurement of large infrastructure work and mega project represents a strategic option for achieving sustainable development objectives (Othman, 2013). These projects play a crucial role in the world economy. They signify the need for higher order technical knowledge and managerial skills; supervision capabilities and efficient monitoring and coordination with multiple stakeholders. Literature examining the role of project complexity, supervision unit capability and unethical practices in contract execution phase is inadequate. Actually, large or megaprojects are the projects which involve a large element of technological innovation pertaining to high risk and characterized by conflict, uncertainty, and fragmentation resulting from poor coordination among various participants (Marrewijk et al. 2008). Megaprojects are also referred as large scale engineering projects limit (Zidanea et al, 2013). They are based on five key attributes: (i) “high” capital investment, (ii) “long” duration and urgency, (iii) technologically and logistically demanding, (vi) multidisciplinary inputs from many organizations, and (v) leading to a “virtual enterprise” for the execution (Hassan et al. 1999). Projects’ evolution is characterized by an increasing complexity (Laufer et al. 1996). In fact, complexity seems to have become a key factor in the management of the projects (Miterev et al, 2011). Complexity has two main components, viz. differentiation and integration (Kleiner, 2006). Differentiation actually denotes the presence of different organizational units, and numerous steps and interactions whereas integration reflects multiple interactions with coordinating mechanisms. Formalization is considered as the degree of standardization. The notion of formalization is receiving continually increasing attention for resolving the problems arising due to complexity. For instance, standardized precast structures and prefabricated items are now being used in construction projects on the line of manufacturing organization to reduce the variability. Baccarini (1996) discribes project complexity as “consisting of many varied interrelated parts. For the purpose of studying its effect, we are conceptualizing complexity as the presence of mutually-interacting multiple parts. This definition is quite congruent with practical realities as evident from real world examples of large projects having multiple teams handling varied tasks like electrical, mechanical, civil construction, logistics, requirement etc. As shown in the Figure 4.1, people in the form of a personnel subsystem affect the processes and technical systems. As human factor is contributory or detrimental to the productivity, the study of human behaviour is very important is important in conceptualizing the organizational controls.

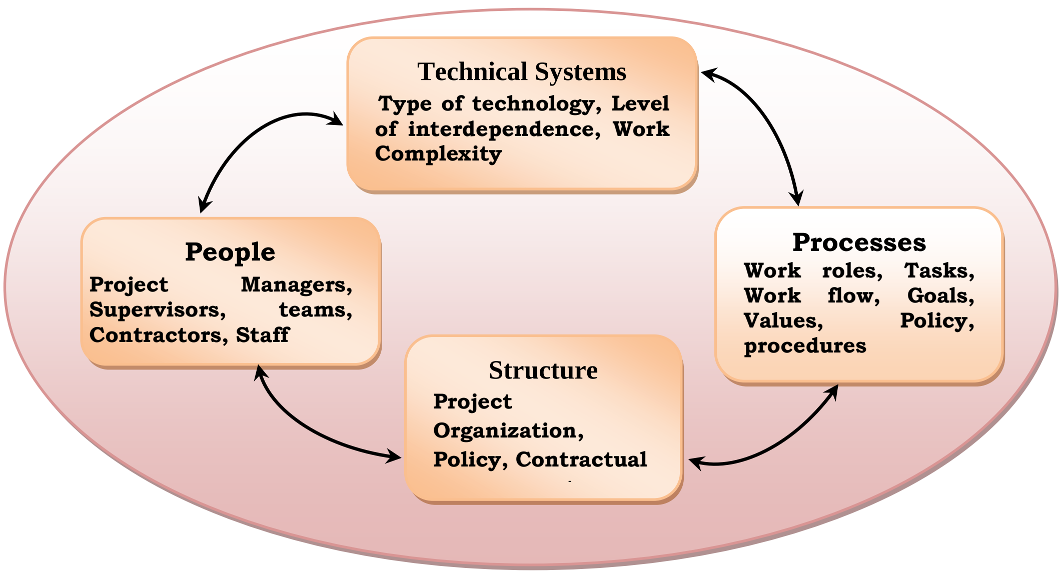


Figure 4.1: Project As Socio-Technical System (Adapted from Leavit, 1964)

Actually temporary forms of organizations like projects provides opportunities for discretionary judgment and considerable freedom in decision making which entitle officials working in key positions with substantial power and influence. The concentration of power in organizations doe not only facilitate in achieving their goals, but also result in some other troublesome actions affecting us (Coleman, 1974). Martini (2002) documents that as engineers role have changed from exclusively providing technical expertise to that of management oriented assignments, therefore, tensions have arisen between business values and professional standards that require reconciliation.

Pryke (2009) highlights that the procurement strategies of 'low bid wins' lead to many undesirable outcomes like opportunism where suppliers will agree to almost all the conditions for getting the work and then seek to improve the profit by compromising the quality of work and materials. In fact, there is substantial evidence that open and competitive bidding compel bidders to quote at unrealistically low price (Brockmann, 2011). Thereafter, contractors try to recover through reductions in quality of materials which result in poor quality assets and high maintenance costs. As inflated claims and poor performance involve cooperation between the contractor and the supervision unit which cause further breakdown of checks and balances embodied in the organizational controls(Wells, 2014). The major impact of corruption in infrastructural work is usually going to stay (Kenny, 2006). Adnan (2012) further points out that increase in unethical behaviour will see a consequential decline in the project performance as revealed from the construction work sites statistics. Therefore, an urgent need emerges to study these counterproductive and harmful practices in the project execution phase. Consequently, current research literature focusing specifically on these aspects been referred and it is found that corruption can manifest in several forms which are summarized in the Table 1 in Annexure. We can find that harmful and counterproductive practices are occurring either as a result of collusion between project officials and contractor, or manifesting in the form of a non collusive practice as contractor's opportunistic behaviour. For constructing an organizing framework based on these two dimensions, it is useful to consider the fact that these practices may result in to either safety consequences or poor quality outcomes. This is a simple categorization but it provides very important and quite useful implications. As represented in the Figure 4.2, these dimensions converge to constitute a 2 x 2 matrix. It highlights the need of introducing differential penalty structure as an organizational control policy and incorporating the non-collusive counterproductive practices like contractors' opportunism in the analysis.

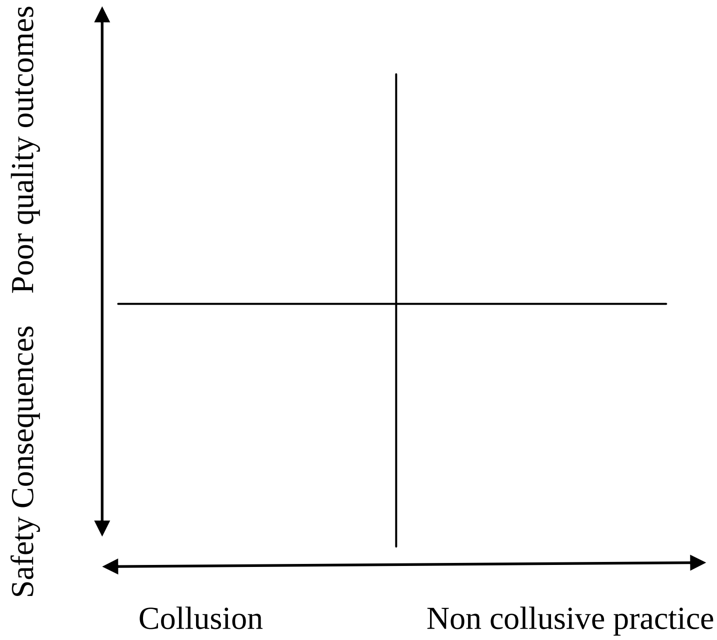


Figure 4.2: Counter-productive work practice characteristics and consequences

4.2.1 SUPPLY CHAIN PERSPECTIVE IN THE CONSTRUCTION PROJECTS

Project management has evolved through several stages which have successively added and complemented to the existing knowledge (Pryke, 2009). The trend of non contractual governance through relationship management, multiplicity of stakeholders and growing complexity in the projects have brought a demand for new initiatives for managing the linkages between various participants. SCM is one of such initiatives. It focuses on understanding and improving the coordination of all the participants which make a supply chain (O'Brien et al., 2002). SCM represents an autonomous managerial concept that endeavors to observe the entire scope of the supply chain where all issues are viewed and resolved by considering the interdependency of the CSC (Vrijhoef et al, 2000). SCM facilitates effective ways and means of creating value by continuous improvement, and integration of systems, thereby improving project performance (Adnan et al., 2012). SCM can be defined as a network of different organizations, linked upstream and downstream in a chain, that aims at producing quality and value in the services and products for customers through integrated processes and activities (McDermott et al., 2006).

Additionally, SCM is the integration of business processes which entail the exchange of assets, information, and knowledge between organizations that are interlinked in the provision of goods or services. Figure 4.3 provides a conceptual overview of the CSC and the way that all the participants interact in CSC. A complete supply chain involves several processes starting from need assessment, design, contract award, supervision, material production and handling, site work, claim disposal and review leading to final asset creation. Management of material, work and information flow affect the project performance in construction industry. Therefore SCM approach can help in improving the performance by facilitating better understanding of the interdependencies and problems arising from myopic control. However, practical solution using SCM approach has to be developed in project itself by taking into account the specific characteristics, work practices and local conditions of CSC (Vrijhoef et al, 2000). Therefore, it is necessary to revisit the problems faced in project works.

Efficiency and effectiveness of the work in the project activities suffer from various factors such as large number of participants, fraud, corruption, opportunism and lack of control. Corruption or non compliant behaviour can also be equilibrium outcome in certain situations (Mishra, 2006). Apart from corrupt behaviour, management of material, work and information affect the project performance in construction industry. In addition, causes of waste and problems in the CSC also include decisions that are made with a lack of understanding or information (Vrijhoef & Koskela, 1999). Actually, CSC has several actors such as consultants, procurement managers, supervision unit, suppliers, contractors and other sub-contractors.

A simple way to capture CSC complexities is by considering a model comprising of owner, supervision units and contractors. The major issues concerning problems with contractors are not adhering to agreed time line followed by non conformance with quality requirements (Serpell & Heredia, 2004). Adnan et al., (2012), in their study, state that materials theft and illogical request for time extensions occurs quite often in their industry. Contractors or sub-contractors may also offer advantages to supervisors for permitting unjustifiable claims for the time extension so as to facilitate their request for compensation from the company (ICAC, 1998). Consultants are usually become accomplices and approve fraudulent payments and also tend to approve inflated claims, unjust changes or variations and time extensions (Osei-Tutu et al., 2014).

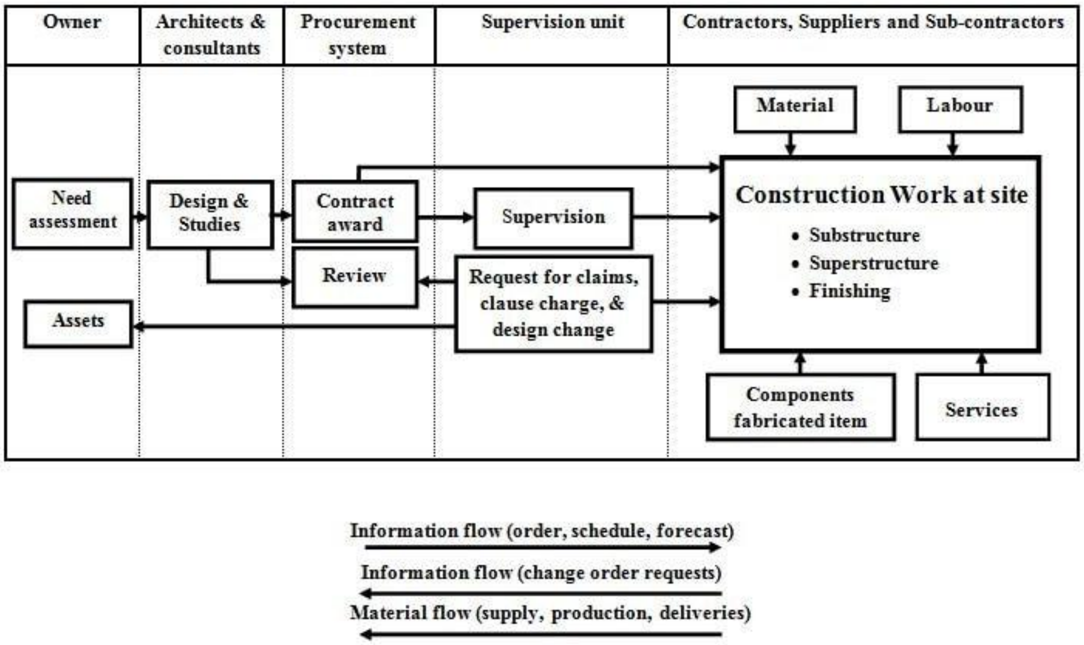


Figure 4.3: A Generic model of the supply chain in construction (Adapted from Vrijhoef and Koskela 2000)

Oxford dictionary defines collusion as a secret or illegal cooperation or conspiracy in order to deceive others. It is done to either obtain a goal forbidden by law by defrauding or drawing some other unfair advantage. Repeated interaction between the contractor and the supervision unit provides an opportunity to engage in collusive agreement. The collusive behavior is quite common in the project execution phase, while earlier research concentrates mainly on bidding phase (Shan et al., 2017). For instance, Hao (2011) studied collusive behaviour at bidding stage of procurement and has suggested for centralized procurement and open bidding. However, open bidding with low-cost bid selection may itself sometimes prompt bidders to take a contract at a low rate and subsequently compromise with quality. In the real world setting of construction projects, control and monitoring functions are usually exercised through a series of decisions and actions of multiple stakeholders. Actually, decisions in supply chain are interconnected and depend upon tackling uncertainty and dynamics of structures and processes in SCs ((Ivanov et al. 2012). Control techniques are considered to have significant practical relevance for SCM. In this regard, Ivanov et al. (2014) point out that SCs may be considered as technical-organizational system, however controller in SC is manager or mangers. Consequently, SC would evolve with managerial decisions as the actions of involved entities may change in response to decisions and actions of one actor. Thus CSC under-performance risks are to be addressed through simulating efficient choices by incorporating this dynamism in the analysis.

4.2.2 Game Theory

Game theory is the mathematical study of interactive decision situations. A game is a mathematical representation of conflict and cooperation situation between two or more interdependent decision makers involving rational choice in their decisions. Initially, it was applied in the field of economics, political science, and psychology. Subsequently, its applicability has become quite broad. At present, it studies a wide range of phenomenon in decision making and behavioral relations. In fact, Game theory has now become an umbrella term for the science of logical decision making in humans, animals, and computers (Hermann, 2017). The important ingredients or elements of the game are described below:

Rules Mathematical games are governed by a set of strict rules which specify what is permitted or what each player is required to do.

Outcomes and payoffs Games may have multiple possible outcomes. Each outcome would produce payoffs for the players. The payoffs may be monetary. Alternatively, they may express satisfaction.

Uncertainty of the Outcome The game cannot be predicted in advance. It implies that a game have either some random elements or have more than one player that make the outcome uncertain.

Decision making Each player has his own preferences on the set of possible outcomes. Based on these, he has to make a decision

Strategy: Players may determine their plan in advance, instead of making individual moves, one at a time. These plans are called strategies and cover all contingencies. It reflects the way in which players would play a game. A player may employ more than one strategy.

Games are simplified versions of real life situations that can be analyzed mathematically to provide insight about possible outcomes. A game is said to be cooperative if the players are able to form binding commitments. Such cooperative commitments are externally enforced through various means like contract law and agreements. On the other hand, game is called non-cooperative if players cannot form alliances or they compete each other. There are two ways of describing the games; viz. strategic form and extensive form. Most cooperative games are represented in the characteristic function form whereas non-cooperative games are defined using the extensive and the normal forms. The strategic form can be used to define both simultaneous and sequential games. At the same time, it allows researchers to quickly analyze each possible outcome of a game. Game outcome depends on the actions of two or more decision makers or players. Each player has two or more strategies, and sufficiently well-defined preferences among the possible outcomes. These preferences provide the basis to assign numerical payoffs for every strategy. On the basis of number of players involved, games can be classified as a two-person or three-person game. In general, it's said to be a N-person game where N is greater than 2.

4.2.2.1 STRATEGIC FORM OF GAME: A strategic form of game is described as a tuple G $(N,(S_i)_i ,(u_i)_i)$. G is the finite and not empty set, of players with typical set element i. The cardinality of G is N and G also refers to N-player games. So for avoiding triviality, its assumed that $N \geq 2$ unless stated otherwise. A not empty set Si of player i's strategies are called pure strategies to distinguish from the mixed strategies. $S = P_i S_i$ is the set of pure strategy profiles, with typical element $s = (s_1, . . . , s_n) \in S$. where u_i is player i's payoff function: $u_i : S \rightarrow R$.

Where, n: number of players, s_i is a pure strategy of player i, and $s = (s_1, ..., s_n)$: the strategy profile of the n players; $S_i = \{s_1^i , ..., s_m^i \}$: the strategy space of player i, where player i has m strategies in the strategy space. As we wish to discuss the outcome of varying strategy of a single player i while keeping the strategy of other players fixed. To represent it, if strategy (action) profile of the other n − 1 players is written as $s_{-i} \in S_{-i}$ which denote a strategy for all player but i, and written $s = (s'_i , s_{-i})$ for the profile $(s_1, ..., s_{i-1}, s_{i+1}, ..., s_n)$. Similarly, $u_i (s_i , s_{-i})$ represents the payoff to player i which is a function of the action profile of the n players.

4.2.2.2 Solution Concepts In Game Theory

A solution concept can be thought as a formal rule for predicting how the strategic interactions will be carried out in a game. These predictions provide the result of the game, and therefore known as "game solutions". Under the umbrella of rational behavior, selfish players will seek to opt those strategies which deliver the best rewards against their opponents' strategies (Mertikopoulos, 2010). This general postulate facilitates many different predictions. Consequently, each of these dissimilar predictions provide a different solution concept of a game. Saddle points, Von Neumann's Minimax theorem, Dominated strategies, Iterated dominance, Best Response, and Nash equilibrium are the commonly used solution concepts in game analysis. A brief theoretical account of Nash equilibrium which is used in this chapter is presented in succeeding paragraphs.

Nash Equilibrium: Nash equilibrium is a fundamental concept. It is a strategies profile with the property that each player's strategy is an optimal response to the other players' strategies (Fudenberg and Tirole, 2015). The existence of Nash equilibrium is a generalization of the Minimax theorem. Therefore, a pure strategy profile $s^* = (s^*_1, s^*_2 , ...s^*_n)$ is a Nash Equilibrium if $u_i(s^*_i , s^*_{-i}) \geq u_i(s_i , s_{-i})$ for all $s_i \in S_i$ and for all players i. It means s^* is a best response to the action profile of all other players. In other words, s^* is a NE if $s^*_i \in BR_i (s^*_{-i})$ for all players i playing game.

Similarly, Nash Equilibrium can be defined for Mixed Strategies. A mixed strategy profile $\sigma^* = (\sigma^*_1 , \sigma^*_2 , ...\sigma^*n)$ is a said to be a NE if it is a best response to the action profile of all other players. σ^* is a Nash equilibrium for all players i if $\sigma^*_i \in BR_i(\sigma^*_{-i})$. So, a strategy profile will be a Nash equilibrium if $u_i(\sigma^*_i, \sigma^*_{-i}) \geq u_i(s_i, \sigma_{-i})$ for all strategy $s_i \in S_i$. A Nash equilibrium is said to be strict if each player has an unique best response to his opponents' strategy profile i.e. $u_i(\sigma^*_i, \sigma^*_{-i}) > u_i(s_i, \sigma_{-i})$.

4.2.3 EVOLUTIONARY GAME THEORY

Classical game theoretic analysis is based on the idea that the players reason intelligently and rationally. It provides the framework for analyzing strategic interactions. Compared to this premise of hyper-rational agents for predicting and best responding to others' strategy to lead to equilibria in Non-cooperative game theory, EGT adopts a somewhat different approach. Social behaviour involves the interaction among individuals. Its key insight is that success of any player depends on how its strategy interacts with that of others and perform in the interdependent sectors of the society. The process of social contexts selection is characteristically frequency-dependent (Ayala and Campbell 1974). Stated simply, the best response would depend on what others are doing. EGT analyzes how the various strategies fare and how the environment is likely to change during the evolutionary process. As a result, it measures the dynamic behaviour of the strategies with regard to the other strategies. It thus helps in understanding the circumstances that explain the status-quo and possible future equilibrium state. This dynamic approach is closely related to the complex adaptive systems study (Santos et al, 2016) and assists in designing measures to encourage the change to alternative desirable equilibrium states.

4.2.3.1 EVOLUTIONARY GAME SOLUTION CONCEPTS

EGT analysis achieves an equilibrium as a result of outcome of adaptation and selection rather than as the product of strategic reasoning of the players. The process is conceptually operationalized by two sets of solution concepts. First set includes static equilibrium concepts, and ESS, that are intimately related to NE. Second set comprises of dynamic concepts that analyze the stability of the evolutionary process. This stability denotes asymptotic or Liapunov one which is described by the standard replicator equation. A replicator system is a set of replicators along with a structured pattern of interactions among them. The replicator is an entity which is capable of making approximately accurate copies of itself. An evolutionary dynamics is captured by the process of change of the frequency of the replicators. It implies that increase in rate of the proportion of population using a certain strategy is equal to the difference between the average payoff of the strategy and that of the population as a whole. Put simply, it shows that how effective an strategy is in surviving and reproducing itself while evolution process modelling tests alternative strategies.

These concepts can be easily applied to construction projects where CSC evolves with rational decision makers. Actually, ESS corresponds to NE. It has key conceptual implications. For instance, concepts and insights from classical game theory such as a payoff matrix, strategy thinking for modelling of 'quasi-rationality' of adaptive behaviour. Every ESS does correspond to a NE and thus it can be considered as 'quasi-rational' behaviour (McNamara and Weissing, 2010). In fact, ESSs and Nash equilibria coincide perfectly in simple games. Actually, every ESS is a NE strategy, however reverse is not true. It indicates that, a stable situation must correspond to Nash equilibrium.

An ESS can be considered as a modified form or special class of a NE. At NE points, if all players opt their respective strategy, no player can derive any advantage by changing to other alternative strategy. Let E(S,T) denotes the payoff for player one's strategy S against his opponent strategy T in a two player game. If strategy pair (S, S) is a Nash equilibrium for all $T \neq S$, it implies that : $E(S,S) \geq E(T,S)$. It includes the strategy T which would perform equally well, but not better than S. A NE is said to be stable even if T perform equally well, on the premise that there does not exist any incentive for players to adopt T in place of S. This signifies a significant conceptual departure from the ESS. In this regard, it is important to refer to essential conditions for a strategy S to be an ESS. These are namely; either (i) $E(S,S) > E(T,S)$, or (ii) $E(S,S) = E(T,S)$ and $E(S,T) > E(T,T)$ for all $T \neq S$. An ESS can be defeated, if it yields a payoff lower than one or more simultaneously competitive strategies. Thus, evolutionary process modelling provides us an alternative approach to interpret the dynamical equilibrium by adapting the concepts of Nash equilibrium which is a static concept.

4.2.3.2 REPLICATOR EQUATION

The central concept in an evolutionary game dynamics is replicator equations. This subsection presents the replicator equation concept. Let $q_i(t), i = A, B$, be the number of individuals which are opting the strategy A and B respectively at the time t. Thus, q(t)=$q_A(t) + q_B(\mathrm{t})$ illustrates the total number of players and x(t)=$\frac{q_1(t)}{\mathrm{q}(t)}$ represents a proportion of the population that plays strategy A . Now, let us assume that during the small time interval e, only an e, fraction of the population participate in the games. Then, we can mathematically express

$$q_i(t+e) = (1-e)\,\mathrm{q}_i(t)\,\mathrm{U}_i(\mathrm{t}); \mathrm{i} = \mathrm{A}, \mathrm{B}, \qquad \text{.. (4.1)}$$

Where $U_A(\mathrm{t}) = \mathrm{ax(t)} + \mathrm{b(1-x(t))}$ and $(\mathrm{U}_B(t) = cx(t) + d(1-x(t))$ are the average payoffs of players opting strategy A and B respectively. It is assumed that all payoffs are non zero which means they are not smaller than zero, hence $\mathrm{q}_A \; and \; \mathrm{q}_B$ are always non-negative and hence we can wrie 0≤ x≤1.

From the above the total number of players can be written as

$$q(\,t+e) = (1-\,e)q(t) + eq(t)\;\bar{U}(t) \qquad \text{..(4.2)}$$

Where $\bar{U}(t) = x(t)\,\mathrm{U}_A(\mathrm{t}) + (1-\mathrm{x(t)}\,\mathrm{U}_B(t)$ denotes the average payoff of all the players i.e. entire population at the time t. By dividing equation (4.1) by (4.2) the equation for the frequency of the strategy A is derived as under;

$$x(t+c) - x(t) = e\frac{x(t)[\mathrm{U}_A(\mathrm{t}) - \bar{U}(\mathrm{t})]}{1-e+e\bar{U}(t)} \qquad \text{..(4.3)}$$

Now both sides of (4.3) is divided by e and applying the limit e→0, the well known differential replicator equation is obtained as follows:

$$\frac{dx(t)}{dt} = x(t)[\mathrm{U}_A(t) - \bar{U}(t)], \qquad \text{...(4.4)}$$

Alternatively equation (4.4) can also be re-written as

$$\frac{dx(t)}{dt} = x(t)(1 - x(t))[\mathrm{U}_A(t) - U_B(t)]$$

$$= ((a\text{-}c + d\text{-} b)\ x(t))(x(t)\text{-}x^*) \qquad \text{...(4.5)}$$

For games having m strategies, a system of m differential equations can be obtained for $x_k(t)$, proportion of the population playing the k-th strategy at the time t and k=1,..,n, equation 4.5 is written as

$$\frac{dx_k(t)}{dt} = x_k(t)[\sum_{l=1}^{n} U_{kl} x_l(t) - \sum_{k,l=1}^{n} U_{kl} x_k(t)\, \mathrm{x}_l(\mathrm{t})], \qquad \text{.. (4.6)}$$

The right hand-side of (4.6) represents the difference of the average payoff of the k-th strategy and the average payoff of the population. The above system of differential equations is known as replicator dynamics (Miekisz, 2008). The replicator dynamics emerge as a particularly simple model for evolution and learning. This replicator equation (4.4) translates the intuition that strategies that do better than average payoff U(t) will grow, whereas those that do worse than the average will diminish. The evolution process of phenomenon under study therefore can be described by evolution system represented by dynamic replicator equations. Using the coupled set of replicator equations for different players one can easily find Jacobian matrix for the evolution system as under

$$J = \begin{pmatrix} \frac{\partial f_1(x)}{\partial x_1} & \frac{\partial f_1(x)}{\partial x_2} \\ \frac{\partial f_2(x)}{\partial x_1} & \frac{\partial f_2(x)}{\partial x_2} \end{pmatrix}$$

The replicator equation has the unique global solution, $\xi(\mathrm{x}^0, t)$, for any initial condition $x^0 \in \triangle$, which would stay in the simplex. $\triangle$. If x* is an ESS of the game, then x* is also an asymptotically stable equilibrium of the replicator dynamic. Moreover, if x* then x* uses all strategies with positive probability. It is also a globally stable fixed point of the replicator equation. It can be found out by Liapunov's method which works on the basis of a very simple idea. Suppose that f(x) is a function of certain state variables, we can show that the dynamics of the system leads to a steady decline in f in the neighborhood of the equilibrium point. It necessarily implies that we are approaching towards the minimum value of V, i.e. equilibrium point – this equilibrium point is stable over the entire neighborhood of x∗ over which f decreases. Such function f is called a Liapunov function and mathematically it is explained as under:

Liapunov's Theorem. Let function $f : R^n \rightarrow R^n$ be C^1 and $x_0 \in R_n$ be a fixed point of $dx/dt = f(x)$ where $f(x_0) = 0$. Let $A = Df(x_0)$ be the linearization of f (so $A_{ij} = \partial f_i/\partial x_j$ is the Jacobian matrix) and $\lambda_1, \ldots, \lambda_n$ be its eigen-values. Then x_0 is

(i) asymptotically stable if Re $\lambda_i < 0$ for all $i = 1, \ldots, n$;

(ii) unstable if Re $\lambda_i > 0$ for some i. If the eigen-values all have real parts zero, then further analysis may be taken up.

4.3 GAME THEORETICAL AND EVOLUTIONARY GAME ANALYSIS

The socio-technical concept views humans and organizational structure and policies as important factors for optimizing the work performance. A key characteristic of socio-technical perspective is that they are interdependent. In the real world setting of project execution, control and monitoring functions are usually exercised through decisions and actions of multiple human actors. For instance, contractor and supervision unit usually interacts repeatedly which may facilitate adoption of collusive strategies. Further, owner may exercise different monitoring strategies depending upon monitoring cost and other considerations. It would affect the actions and decisions of contractor and supervision unit. Presence of these interacting multiple actors makes modelling of these situations quite difficult. However, these interactions and interdependence among different players having differing interests can be easily considered in the game analysis for driving useful policy implications for mitigating the risk of underperformance in the contracts. Following section presents the game theory application:

4.3.1 GAME THEORY APPLICATION

Game theory is more suitable to mathematically capture behaviour in the strategic situations present in the execution phase in comparison to other standard optimization methods which involve one decision maker who aims to minimize an objective function by choosing values of variables from a constrained set such that the system performance is optimized. If understood in a game theoretic framework, systemic and widespread unethical practices seem to be a case of an extremely robust negative equilibrium (Bardhan, 1997). Therefore, Game theory model is developed in following subsections for analyzing problem of harmful and counterproductive strategies and consequent contractual under-performance and useful inferences are drawn. Subsequently, this section to develop an evolutionary game model of large projects by applying supply chain perspective. The game model and monitoring cost analysis are presented below;

4.3.1.1 RISK SCENARIO DEVELOPMENT AND GAME ANALYSIS: As several factors like information asymmetry, project complexity, inadequate supervision including supervisors' capacity plays role in performance obtained in the contract, their effect need to be considered in conceptualizing various risk scenarios. Information asymmetry is the distribution of knowledge or probability about certain events distributed asymmetrically (Yan et al. 2014). Firstly, there exists information asymmetry between contractor and supervisor, supervisors and owner and owner and contractors. Consequently, owners do not possess full information about contractor's performance. Likewise, contractor does not completely know about supervision unit; their skill and inspection strategy and efforts. Similarly, supervision unit do not fully know about contractors' quality of personnel, material and methods. Majority of supervision unit usually works on fixed compensation and cannot earn profit from the project construction and even though they work hard for project completion would not get extra income (Wen et al. 2014). The information from the supervision unit is incomplete and supervisors may abuse their power to collude with contractors probably in order to obtain additional income (Shurong and Miao, 2012). Thus both the supervisor and the contractor face the risk of moral hazards because of the information asymmetry (Yan et al. 2014). Contractor may also behave opportunistically to maximize his profit by compromising on quality of material or work. Opportunistic behaviour emanates from the motive of maximization of one's own (Carson et al. 2006). Such a probability will be more when their behaviour cannot be observed by the owner. Therefore, owner has to strengthen the monitoring, if he wants to detect contractual violations by arranging independent verification of work progress and records and ensuring adequate quality testing on all important aspects. The proposed model is applicable for both the public and private organizations as both may have internal supervision units to supervise the contractual work or alternatively engage outside agency to supervise the work. Secondly, in case of complex projects, owner had to monitor multiple aspects affecting the quality. Baccarini (1996) defines project complexity as "consisting of many varied interrelated parts. For the purpose of studying its effect, we are conceptualizing complexity as the presence of mutually-interacting multiple parts. This definition is quite congruent with practical realities as evident from real world examples of large projects having multiple teams handling varied tasks like electrical, mechanical, civil construction, logistics, requirement, etc. As per contractual requirements certification of these works would be essential for making payments. However, concealment is often possible due to information asymmetry and lack of transparency of such projects (OECD, 2007). As a result, supervision has to be strengthened by undertaking inspection on every important aspect of complex project which would have implication on monitoring cost. The quality measurements for a product having multiple characteristics is generally expressed as

$$Y = \Gamma . u + \varepsilon \qquad \text{..(4.7)}$$

Y represents n x 1 vector of product quality measurements, Γ represents n x p constant system matrix determined by process complexity, u is a p x 1 vector representing process faults or quality failures and ε is n x 1 vector representing noises. If C_j is a cost of monitoring one aspect, cost of n aspects would be given by $C_j.Y$.

In case of supervisor's capacity deficit, owner had to hire additional supervisors for making supervision adequate and therefore had to spend more on supervision. Otherwise, it might lead to both type I and type II error and consequent increased variation. While in case of type-I error (false-positive) an investigator rejects defect free work which would lead to subsequent inspections which is not actually required. On the other hand, in case of type II error (false-negative), the investigator fails to reject a substandard work which ultimately would require rework or need re-inspection if not accepted by contractor. Considering ũ be the accuracy of supervision unit represented by capacity of supervisors. A general formula for sample size estimation for a two sided CI for a single test accuracy is

$$N = \left(z^2_{1-\alpha/2} V(u) \right) / L^2 \qquad \text{...(4.8)}$$

where $z_{1-\alpha/2}$ is the 1-α/2 percentile of the standard normal distribution, α is the confidence level, V(ũ) is the variance function of ũ (McCullaugh and Nelder, 1989) and L is the desired width of one half of CI. At 95% CI level, α equals .05 and $z_{1-\alpha/2}$ is 1.96. Therefore sample size N varies proportionally with V(ũ) i.e. it would vary inversely with capacity deficit of supervision unit and lets represent it by V(ũ) = (σ^2_{cd}) therefore required sample size can be represented as follows:

$$N = \left(z^2_{1-\alpha/2} \sigma^2_{cd} \right) / L^2$$

$$or\ N = f_1\left(\sigma^2_{cd}\right). \qquad \text{...(4.9)}$$

From the above, it may be seen that sample size would increase with capacity deficit. Thus, owner had to hire additional consultant or engage additional manpower by shifting them from other project by conducting more number of inspections. It is required to overcome supervisor's capacity deficit. Let ΔC is the additional cost owner is spending for adequate supervision in case of capacity deficit in existing supervision unit. Now following hypothesis are made for constructing the game model for the owners, the supervision unit and the contractor:

(i) P is the probability of contractor having collusion with the supervision unit,

(ii) α is the probability of owner exercising adequate supervision

(iii) β is the probability of the owners detecting the collusive behaviour successfully or contractual violations.

(iv) Contractor earns ‘I’ as collusion income proceeds from the collusion and gives share S from it to supervisor. If owner detect the collusion, income proceed ‘I’ is recovered and an additional n-time penalty is also imposed on both supervisor and contractor. The penalty coefficient is defined as under;

$n = n_s$ for unethical practices having safety consequences,

$n = n_{ns}$ for unethical practices having other than safety consequences.

(v) Owner’s supervision cost is C if supervision is inadequate. In case, owner decides to exercise adequate supervision by ensuring inspection on every important aspect of complex project and in overcoming supervision capacity deficit. Therefore additional supervision cost will be $Cj.Y + \Delta C$, (Let’s assume $CjY + \Delta C = KC$). Hence, owner’s cost of adequate supervision turns out to be $(K + 1)C$.

(vi) In case of non collusion, contractor may still deliver substandard material and perform below quality work, which if remain undetected ,would save R from his expenditure and it would result in a rework cost R to owner.

Building on the categorization framework of Figure-1 and considering cases of collusion and non collusion between contractor and supervisors, it is seen that six different risk scenarios may arise. Risk identification exercise should essentially identify potential risk scenarios - that is to find out what adverse could happen and how it can happen (Sharma et al. 2016).

4.3.1.2 Collusion And Opportunism Risk Analysis

In the risk scenario-1, contractor and supervisors collude, and owner exercise adequate supervision. As a result, owner successfully detects the collusion and takes the punitive action against them. On the other hand, owner fails to detect the collusion in risk scenario-2, despite exercising the adequate supervising them. However, contractor and supervisors collude and successfully earn collusive income. In the risk scenario -3, contractor and supervisors collude. However, owner chooses not to exercise the adequate supervision and therefore fail to detect the collusion. In scenario-4, contractor and supervisors do not collude but owner exercise adequate supervision. Consequently, owner successfully detects the contractor's opportunism by uncovering the underperformance in the project execution. In the scenario 5, collusion does not take place between contractor and supervisors but contractor underperforms. However, owner fails to detect contractual violations despite adequate supervision. The game between owner, contractor and supervision unit on the basis of the above assumptions would lead to different risk scenarios which are shown in Figure 4.4..

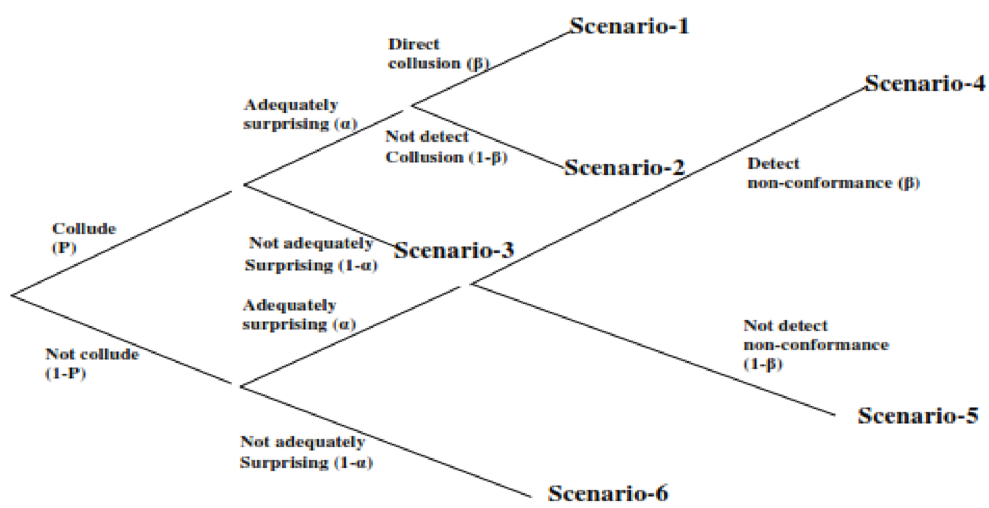


Figure 4.4: Contractual underperformance risk scenarios

Contractor and supervisors do not collude and owner does not exercise the adequate supervision and therefore fail to detect the contractual violations in scenario-6. According to these risk scenarios, the game income matrix of the owner, contractor and supervisors in different risk scenarios is as below, as shown in Table 4.1.

Table 4.1: **Payoff matrix of owner, contractor and supervisors**

Sl No	Risk	Owner's payoff	Contractor's	Supervisors payoff
1	Scenario-1	(n+1)(I+S)-(K+1)C	-nI-S	-nS
2	Scenario-2	-I-(K+1)C	I-S	S
3	Scenario-3	-I-C	I-S	S
4	Scenario-4	-(K+1)C	0	0
5	Scenario-5	-R-(K+1)C	R	0
6	Scenario-6	-R-C	R	0

From the analysis of tripartite game conditions with above payoff matrix, following is obtained:

(A) Considering the probability of collusion between supervision unit and the contractor is fixed as P. The owner is adequately supervises or not; the expected benefits of owner in each case are

[Let's assume (n+1)(I+S)=M]

$E_1 = P[\beta\{(n+1)(I+S)-(K+1)C\} + (1-\beta)\{-I-(K+1)C] + (1-P)[\beta\{-(K+1)C\} + (1-\beta)\{-R-(K+1)C\}]$

$= P[\beta M-(1-\beta)I-[\beta+1-\beta](K+1)C]+(1-p)[-(1-\beta)R-\{ \beta+1-\beta\}(K+1)C]$

$= P[\beta M-(1-\beta)I-(K+1)C]+(1-P)[-(1-\beta)R-(K+1)C]$

$E_2 = [(-I-C)]+(1-P[-R-C]$

$= -PI-R+PR$

When the owner's expected gains do not differ in carrying out adequate supervision or inadequate supervision, it will have the optimum probability of the collusion between the supervisor and the contractor which is as follows:

$E_1=E_2$

P[βM-(1-β)I-(K+1)C]+(1-P)[-(1-β)R-(K+1)C] = -PI-R+PR

$$P^* = \frac{(K+1)C}{\beta[(n+1)(I+S)+I-R]}(1-\frac{\beta R}{(K+1)c}) \qquad \text{......................(4.10)}$$

(B) Given α the probability of the owner's exercising adequate supervision, whether supervision unit is involved in the collusion or not, the respective expected benefits of supervision unit are:

$E_3 = \alpha[\beta\{-nS\}+(1-\beta)S]+(1-\alpha)(1-\beta).S$

$= \alpha[-nS\beta+(1-\beta)S]+(1-\alpha)(1-\beta)$

$= -\alpha\beta.nS+(1-\beta)S,$

$E_4 = \alpha[\beta.0+(1-\beta).0]+(1-\alpha).0$

$= 0$

In this condition, the best probability of the owner's supervision as follows:

$E_3 = E_4$

$-\alpha\beta nS+(1-\beta)S = 0$

$$\alpha_1 = \frac{1}{n}[\frac{1}{\beta}-1] \qquad \text{..(4.11)}$$

(C) Considering the probability of the owner's adequate supervision is fixed as α. The contractor is involved in the collusion or not, the expected returns of the contractor in each case are

$E_5 = -\alpha\beta(n+1)I + I - S$

$E_6 = (1-\alpha\beta)R$

In this situation, one can find the best probability of the owner's supervision as under

$E_5 = E_6$

$$\alpha_2 = \frac{1}{\beta}[\frac{I-S-R}{(n+1)I-R}] \quad ....(4.12)$$

4.3.1.3 GAME ANALYSIS FINDINGS

The above findings indicate that owner's cost of ensuring adequate supervision is one of the chief factors that affect the optimum probability of collusion between supervision unit and contractor. In turn, owner's supervision cost depends on two important factors i.e. complexity and supervision capability limitation. As a result, optimum probability of the collusion between the supervisor and the contractor would rise with increase in complexity in the construction projects. It would, therefore be, imperative for owner to take measures to reduce information asymmetry in such circumstances. Several measures like using objective measures of performance measurement, improved record keeping, bringing advanced inspection technological methods can be helpful in reducing the information asymmetry. Similarly, $P*$ would also increase with supervision unit capability limitation. It implies that contractor would find it easier to collude with supervision unit when supervision unit suffers from capability limitation. It also indicates that supervision unit may find it easier to apply less effort and accept the underperformance rather than querying the contractual non-conformances. Therefore owner should also focus on addressing the issue of capacity deficit in their supervision units.

As the comparison between gains and losses would influence the strategy of supervision unit, contractor and the owner, they are more likely to choose the strategy that can bring higher earnings. This suggests that supervision unit and contractor may adopt that measure which can improve the income arising from collusive behaviour. They may adopt more rewarding cooperative strategies from wide ranging set of accepting poor quality or certifying non existing work or accepting the illogical request for design change and time extension to escape the penalty. However, it also contains key policy implication for owners i.e. owner can change the other two agents strategy by increasing the penalty for collusive behaviour. In other word, owner should enlarge corruption control policies i.e. include choice of differential fines for more serious lapses and minor failures. By setting $n_s > n_{ns}$, higher fines for those unethical practices which have adverse safety consequences, owner can reduce the optimum probability of collusion in those aspects which can endanger safety in the projects. The key argument underlying this suggestion is that contractors may earn by under-performing, but judicious choice of the fine function imposed on firms ensures that income depend on performance deficit in a way that contractor ends up with the right marginal disincentives for unethical behaviour. The future consequence may be made serious, if owner chose to include the past performance in the criteria for awarding the tenders for work the projects. These measures can help greatly in controlling both problems as such strategy can adjust contractor's expected income downward in the future. Similarly, future earnings of supervision unit personnel can be controlled by linking their future career growth to ethical behaviour. It may require for owner to develop open and fair tender assessment mechanism, establish the past performance criteria for bid evaluation, incentive and disincentive mechanism in the organization. To avoid losses of net revenues for the government, controlling collusion also requires owner should devise the ways to optimize their monitoring costs. However, the monitoring costs have not yet been modeled in the earlier game models available in the existing research which is necessary for conceptualizing owner's monitoring strategies.

4.3.2 EVOLUTIONARY GAME APPLICATION

A social interaction can be modelled with evolutionary game analysis by specifying the set of feasible strategies and the players participating in the game. These strategy set reflects assumptions on the interaction characteristics, the information possessed by players, limitations and constraints, and finally the actions available in a given situation (McNamara and Weissing, 2010).

As CSC entails multiple interdependent activities, there's a large number of interacting and interdependent participants. However, out of them, interactions and behavior of only three participants/ organizations are important for the performance analysis of contract execution phase comprising of owner, supervision unit personnel, and contractors and suppliers; details of which are shown in Figure 4.5. Generally, owners representing Government or Public organization engage either an internal or external supervision unit for monitoring the project works. Supervisor unit personnel are given an authority and responsibility for planning and controlling the quality of project work. Supervision is thus considered to have significant effect on the quality of construction work, consequently impacting directly on the value of assets created.

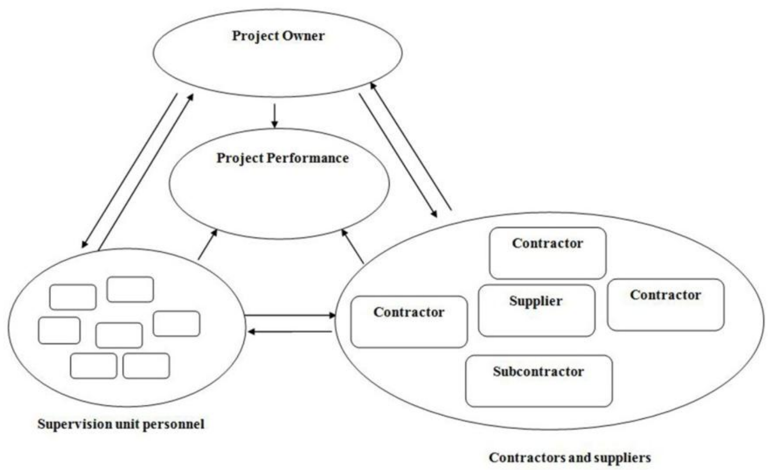


Figure 4.5 A Conceptual model showing relationship between owner, contractor and supervision unit

In the figure above, the double arrows show inter-dependencies between owner and supervision unit, supervision unit and contractors and finally owner and contractors. Further, it also highlights that the interaction among owner, contractor, and supervision units is dynamic nature involving continuous communication and coordination with each other. In other words, the players (i.e. owner, contractors and supervision units) can change their behavior as they accumulate experience, which in turn affect project performance. However, outcome for each player not only depends upon his choices but on others' actions also. In here, it is worth noitng that the strategies of contractor, supervisor, and owner are not only influenced by information asymmetry but also by organizational practices, quality of supervision, owner's management intervention and industry practice etc. While executing a project, it is easy to reach some sort of agreement with the supervision unit and then relax the supervision to the Contractor appropriately (Wen et al., 2014). The magnitude of outsourcing accompanied by competitive procurement makes the CSC more prone to opportunism, which compromises the quality standards expected for project completion , thereby overlooking safety standards more often than not (Crosno and Dahlstrom, 2008). Corruption also occasions a lot of setbacks to project like the project abandonment and completion below standard (Oyewobi et al., 2011). Time delays and cost overruns for instance are just some of the consequences of unethical practices, wherein contractors deliberately overstate the time and cost requirements in order to get a higher contract price, and also engage in concealment of the material and work quality, whereby defective/cheaper materials with inferior specifications are used (Sohail et al., 2009). Based on the categorization, of harmful and counterproductive work practices as described in the figure 4.1, EGT application is presented in following subsection;

4.3.2.1 EGT MODELING

The evolutionary game model is built around owner, contractors and supervision unit, from which conditions of stability of evolutionarily stable strategies are derived and analyzed. Numerical examples are then presented to illustrate the applicability of the model which in turn simulates the evolutionary strategy in different initial conditions. As seen from the discussions in preceding paragraph, contractors may earn an undue profit in collusion with a supervision unit either by supplying poor work or substandard material, and/or by false claim or by escaping penalty on unjustified time delays. These income matrix are termed as I_{mat}, I_{claim} and I_{time} respectively for the purpose of this study. Contractor and supervision unit may give rise to co-operative strategies whereby profits arising from lower than the contractually agreed levels of performance are shared between them (CSD, 2013). Thus considering the prevalence of incidences of unethical practices, opportunistic behavior and the existence of information symmetry in the procurement system, it could also be assumed that a contractor may deliver sub-standard service, materials or poor quality of work without the support of supervision units to maximize their gain. However, in such a scenario, the contractor may neither earn through false claim nor escape penalty on time delays.

The nomenclature, used in this modeling, is explained as follows:

I_{mat} Collusive income by supplying poor work or substandard material

I_{claim} Collusive income by the false claim

I_{time} Collusive Income by escaping penalty on time delays

I = $(I_{mat} + I_{claim} + I_{time})$

= Total Income proceeds gained by the Contractor by supplying deficient quantity, substandard material false claim and by escaping penalty on unjustified time delays due to collusion with supervision unit.

S = Share of collusive income given to supervision unit.

C = Cost of inadequate supervision including administrative expenditure.

KC = Additional cost borne by the owner to make supervision adequate

p_s = Fixed salary of supervisors

p_f = Normal profit of contractor without collusion

m = Penalty coefficient for supervisor

n = Penalty coefficient for contractor

R = Further loss suffered by the owner due to the ost of rework or additional expenditure on maintenance

R' = Non-collusive income of contractor by supplying substandard material or poor work

If the contractor and supervision unit agrees among themselves to be collusive, contractor earns 'I' as income proceeds due to collusion. The contractor, in turn, gives a share 'S' from the collusive income to a supervisor/supervision unit. However, even when a contractor is not making collusion with the supervision unit, he/she may still deliver substandard material and perform poor quality/ substandard work which if remain undetected would save R from his (contractor's) expenditure. In case, where the, owner detects the collusion, income proceed is recovered and 'm' times penalty on supervisor salary i.e. 'mp_s' is imposed. A 'n-time penalty' over collusive income i.e. 'nI' is also imposed on the contractor. The cost of the owner supervising is 'C' for inadequate supervision. In case, the owner decides to exercise adequate supervision by ensuring inspection on every important aspect of a complex project by engaging additional sources, he has to incur additional cost 'KC'. Therefore, this model has two strategies that are available to the contractor and supervision unit i.e. either collude or don't collude as denoted by 'O_1 & O_2'. In here, even the owner isn't deprived and has also two strategies: to adequately supervise or not, as represented by 'S_1 & S_2'. The pay-off matrix for owner and Contractor and supervision units are,

$$M_1 = \begin{array}{c} \\ S \\ S_2 \end{array} \begin{array}{c} \begin{array}{cc} O_1 & O_2 \end{array} \\ \begin{pmatrix} mp_s+nI-(k+1)c & -(k+1)c \\ -I-c-R & -c-R \end{pmatrix} \end{array} \quad \text{.............(4.13)}$$

$$M_2 = \begin{array}{c} \\ O_1 \\ O_2 \end{array} \begin{array}{c} \begin{array}{cc} S_1 & S_2 \end{array} \\ \begin{pmatrix} -mp_s - nI + p_s + p_f & I + p_s + p_f \\ p_f + p_s & R' + p_f + p_s \end{pmatrix} \end{array} \quad \text{............. (4.14)}$$

Assuming that proportion that contractor and supervisor collude or not is x_1 and $(1-x_1)$. Similarly that the proportion that owner supervises adequately or not is x_2 and $(1-x_2)$ respectively. The owner's expected pay off represented by U_A and U_B respectively for strategy S_1 & S_2 are thereby:

$U_A = x_1 [\, mp_s + nI] - (k+1)C$ .... (4.15)

$U_B = (-C - R - x_1 I)$ .... (4.16)

The average expected pay off of owner is:

$\bar{U} = x_2 U_A + (1-x_2) U_B$

$\bar{U} = x_2 U_A + (1-x_2) U_B$

$= x_1x_2 (mp_s + nI) - x_2(k+1)C - (1-x_2)(C+R+x_1I)$ .... (4.17)

Now the expected revenue represented by V_A and V_B for Contractor and Supervision unit in case of strategies O_1 and O_2 are

$V_A = -x_2 (mp_s + nI) + (1-x_2) I + p_s + p_f$ .... (4.18)

$V_B = (1-x_2) R' + p_s + p_f$ .... (4.19)

$\bar{V} = x_1 V_A + (1-x_1) V_B$

$= -x_1x_2(mp_s + nI) + x_1 (1-x_2) I + (1-x_1)(1-x_2) R' + p_s + p_f$ .... (4.20)

The evolution process of construction project supply chain may be described by by dynamic replicator equations. Using replication dynamics, the coupled set of replicator equations from eq. (4.9) & (4.11) and eq. (4.12) & (4.14) are as follows:

$f_2 (x) = dx_2/dt = x_2 [U_A - \bar{U}]$

$= x_2(1-x_2) [x_1 \{mp_s + (n+1)_I\} - k C + R]$ .... (4.21)

$f_1 (x) = = dx_1/dt = x_1 [V_A - \bar{V}]$

$= x_1 (1 - x_1) [I - R' - x_2 (mp_s + nI + I - R')]$ .... (4.22)

The Jacobian matrix for the evolution system is given by

$$J = \begin{pmatrix} \frac{\partial f_1(x)}{\partial x_1} & \frac{\partial f_1(x)}{\partial x_2} \\ \frac{\partial f_2(x)}{\partial x_1} & \frac{\partial f_2(x)}{\partial x_2} \end{pmatrix}$$

From eq. (9) and (10) we get,

$$J = \begin{pmatrix} (1-2x_1)\{I - R' - x_2(mp_s + nI - R')\} & -x_1(1-x_1)(mp_s + nI + I - R') \\ x_2(1-x_2)\{mp_s + (n+1)I\} & (1-2x_2)[x_1(mp_s + nI) + R - kC] \end{pmatrix}$$

.... (4.23)

4.3.2.2 EGT ANALYSIS AND FINDINGS

The central idea of EGT is the basic dynamic postulate which states that the better a strategy performs in the present situation, the faster it grows among players. According to the method proposed by Friedman (1998), the stability of the evolutionary system can be analyzed by determining the sign of real parts of Eigen values of the Jacobian matrix 'J' as given in eq. (11). The characteristics roots (Eigen values) $\lambda_{1,} \lambda_2$ are the solutions $|J-\lambda I| = 0$. Alternatively, sum of the Eigen values is the trace of the Jacobian matrix, and the product is the determinant of J. For stability, replication equation should have both Eigen values to be negative. As the trace of 2 x 2 matrix and its determinant must be negative and positive for a system to be stable. The determinant and trace of Jacobian matrix obtained are:

$$\det J = (1 - 2x_1)(1 - 2x_2)[I - R' - x_2(mp_s + nI + I - R')][x_1(mp_s + nI) + R - kc]$$
$$+ x_1x_2(1 - x_1)(1 - x_2)[(mp_s + nI) + I][mp_s + nI + I - R'] \qquad \text{...........(4.24)}$$

$$\text{trace } J = (1 - 2x_1)[I - R' - x_2(mp_s + nI + I - R')] +$$
$$1 - 2x_2)[x_1(mp_s + nI) + R - kc] \qquad \text{........... (4.25)}$$

According to stability analysis, following results are obtained from equations (4.24) & (4.25) and are further elaborated in Table -4.2 & 4.3:

Table 4.2: the value of Jacobian Matrix Determinant and Trace

Equilibrium	**Det J**	**Trace J**
O: $x_1 = 0, x_2 = 0$	$(I - R')(R - kc)$	$(I - R') + (R - kc)$
P : $x_1 = 1, x_2 = 0$	$(I - R')(mp_s + nI + R - kc)$	$mp_s + (n - 1)I + R + R' - kc$
Q: $x_1 = 0, x_2 = 1$	$(mp_s + nI)(R - kc)$	$-(mp_s + nI + R - kc)$
R: $x_1 = 1, x_2 = 1$	$-(mp_s + nI)(mp_s + nI + R - kc)$	$-R + kc$
S: $x_1 = x_1^*, x_2 = x_2^*$	-	0

$$x_2^* = \frac{I - R'}{mp_s + (n+1)I - R'} \qquad \text{.............. (4.26)}$$

$$x_1^* = \frac{KC - R}{mp_s + (n+1)I}$$

................(4.27)

Table 4.3: All cases of Dynamic stability analysis

Case Sr. no.	Conditions	O	P	Q	R	S
1	I > R', R > kc	Instability	Instability	ESS	Saddle Point	Saddle Point
2	I <R', R< kc	ESS	-	-	-	Saddle point
3	R< kc, mp_s + nI + R > kc	-	-	Saddle Point	Unstable	Saddle point
4	I>R', mp_s + nI + R < kc	-	ESS	-	ESS	-

As seen from the table 4.3, there is one stable strategy O (0, 0) for Case 2 whereas Q (0,1) is stable strategy for case -1. However there are two kinds of stable strategies P(1,0) and R (1,1) for case 4. Further the stable strategy analysis of supervision unit and contractor shows that when $x_2 = x_2^*$, the value of f_1 (x_1) becomes 0 which means all x1 are stable states. If $x_2 \neq x_2^*$, then there exists two possible steady states when x_1^* is either 0 or 1. However, if $x_2 > x_2^*$ then f'_1 (x_1^*) < 0 and x_1^* = 0 therefore supervision unit & contractor will not chose to collude. If $x_2 > x_2^*$ then f'_1 (x_1^*) < 0 and x_1^* = 1 then supervision unit & contractor will not chose to collude.

Since, x_1 is related to model of frequency, it represent risk (Holler, 2002) of collusion and hence consequent risk of underperformance arising from collusion. Similarly, (1- x_1)(1- x_2) represents the risk of contractors' opportunistic behaviour in the execution phase. The parameter analysis reveals that when collusive income is less than the non-collusive income earned by contractor, and the cost of rework is lesser than the owner's cost of ensuring adequate supervision, the contractor will prefer not to collude with the supervision unit. Such a situation may arise when there's a high level of information asymmetry i.e. supervision unit may not have the expertise or infrastructure to detect quality deficiencies. Alternatively, it may also happen that when contractors take on the contract at unworkable rates following low bid rate procurement system, they engage in opportunistic behavior to minimize their losses. Under these circumstances, the owner should review the existing procurement system, especially the process of evaluating bids from the perspective of workability of bid rates. An owner should also take measures to reduce the information asymmetry and strengthen monitoring system. However, information asymmetry is likely to be increased with project complexities. Similarly, any limitation in supervision unit's capability would affect the owner's monitoring system.

The first case represents a scenario where the cost of adequate supervision is less than the rework and at the same time, collusive income is more than non-collusive income. The dynamic stability analysis reveals that an owner will choose to exercise adequate supervision, and contractor shall become rational not to collude as a stable strategy. The second case involves a situation wherein the cost of adequate supervision is more than the cost of rework and collusive income is less than non-collusive income. In this case, the owner will choose not to exercise adequate supervision, and the contractor shall become rational to not to collude with the supervision unit as a stable strategy. The third case reflects that when owner's cost of adequate supervision is more than rework cost but less than the penalty on contractor and supervision unit and rework cost taken together. There will not be any stable strategy and system will be unstable. Further, in this case, the owner should bring down the monitoring cost and try to reduce information asymmetry by strengthening monitoring to minimize any rework.

In the fourth case, the owner's monitoring cost outweighs the recovery made through penalty & rework cost taken together. At the same time, collusive income is more than the non-collusive income earned by the contractor. Under these conditions, the stable strategy for the contractor and supervision unit is to collude. In such circumstances, the owner should focus on monitoring cost and penalty structure. However, the system becomes bi-stable in this case, as an owner may or may not choose to adequately monitor or supervise, depending upon his/her initial selection strategy. Further, under such a scenario, collusion between contractor and supervision unit would persist even if the owner decides to undertake adequate supervision measures. This clearly explains the prevalence and spread of collusive strategy by contractors and supervision unit personnel irrespective of the owner's monitoring strategies. In fact, the owner may feel frustrated on the issue of control of losses caused by collusion. Under these circumstances, the owner should think about monitoring cost by means of improving the efficiency of the monitoring mechanism. An owner's other options shall include rationalizing the penalty structure; for instance, the contractors' collusive gains could be further reduced, if past performance is considered while awarding new works to the contractor. The owner should also focus on reasonability of contract prices to avoid a situation where contractors are being awarded the work or supply contract on the basis of low bid system, even if it be unreasonably low.

As seen from the above analysis, collusive income may be earned by accepting the use of sub-standard material or work, false claims and performance failure to meet work or supply delivery timeline (if either I_{mat} or I_{claim} or I_{time} is significant, collusive income would become significant). Hence, the owner should strengthen the structure for verifying the design change and cost claim request from contractors. Similarly, it would be necessary to critically review time overruns in the light of actual reasons for delays.

These policy measures would enhance flexibility of owner strategies and also result in better preparedness to handle disruptions in the work flow arising out of collusion, opportunism and information asymmetry etc., thereby contributing to an improved CSC performance. At the same time, it also provides insights for improved decision making for efficiently managing CSC. Actually, the efficiency of supply chains mostly depends on management decisions. Supply chain design's vital decision pertains to selecting suppliers, parts, and processes at various stages. In this regard, this study suggests that procurement system selecting vendor on the basis of lowest rate may become counterproductive. Rather, it would be better to consider the contractors' capability and past performance along with the workable procurement price while outsourcing the work.

4.3.2.3 NUMERICAL SIMULATION

In this sub-section, we present a hypothetical case and some numerical simulations of the replication model above. The hypothetical case is taken to illustrate the evolution stability analysis of collusive behaviour in a construction project. In this case, various indices of payoff matrix are assigned a numerical value. The penalty coefficients m and n are assumed to be 1 and other indices are as follows; I = 100, p_s = 20, R = 80, R' = 50, KC=150. For this case, simulations were conducted in MATLAB using the ODE45s solver with a variety of initial conditions i.e. [0.1, 0.9], [0.2, 0.8], [0.3, 0.7], [0.4, 0.6], [0.5, 0.5], [0.6, 0.4], [0.1, 0.3] and [0.3, 0.1].

The simulation results are shown in Figure 4.6 which confirm the robustness of the model as the value of probability of collusion between contractor and supervision unit and the probability of adequate supervision varies between 0 and 1. Secondly, the value of x_1 and x_2 converge into opposite direction i.e. when the probability of owner's supervision decreases, the probability of collusion increases, which is also in conformance with the intuition. It is also seen that higher is the disturbance i.e. difference between the initial value of x_1 and x_2 and corresponding steady state, greater is the time taken to reach a steady state.

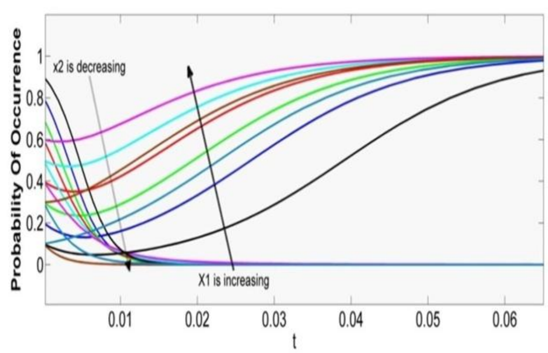


Figure 4.6 Dynamic evolution of collusion strategy

The dynamic evolution process of strategy choice is also simulated in Matlab 2010 with a new set of payoff indices values where R-KC > 0 i.e. I = 100, p_s = 20, R = 80, R' = 50, KC=50. We now set the value of x_2 above 0.5 and simulation is carried out for each value. The resultant dynamic evolution process of the strategy of collusion changes with time as is evident from the Figure 4.7. The simulation results depicted in Figure 4.7 shows that the probability of collusion strategy under different initial strategies of owner's supervision finally converges to zero. It is also seen that higher is the initial value of x_2, greater is the speed of convergence.

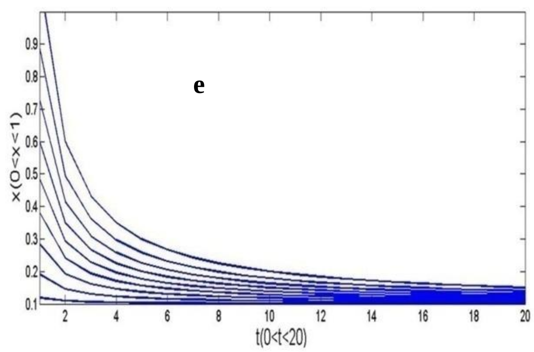


Figure 4.7: Dynamic evolution of collusion strategy

Now let's take another set of values to carry out simulation. These values are as follows:- I = 100, p_s = 20, R = 80, R' = 50, KC= 210. Here R-KC < 0 and value of x_2 are assigned value below 0.5 and the results for dynamic evolution for collusion strategy are shown in Figure 4.8.

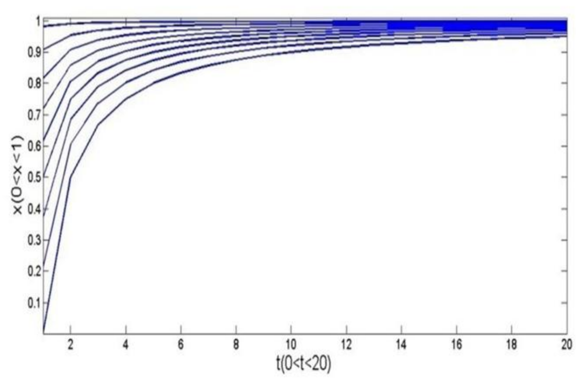


Figure 4.8: Dynamic evolution of collusion strategy

These results show that when the probability of the owner choosing adequate supervision strategy increasing, the contractor eventually adopts the strategy of not colluding with the supervision unit, effectively signaling that collusion risk may be hedged by the owner by choosing a strategy of adequate supervision; however such a decision would depend on the monitoring cost. Although these simulation results are similar to the ones found by Wen et al., (2014), our model considers additional parameters for analyzing different risk scenarios.

4.4 COMPARATIVE DISCUSSION AND CONCLUSION

Game theory and evolutionary game modelling were utilized for analyzing the underperformance risks in the projects or works execution phase. Both the model has given relevant and interesting insights about role of various factors in affecting the performance during the work execution. However, it is considered useful to present a comparative perspective discussion before conclusions of the game modelling and simulation.

4.4.1 COMPARATIVE DISCUSSION

The game theory model is defined by the Nash player who is rational and also implicitly assumes that all players are rational enough to coordinate their strategies resulting in a unique or multiple Nash equilibrium. The rational actors behave like payoff maximizer in the isolated encounters which is the case of simple projects or small works. Examples of these encounters include quality inspections and work measurements conducted by supervision units, audit or technical checks, on the work, examination of additional cost claims etc. The model reveals that collusion probability and consequent risk of underperformance increases in presence of supervisors' capacity deficit and project complexity. Further, when the value of rework increases, the probability of collusion decreases i.e. supervisor may desist from collusion in case of large rework requirement. It implies that owner should ensure that rework is done properly by the contractor himself to bring the quality of work up to acceptable standard in case contractual violations in terms of deficient or substandard work are detected. This finding also implies that contractual activities should be supervised adequately to minimize the chance of subsequent rework even though supervisors may collude with contractor.

In case of evolutionary model, it is assumed that player is rational but does not knows much about the other players such as payoff functions or preferences, competence, or importance of various project activities, etc. This limitation arises from cognitive capacity or complexity of real world situation as is the case with large or mega construction projects. As a result, it can be interpreted as the "rational conclusion" of the constrained cognitive capacity of the decision maker, or the complexity of the decision situation, or seen as the consequence as suggested by empirical results which challenge the rational choice game theory model (Frohn et al., 2001).This key constraint is resolved by agents or players by following an evolutionary approach whereby they imitate the observed successful behaviour of other agents. Accordingly, adaptation (or learning) and selection phenomenon replaces strategic reasoning by rational agent in reaching equilibrium states. These dynamic changes in the strategies were formalized by static equilibrium concepts and ESS. The dynamic concept of replicator is applied to examine the stability of the evolutionary.

Consequently, the evolutionary game analysis describes a macro social behaviour (Gintis, 2000) which embeds socially or temporally isolated encounters in itself. The outcomes of these encounters guide the individual actor's decision making through evolutionary adaptive process whereby it affects the environment also. What EGT analysis emphasizes is that fitness of any individual player's strategy can't be measured in isolation; rather it has to be assessed in the context of the population of contractors, suppliers, project managers and supervisors.

At evolutionarily stable points, players have to opt their strategies on the basis of their learning or information acquired. Consequently, the information available in the form of penalty structure, quality norms, response to quality and time line failures can be manipulated or modified so that other player learns to align their strategies with desired procurement outcomes. It is interesting to observe is that the learned behaviour strongly depends on the project work environment and vice-versa. If the large majority of individuals behave opportunistically like delivering poor quality or performing substandard work, this strategy is recognized as successful and hence may be adopted by others also which in-turn would increase the risk of underperformance. If such opportunistic behaviour is perceived as unsuccessful, a population of contractors and suppliers —initially consists of those who behave opportunistically, but due to simple local imitation of successful behaviours,—will self-organize into a similar state with performing to desired level of performance parameters. These findings are applicable for large projects where large number of contractor, suppliers and vendors participate or any organizations undertaking large numbers of smaller or large works.

On the other hand, findings from game model though focus on isolated interactions would provide useful policy implications for both smaller and large projects as it operationalize the complexity as one of the analysis parameters. However, it does not explain the effect of strategic interactions on the change in the work environment. Whereas, evolutionary modelling explains that how various strategies fare and how the environment is therefore likely to change because of spread of more successful strategies. Thus, evolutionary game analysis also tells about how the project work environment can be changed from undesirable states to more desirable alternative equilibrium states and thereby, assists in devising necessary measures and/or actions to be taken in order to promote these shifts. Therefore, EGT model helps in understanding the conditions which explain the status-quo and brings out the possible future equilibrium states. In essence, both the model complement each other to scope out the execution phase in its entirety in the analysis because the work may be large or smaller in size and strategic interactions and work environment affect each other .

4.4.2 CONCLUSION

Game theory and evolutionary game modelling were used to model the strategic interactions between three players, viz. owner, supervision unit and contractor in the projects' execution. Considering the importance of performance delivery in the projects to socio-economic development, we used socio-technical system concepts and supply chain perspective to improve our understanding of the problem of underperformance and find the factors influencing the performance. It was found that project complexity, organizational policies, and supervision unit capability limitations are the important factors that affect the performance outcomes. As several harmful and counterproductive work practices, are affecting the project sustainability, these work practices were reviewed and organized on the basis of their consequences. Consequently two important insights emerged. First key insight is that unethical practices resulting in safety consequences and non-safety consequence, therefore, different penalty structure should be considered for collusive behaviour resulting in safety then non-safety consequences. Secondly, contractors may choose strategically to behave opportunistically or underperform to maximise their self interests, however, earlier models have considered collusion between contractor and supervision unit for poor performance. The introduction of these choices into the strategy space of the contractors and suppliers is necessary for a comprehensive analysis. These two insights were included in the analysis. Specifically, we assumed that contractor's incentives are not aligned with those of the public as the contractor may deliver substandard material or work even without collusion of the supervision unit. Game model findings show that probability of collusion and consequent risk of underperformance depends on 6 important risk factors, viz. cost of ensuring adequate supervision, project complexity, supervisor capacity deficit, rework cost, penalty structure, undue benefits. It is expected that the game theory model would facilitate more effective conceptualization of risk scenarios in analyzing contractual underperformance and inferring policy correctional measures.

To undertake further deeper analysis, this study, then adopts a supply chain perspective and applies Evolutionary Game theory. By adopting supply chain perspective, several important insights were acquired about the problems and challenges in the construction projects. There exist indeed several teething problems in CSC; for instance, presence of multiple players and consequent fragmentation; uniqueness of projects and prevalence of unethical practices etc., which affect the smooth functioning of CSC. After formulating the evolutionary game model, stability analysis is carried out, whereby conditions of stability of evolutionarily stable strategies are analyzed for deriving useful policy measures. The research findings further elaborate that a steady state of collusion behaviour depends on 5 key factors, viz. an owner's cost of adequate supervision; rework cost, penalty structure, collusive and non collusive income. The results reveal that non-collusive income earned by contractors through opportunistic behaviour and procurement system characteristics may also affect the project performance and stable state.

The stability analysis also yielded several useful findings. For illustration, when owner's monitoring cost outweighs the penalty and rework cost taken together and collusive income is more than the non-collusive income, the stable strategy for the contractor and supervision unit is to collude irrespective of the fact whether owner exercises adequate supervision or not. It is interesting to find that CSC turns out to be a bistable system in such a scenario. However, this result does not mean that all the construction projects will continue to suffer from lack of control resulting in contractual underperformance. Rather, it implies that 'performance conscious owners will decide to focus on putting more effort in reducing monitoring costs, information asymmetry, and on rationalizing the penalty structures to mitigate the risks. Other circumstances have also been described detailing when the system would become unstable or when the stable strategy for the contractor and supervision unit is not to collude. Based on this analysis, the article then explicitly identifies several countermeasures under different scenarios in the project supply chain.

Finally, an implication of our results is that probability of collusion and consequent underperformance risk increases when owners monitoring cost increases. As owner's monitoring or supervision costs depend on the monitoring efficiency, owner should pay attention on optimum use of supervision resources to reduce supervision costs. However, future research is necessary to optimize the owner's monitoring cost. In this regard, it would be quite important to identify the unique features of construction project for appropriately modelling the quality failure costs and study the monitoring strategies for real time decision making and optimizing monitoring cost. We deduce this is the key issue underlying the problems of timely tackling the poor performance and unethical behaviour in the projects, which deserves more attention in future research.

CHAPTER

5

MODELLING QUALITY FAILURE COSTS AND MONITORING STRATEGIES

5.1 INTRODUCTION

Efficiently handling the procurement outlays is a major challenge for procurement managers and researchers. In this regard, organizations need to devise suitable mechanisms for timely tackling the problems pertaining to poor performance in the execution phase. Actually, public organizations can draw significant sustainable advantages from efficient monitoring of quality failures by optimum use of supervision resources. The quality failures not only reduce project worthiness and introduce performance uncertainties but also adversely affect socio-economic benefits from them. Therefore, research efforts are required for appropriate modelling of the quality failures costs to suggest efficient monitoring strategies.

In this context, it is felt necessary to first understand the process by which various works are undertaken and/or organized in the organizations. Large firms are re-organizing into less bureaucratic, more adaptable and flexible project-based units (Sydow et al. 2004). In fact, even smaller units of work are being organized as projects (Maylor et al, 2006). This reflects the projectification trend as relatively simple works are also undertaken as projects. Projects are now playing a progressively more important role in the world economy. They do not only deliver products, services or infrastructure but also used strategically for transforming organizational processes and practices (Bjørkeng et al. 2009). The reason for projectification is servicefication of the economy and project based financing (Kuura, 2011). New Public Management reforms concerning efficiency, result orientation, and value for money considerations have also led to increasing use of projects, as organizational solutions, in public organizations (Van Thiel &

Homburg, 2007). The characteristics of uncertainty, transiency and non-repetitiveness, differentiates projects from production process and other forms of organizations. These characteristics may fragment the organizations' ability to maintain coordination and continuity in public sector (Sjöblom et al 2015) that result into several problems and challenges. For instance, project failures are often associated with fatal accidents, catastrophic collapses of buildings, facilities, and bridges, as well as political and/or business scandals (Pietroforte and Miller 2002; Sha 2004; Olanitori et al. 2011; Adnan 2012, Shittu et al. 2013; Bowen et al. 2012, Moodley 2014). Due to globalization, economic growth, technological advances, changes in economic structures, and fierce market competition, construction projects will face more uncertainties and considerably higher risks in the future (Xiang et al, 2011).

Uncertainty reflects potential, unpredictable, un-measurable and uncontrollable outcome (Knight, 1921 and Crouhy, 2005). Uncertainty in the construction project arise from several sources and often involves multiple project participants (Hendrickson et al, 2003). The problem multiplies with project size because uncertainties in project outcome increase with size (Dey et al, 2002). However, uncertainty not only decreases with passage of time but it also reduces by risk management, specifically by decision-making (Antunes et al, 2015). Therefore, the impact of uncertainty need to be minimised by monitoring and timely decisions making to reduce variability. Actually, various risks may arise in the process: supervision unit and the project contractor may collude; the construction contractor submits false claim and supply substandard material and poor quality management by contractor and contractor capacity deficit, conflict of interests and negligence etc affect project performance. Where the control mechanisms are weak, or have broken down, an environment is generated where any two parties can agree for bending the rules (Wells, 2014). Contractor may deliver sub-standard goods and works and use shortcuts leading to poor quality assets and high maintenance costs. This often occurs with the collusion of the supervision unit or engineer (Mawenya 2007) . it may also occurs when conflict of interest exists or negligence. Conflict of interest signifies a situation where a professional in a position of trust, like a worksite supervisor or an auditor cannot fulfill their duty in a fair or impartial manner because of ambivalent professional or personal interests (Hartley 2009; Jong et al. 2009, Le et al. 2014). Specific forms of negligence found in execution are inadequate quality specifications, poor workmanship, deficient specifications, poor quality materials and inadequate process supervision, etc. (Vee and Skitmore 2003). In fact, 20–30 % of project value is lost usually through corruption (Wells, 2014). Procurement practice of awarding the work at lowest price leads to adoption of well-known practice of "bid low and sue later" which forces the contractors to bid aggressively and then work inflexibly, for example, claiming more compensation with every change in the project work (Lenfle et al,2015). However, such aggressive underbidding strategy may lead to performance uncertainty due to opportunistic behaviour. Information asymmetry also induces opportunism in the construction projects. It is the situation where knowledge or information about certain events is distributed asymmetrically among involved entities. This relative information advantage provides an excellent opportunity for opportunism (Qu and Loosemore, 2013) during work execution.

Abdul-Rahman (1995) stress that poor quality resulting from non-conformance leads to extra cost and time overrun and subsequent costs of rectifying non-conformance can also become considerably high. Jafari et al (2013) reports that numerous studies (Barber et al, 2000; Nylen,1996; Palaneeswaran et al, 2008) examining quality failures have identified their costs as ranging from 5 to 20% of a project's contract value. As a result of complexities, information asymmetry, transiency and non-repetitiveness of the projects, the principal cannot accurately understand the behaviour, quality, and efforts of the agent who may take advantage of this situation to maximize his gains. To what extent owner's vulnerability will be taken advantage of is actually a probabilistic problem (Chang et al 2015). The collusive behaviour of supervision unit and contractor has been studied by several scholars (Hao, 2011; Shurong and Miao , 2012; Zhang et al., 2015;Yan and Feng, 2014; Yuan et al., 2016). However, these researches do not provide efficient measures and/or tools to respond to above problems. How to efficiently monitor underperformance risk hazards is, therefore, one of the most important issues in the project governance.

As seen from the section 4.3, risk of collusion and opportunism can be reduced by owners by reducing their monitoring costs (Sharma et al, 2017), it is required to find as to how to reduce owner's monitoring or supervision costs and improve monitoring strategies. It would necessitate identifying and understanding the unique features of work execution phase for appropriately modelling the quality failure costs and study the monitoring strategies for improved decision making to timely tackle the problem of poor performance. Traditional methods of performance bonds, procurement method, contract terms, etc, can be used to manage some of uncertainties in the construction project (Ford et al., 2002). Performance bonds, guarantees, insurance and warranties are the most common financial instruments which are used to hedge the underperformance risk or reduce risk exposure. Similarly, forms of contract viz. Lump sum or cost plus contract can be used to shift the risks between owner and contractor. However, owners are not sure whether undertaker will perform at their best (Chang, 2015). These traditional safeguards do not necessarily reduce the risks of underperformance arising from, collusion and opportunism nor do they provide flexibility to strategically respond to future project conditions. These uncertainties are the project conditions which cannot be addressed by pre project planning strategy. Further, available engineering quality control programs are mainly concerned with technical aspects and do not provide economic implications of quality failures. As a result, options ingrained in the contractual agreements as a potential safeguard remained mostly underutilized. Therefore, analytical methods that can model quality failure costs for controlling and responding to performance uncertainties and maximizing the value of the money in the construction project need to be developed. This paper attempts to address this need. It is considered that if the quality failure costs can be modelled appropriately, one can take corrective actions on the basis of the observed performance. For instance, if the deterioration of the quality drops below a lower acceptable threshold, the work acceptance may be delayed till it's brought to acceptable level.

Actually, worthiness of project at any time would depend on contractor's performance on the site and the materials used and supervision of work up till now. Thus present value of quality failure costs is important for predicting the future. Cui et al (2004) have also argued that project failure cost varies according to the contractor's performance and the quality of materials. The performance uncertainties result in volatility in cost of quality failures. Thus variation in quality failure cost over non-overlapping time interval can be considered to be independent. Moreover, if present value of the quality failure high, asset value will be less i.e. future states depend on Present state. This shows that quality failure cost to be Markovian in nature. In fact, Cui et al (2004) find that quality failure cost follow Geometric Brownian Motion (GBM) and has been successfully modelled accordingly in warranty contracting study. GBM is a special class of Wiener process which serves as a building block to model a broad range of phenomenon with stochastic properties. Because of property of normal distribution of random variable and its application capabilities, the Brownian motion may be universally applied (Valis, 2014). Wiener process was already used in assessing the vulnerability of critical infrastructure projects by Ford et al (2002) and (Li, 2016). We, therefore, model quality failures costs as a geometric Brownian motion. In addition, a barrier is also imposed which will act as a constraint to the stochastic process. This barrier may cause the process to stop earlier when value of project reaches acceptable threshold. The model facilitates decision making through information acquisition which helps in reducing performance uncertainties. It also characterizes the optimal monitoring policy that may induce performance effort and makes suggestion for preventing quality deterioration. The strength of the proposed method is that it take advantage of quantifiable parameters that has immense scope of further refinement in future with availability of new data resulting from the increasing use of information communication technology in construction project processes.

The rest of the chapter is organized as follows. Section 5.2 introduces relevant literature, presents theoretical foundations on project governance and management, Geometric Brownian Motion and Wiener process for stochastic modeling. Next section 5.3 outlines the assumptions and formulates the stochastic model for analyzing the monitoring strategies and quality failure costs. The modeling problem is then solved and numerical simulation is presented to illustrate its applicability. Finally, section 5.4 presents conclusions, summarizes the managerial implications and charts the opportunity for future research.

5.2 RELATED LITERATURE

Empirical evidences suggest that large projects often fail (Flyvberg et al. 2002). A dataset of 318 industrial megaprojects, which was collected from various sectors, demonstrates that as high as 65 percent of these projects can be considered a failure (Merrow, 2011). Szyliowicz and Goetz (1995) point out the difficulty in specifying ex ante the relevant risks of large-scale projects as they are vulnerable to unforeseen events. The viability of a project depends not only on the financial status of the project organization but also other participants such as consultants, contractors and suppliers. Large projects are characterized by large scale investments, enormous complexity and long-term impact on the economy and society (Brookes and Locatelli, 2015).

Miller and Lessard (2000) undertook study of sixty engineering projects with an average size of $1 billion undertaken around the world between 1980 and 2000. They found that about forty percent of these projects performed poorly and were either abandoned completely or restructured due to severe financial crisis. Actually, the project performance gets affected by random risks or opportunism based behaviour uncertainty. Several factors like complexity, technological sublime weakness in design and capability undermine the project performance and corruption is one of them however, it is not considered in the management literature (Locatelli et al, 2017). Corruption and opportunism represent important factors contributing to the deterioration in the construction work (Jagtap et al, 2015). Vilanova (2006) analyzed the difficulties of Eurotunnel and showed that the shareholders and bank syndicate, were unable to stem the opportunistic behaviour of the construction companies because of lack of technical expertise. As open competition is considered one of prerequisite for efficient public procurement, many developing countries have adopted open tendering system followed in developed nations. However, this kind of bidding system compels contractors to price the work at unrealistically low levels (Brockman, 2011) which may subsequently lead to opportunistic behaviour.

The annual loss as estimated by Sohail and Cavill (2008) from corruption in the global construction market reaches approximately US$340 billion, which is quite substantial. The major impact of corruption lies in infrastructure built or asset created as evident from their failures or high maintenance costs (Kenny, 2006). With competition turning out to be higher and higher, supervision profit getting shrink leading to risk of the collusion between supervision and contractor during execution phase. In fact, quantity surveyor may issue completion certificates to the contractor even when jobs are incomplete or sometimes abandoned (Shan et al. 2017). Companies having qualified certificates may reach collusive pacts with unqualified companies in some cases and let its certificates out to them on rent Shan et al. (2017). By using the rented certificates, the unqualified and incapable companies can participate in bid for projects. It would bring numerous risks to the projects. These unethical practices make contractors' capability an important issue in work execution.

As discussed in section 5.1, owner can rely upon three types of contractual means, viz. procurement systems choice, type of contracts, and financial instruments to manage above risks in the projects. Project governance has emerged as a central tool for controlling the risk exposure in various projects. As an overarching management tool, it offers a framework for organizing various organizational processes and project management, decision-making modeling. Efficient management of hazards in continually occurring project transactions by using above mentioned contractual means is the key issue in the project governance.

As uncertainties are the project conditions that need to be tackled by various provisions available in the project agreements, these provisions are viewed as options or real options in terms of economic theories. A real option can be considered as the investment in 'nonfinancial assets' like physical and human assets that facilitates the more efficient managerial decision-making to respond to future contingent events. Real options have emerged as a significant decision making tool in the governance of projects. Several scholars (Dixit & Pindyck, 1994; Trigeorgis, 2000; Yeo & Qiu, 2003; Topal, 2008; Madhani, 2013, Huang & Pi, 2014) have considered them as a strategic decision making tool that explicitly add value and provide flexibility. It lends flexibility to management by expanding the list of identifiable available resources and alternatives. Several academicians and practitioners have proposed the use of real options based-methods for analyzing project investments (Ho and Liu, 2002; Pellegrino et al., 2011; Liu and Cheah, 2009). Cheah et al. (2006) and Huang and Chou et al. (2006) have used this approach by assuming that the governing stochastic process is a diffusion or Wiener process. The essence of a real option therefore lies in the value of optimal utilization of all its available choices. For example, Growth option provides an option to expand the work quantity or its scope. Short closure option is exercised by owners and contractors mutually when it remains no more viable to execute contract. The exit option provides the option to abandon a project. Similarly, termination option provides an option to terminate the contract by the owner when value of project falls below acceptable standards. However, the main difficulty is in quantifying the costs associated with various options. Engineering quality control programs mainly addresses the technical aspects of quality failures which is also often marred by collusive arrangements between supervision unit, consultant and contractors, etc. Consequently, these methods find out defects and associated causes but do not provide timely information about their economic implications nor do they help in predicting future project states. However, economic implications of these failures on the project value are essential to analyze project risk by integrating the owner monitoring policy with decisions on the contractual means We have applied GBM for the purpose therefore GBM process along with related stochastic process concepts are discussed below.

5.2.1 WIENER PROCESS

Wiener process and the Gamma process are two classes of stochastic processes which are quite extensively applied in data analysis such as degradation modelling (Noortwijk, 2009; Ye et al, 2013; Sun et al, 2016), maintenance optimization (Guo et al, 2013), measurement errors (Ye et al, 2013) and banking supervision(Belhaj and Klimenko , 2011). Wiener process can be used as a building block for modelling a vast range of variables which vary continuously and stochastically (Dixit & Pindyck, 1994). Among the degradation models, Wiener process with positive drift is a favourable choice because of its mathematical properties and physical interpretations (Ye et al, 2013). It has been used intensively for its flexible and meaningful characteristics (Sun et al, 2016). Actually, it has more advantages than other stochastic models for non-monotonic degradation data. A Wiener process is a continuous-time stochastic process. It is a kind of Markov process and also known as a Brownian motion. A stochastic process can be considered as a collection of random variables whose value varies in an uncertain way which is indexed by some mathematical set. Thus, distribution of the possible values of the process at any given point of time can only be known. Wiener process does have three important defining properties. First of all, it is a Markovian process. This implies that probability distribution for all future values of the process would depend only on its current value. Its value remains unaffected by past values of the process or by any other current information. Secondly, it has independent increments. As a result, probability distribution for the change in the process is independent over non-overlapping time interval. Thirdly, changes in the process are normally distributed during any finite interval of time. The Markovian property of Wiener process is considered particularly important. Therefore, Wiener process illustrates a stochastic process in which only the present process states or current quality level are pertinent for forecasting the future state. As a result, past history of the process is not considered relevant as current quality level is a result of all past states.

To define the Wiener process dw is introduced. By using suitable transformations, one can apply Wiener for modelling quite a wide range of stochastic process variables. Now, the above properties of a Wiener process are described formally. Let *w*(t) be a Wiener process, any change is value of *w*, Δw in a time interval Δt, follows following conditions :

1. Change in value of winner process Δw and Δt are related by

   $\Delta w = \in_t \sqrt{\Delta t}$, where $\in_t$ is a normally distributed random variable. It has a zero mean and a standard deviation of one i.e. N(0,1).

2. The random variable is serially uncorrelated. Mathematically, we write $E[\in_t, \in_s] = 0$ for $t \neq s$. It implies that $E[\Delta w] = 0$ for non overlapping intervals. Thus, the values of Δw over any two different time intervals which are independent. It shows that change in Wiener process w(s+ t) − w(s) and w(u) are independent, for u ≤ s < T.

To examine the implications for the change in *w* of above two conditions, it is useful to break the time interval Δt into n units of length i.e. n = t/Δt. Then the change in z over this interval can be mathematically expressed as under:

$$\mathrm{w}(s+t) - w(s) = \sum_{i=l}^{n} \varepsilon_i \sqrt{\Delta t} \qquad \text{.....} (5.1)$$

As ε_i 's are independent, central limit theorem can be applied to their sum. Hence, changes in value of Wiener process i.e. *w*(s +t) - *w*(s) is normally distributed with mean zero and variance Δt. It implies that change in the Wiener process Δw depends on $\sqrt{\Delta t}$ whereas its variance develops linearly with the time horizon *t*. Considering Δt be infinitesimally small, the increment of a Wiener process dz, in continuous time can be expressed as under:

$$dz = \in_t \sqrt{dt} \qquad \text{.....} (5.2)$$

As discussed above, $\in_t$ has zero mean and standard deviation of one unit, $\varepsilon(dz) = 0$ and $v[dz] = \varepsilon[(dz)^2] = dt$. However, Wiener process does not have time derivative in the conventional sense; $\Delta z / \Delta t = \varepsilon_t (\Delta t)^{-1/2}$, that becomes infinite as Δt moves towards zero. Actually, Wiener process is the outcome of letting the intervals of a discrete time random walk to tend to zero. Therefore, process is defined over a continuum of time. Consequently, it becomes a process that is continuous almost everywhere but nowhere differentiable.

5.2.2 GEOMETRIC BROWNIAN MOTION

The domain of a normally distributed random variable extends from - ∞ to + ∞. However, many variables, especially those represent physical quantities, like quality failure costs, stock prices, value of physical assets are restricted to lie in the non negative interval. Therefore, it is not appropriate to describe these variables with a model that corresponds to a linear function of a random variable. In this regard, GMB is preferred among other stochastic model as it overcome this difficulty by replacing the variables in question by their logarithms. GBM is the model which is frequently used for modelling the behaviour of a variety of assets.

It can be defined as log-normally distributed Wiener process thus it can be considered as a special case of the Wiener process. A generalized simple Brownian motion with drift is written as a stochastic differential equation (SDE) given below:

$$dx=a(x,t)dt + b(x,t)dw. \quad \ldots\ldots (5.3)$$

where, stochastic differential dw , represents an infinitesimal increment of Brownian motion, w also called the Wiener process. a(x, t) and b(x, t) are some known functions which are non-random in nature and represent deterministic component and instantaneous drift respectively. The key feature of the drift and variance coefficients i.e. a and b is that they are functions of the current state and time. In other words a and b depends upon current value of x. The continuous-time stochastic process represented by x(t) in equation (5.3) is also called an Ito process.

An important special case of equation (5.3) is the GBM. In this case ($a(x,t) = \alpha x$ and $b(x,t) = \sigma x$ where α and σ are constants. Thus, stochastic process x follows a GBM if it satisfies the following SDE:

$$dx = \alpha x dt + \sigma x dw \quad \ldots\ldots (5.4)$$

Let's elaborate this definition, a is called the percentage drift and σ is called the percentage volatility. If a Brownian motion trajectory satisfy this SDE, the right hand side term αxdt governs the trajectory's trend while the other term σxdw describes the random noise effect of this trajectory.

By applying the technique of separation of variables, the equation (5.3) turn out to be as under:

$$\frac{dx}{x} = \alpha dt + \sigma dw \qquad \text{……………………………………………. (5.5)}$$

Now we take the integration of both sides

$$\int \frac{dx}{x} = \int (\alpha dt + \sigma dw) dt$$

As $\frac{dx}{x}$ pertains to derivative of ln(x), so we apply the Ito calculus and arrive at the following equations:

$$dx = (\alpha - \frac{1}{2}\sigma^2)\,\mathrm{dt} + \sigma dw$$

……………………………………………. (5.6)

Thus over a finite time interval t, the change in the logarithm of x is normally distributed with mean $(\alpha - \frac{1}{2}\sigma^2)\,\mathrm{t}$ and variance $\sigma^2 t$. As for x itself, it can be shown that if currently x(0) = x_0 , the expected value of x(t) is given by

$$x = x_0 \exp((\alpha - \frac{1}{2}\sigma^2)\,\mathrm{t} + \sigma w) \qquad \text{…………………. (5.7)}$$

A GBM process also satisfies the Markov Chain property. As seen from the above value of x is given by analytical solution: x(t) = $x_0 e^{S(t)}$ where

$$S = (\alpha - \frac{1}{2}\sigma^2)\,\mathrm{t} + \sigma w$$

we have

$$x(\mathrm{t+h}) = x_0 e^{S(\mathrm{t+h})} = x_0 e^{S(\mathrm{t}) + S(\mathrm{t+h}) - \mathrm{S(t)}} = x_0 e^{S(\mathrm{t})} e^{S(\mathrm{t+h}) - \mathrm{S(t)}} = x_t e^{S(\mathrm{t+h}) - \mathrm{S(t)}}$$

Thus the future states x(t + h) depends only on the future increment of the Brownian Motion, namely S(t + h) − S(t), which is independent and reflect the markovian chain property.

5.2.3 MEAN REVERTING PROCESS

A key feature of the GBM is proportionality of the drift term to the process variable x_t itself. Therefore, Brownian motions tend to wander quite far from initial state x = 0. In other words, the process can be interpreted to be repelled from the starting point. This phenomenon is realistic in many cases. However, some of the variables like prices of raw commodities such as copper, steel, oil, etc may not show such characteristics in reality. Stated simply, while the oil price of might fluctuate randomly up and down in the short run because of response to socio- political uncertainties in oil-producing countries, Oil cartel decisions, etc. However, it ought to be drawn back towards the marginal cost of producing oil in the longer run. Thus price of such commodities oil is required to be modelled as a mean-reverting process. The simplest mean-reverting process-also known as an Ornstein-Uhlenbeck process and mathematically expressed as following:

$$dx = \eta(\theta - x)\,\mathrm{dt} + \sigma\,\mathrm{dz} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5.8)$$

In above equation, η is the speed of reversion, and θ is the "normal' level or equilibrium level of stochastic variable x. It represents the mean value to which x tends to revert. For illustration, if x is a commodity price, let then θ be the long-run marginal cost of producing this item. The expected change in x will be governed by the difference of x and θ instead of x . It implies that if x is greater than θ , x is more likely to reduce in the next time interval. Hence, this process, although satisfying the Markovian property, it does not have independent increments over non overlapping time intervals. If the value of x is currently x_0 and follows equation (5.8) then its expected value at any future time t is

$$\varepsilon[x_t] = \theta + (x_0 - \theta)e^{-\eta t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (5.9)$$

5.2.4 ITO PROCESS

As discussed in section 5.2.1, it is observed that a sample Brownian path is continuous in time but differentiable nowhere. In simple words, the differentiation dw_t/dt does not exist. However, while using various real life processes with Wiener processes or Brownian motion, we often need to work with the situation of estimating the difference of a function of the type $f(w_t)$ over an infinitesimal time difference. It implies that, we are considering a function which depends only on another variable. For example, project worth depends upon quality failures. Thus, there is an implicit dependence on time since the GBM depends on time in this case. To undertake this kind of differentiation and integration, we need to make use of Ito's Lemma. Ito Lemma can be easily understood as Taylor series expansion (Dixit and Pindyck, 1994). As we are interested in finding total differential of function f, the study consider usual rule of calculus and obtain following:

$$df = f^{'}(w_t)dw_t$$

$$df = \frac{\partial f}{\partial x}dx + \frac{\partial f}{\partial t}dt \quad \ldots\ldots (5.10)$$

If we include higher order terms of changes in x,

$$df = \frac{\partial f}{\partial x}dx + \frac{\partial f}{\partial t}dt + \frac{1}{2}\frac{\partial^2 f}{\partial x^2}(dx)^2 + \frac{1}{6}\frac{\partial^3 f}{\partial x^3}(dx)^3 + \ldots\ldots\ldots\ldots$$

$$\ldots\ldots (5.11)$$

From equation (5.4), we find

$$(dx)^2 = a^2(\mathrm{x,t})(dt)^2 + 2a(\mathrm{x,t})\,\mathrm{b(x,t)(dt)}^{3/2} + b^2(\mathrm{x,t})\,\mathrm{dt}$$

$$\ldots\ldots (5.12)$$

When time interval dt becomes infinitely small, $(dt)^2 \, and \, (\mathrm{dt})^{3/2}$ approaches zero, we get

$$(dx)^2 = b^2(\mathrm{x,t})\,\mathrm{dt}$$

Similarly, other higher order terms of dt would approach zero when dt becomes infinitely small and equation (5.10) becomes

$$df = [\frac{\partial f}{\partial t} + a(\mathrm{x,t})\frac{\partial f}{\partial x}dt + \frac{1}{2}b^2\frac{\partial^2 f}{\partial x^2}]dt + b(\mathrm{x,t})\frac{\partial f}{\partial x}dw$$

$$\ldots\ldots (5.13)$$

The equation (5.13) is known as the Ito's lemma. It is the main equation of Ito's calculus used in analyzing Ito processes. More generally, one can extend this Taylor series to find functions of several Ito processes.

5.3 MODELLING

As this research attempts to systematically study various monitoring strategies by modelling quality failures along with their economic implications to address the execution phase problems, it is necessary to begin with basic analysis of owner costs for random inspection, continuous inspection and their combined inspection strategy. Based on its finding we would develop our model by considering interaction of monitoring, quality failure costs and project value.

5.3.1 BASIC ANALYSIS OF OWNER'S MONITORING COSTS

In order to ensure adequate preventive supervision without excessive costs, authors first studied monitoring strategies by introducing the concept of mixed super-vision strategy that combines two supervision techniques: continuous inspections and random checks. In case of construction work, if the defects of initial phase of are not detected, they will get covered up by subsequent stage of work. It is true for other engineering projects. These defects are unlikely to be detected by conducting inspections at later stages. Sometimes, these undetected defects may lead to undesired safety consequences. For example, Shittu et al. (2013) document that problem of defect is a safety problem in construction industry arising as a consequence of poor quality materials and workmanship that might lead to serious work-site accidents because of structure failures or building collapse. Therefore, it's considered necessary that certain stages are required to be monitored 100% or continuous inspections either by internal supervision unit or external organization. Presently, many of the private consultant organization offers services for supervising the engineering and construction projects at almost comparable cost and therefore their services are hired by public organizations for supervision work.

We conceptualize that project performance can be monitored by three strategies i.e. either by 100% continuous inspection or random inspections or by combining continuous inspection with fixed random inspections. It is also assumed that random inspections are conducted at λ frequency and have Poisson distribution. Now the cost of the above three inspection strategies for internal supervision is estimated;

<u>Strategy 1</u>: 100% inspection where C_i is the cost of one inspection and project execution time is T. In this case total supervision cost would be as follows:

$$TC_1 = \lim_{\lambda\to\infty}[\int_0^T \lambda.\mathrm{e}^{-\lambda t}\, C_t dt] \qquad \ldots\ldots(5.14)$$

Strategy 2: In this monitoring strategy, owner considers to conduct only random inspections throughout the project cycle T for controlling the quality and contractual performance but such a strategy may not be opted due to possible safety considerations. However, total supervision cost for internal supervision in this situation would be as follows;

$$TC_2 = \int_0^T \lambda.\mathrm{e}^{-\lambda t}\, C_t dt] = C_i[1-\mathrm{e}^{-\lambda t}] \qquad \ldots\ldots(5.15)$$

Strategy 3: When a combination of continuous & random inspection is employed. Let us say regular inspection is conducted for the period from 0 to t_1 (where $t_1 = \alpha T$, and $0 < \alpha < C_i$) and random inspection are conducted from t_1 to T. The total supervision cost by following this inspection strategy would be as follows:

$$TC_3 = \lim_{\lambda\to\infty}[\int_0^{t1} \lambda.\mathrm{e}^{-\lambda t}\, C_i dt] + \int_{t1}^{T} \lambda.\mathrm{e}^{-\lambda t}\, C_i dt = \alpha.C_i + \int_{t1}^{T} \lambda.\mathrm{e}^{-\lambda t}\, C_i dt$$

$$\ldots\ldots(5.16)$$

A positive cost gain is possible when combination of continuous & random inspection over 100% inspection only if,

$$TC_1 - TC_3 \geq 0$$
$$or\, C_i - \alpha.C_i - C_i[e^{-\lambda t}i - e^{-\lambda T}] \geq 0;$$
$$or\ (1-\alpha) \geq e^{-\lambda t}i - e^{-\lambda T}$$
$$or\,(1-\alpha)\, e^{\lambda T} \geq e^{\lambda T(1-\alpha)} - 1$$
$$[Using\ e^{-\lambda T\alpha} = 1 - \lambda T\alpha + \tfrac{\lambda^2T^2\alpha^2}{2!} - \tfrac{\lambda^3t^3\alpha^3}{3!} - \tfrac{\lambda^4T^4\alpha^4}{4!} + \text{---}]$$
$$or\, e^{\lambda T} + 1 \geq e^{\lambda T} + \alpha$$
$$or\ 1 \geq \alpha \quad : it\ is\ true\ as\ 0 < \alpha < 1$$

The supervision cost savings ($TC_1 - TC_3$) achieved by employing combination of continuous & random inspection can be used efficiently by owner to engage external agency for effective monitoring. If owner engage external agency to inspect a proportion (lets us say μ) of the inspection done by internal supervision unit. In such a case, the total cost of adequate supervision TC_4 for owner would be

$$TC_4 = (1+\mu)\ TC_3. \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.17)$$

From the above (5.15), (5.16) and (5.17), it's seen that $TC_4 \le TC_1$ if $\mu \le 1-\alpha$. This finding gives an important inference for reducing owners monitoring costs i.e. that owner can effectively reduce the risk of collusion as well as risk of underperperformance not being detected.

In this regard, Richard (2011) recommends for hiring a technical auditor for guarding the guardian (Supervisor) in a roads project. Hart (1983) has formalized the idea that principal can increase his utility by using alternate source of information. A technical auditor periodically inspects the project to ascertain "whether the materials and labor provided are appropriate to their intended purpose and were delivered in the quantity, quality, and location or disposition specified" (Patterson and Chaudhuri 2007, p181). One such field experiment was conducted by Olken (2007) in Indonesia where one group of villages were allowed to participate in the monitoring of a nationwide road construction program. The results shows that the difference between claim made by contractors on their invoices and the amounts actually spent is on an average 8 % less in those villages which were audited than in those villages which were not subjected to audit. Therefore, an additional supervision unit is considered in our model as an alternate information source for modelling owner's monitoring strategies and reducing underperformance risks.

5.3.2 MODEL SETTING FOR MONITORING STRATEGY

The work quality will vary according to the contractor's work-site performance and quality of the materials used in the construction work. If the quality of material and construction work in the project is ensured by monitoring and proper supervision during construction, the asset created is likely to last longer without rework or failure. Therefore, future maintenance expenditure will be less. This fact also implies that if the present value of the quality failure or underperformance is high, the value of the underlying asset will be less and may result in project failure.

As regards quality variations, the changes in the quality over non-overlapping time interval are considered to be independent. The assumption of independent non-monotone increments in quality seems to be reasonable as the contractual performance quality may either improve or deteriorate independently depending upon the performance and material used during the time interval under consideration. Moreover quality degradation increments in an infinitesimal time interval can be viewed as an additive superposition of a large number of factors. At the same time, the probability distribution of the cost of quality failures at any future time is not dependent on the particular path followed by it in the past. As the prices and investment costs are non negative everywhere and uncorrelated at different moments of time, geometric Brownian motion is considered appropriate to develop the model for analyzing owner's monitoring strateies. The increments in quality failures costs as a combined effect of multiple factors can be assumed to be log-normally distributed because of central limit theorem. Thus it is considered logical to assume performance uncertainties as a GBM which is also known as exponential Brownian motion. A GBM is a continuous-time stochastic process in which the logarithm of the random process variable follows a Brownian motion. It is also called a Wiener process with drift.

Let c be the cost of quality failures and evolves through GBM and defined as under

$$dc = \mu c dt + \sigma c dW_t \qquad \text{……………………………………………(5.18)}$$

μ and σ are the mean and standard deviation of percentage change in failure cost c and dWt is a standard Brownian motion i.e. Wiener process parameter.

Like Tirole (1986) it is hypothesised that the principal lacks either the time or the knowledge required to supervise the supervisor manager but we differ in respect of independent supervisor in the sense that external supervisor have the resources required to run the vertical structure and can do the job at almost equal cost. Therefore it is consider practically possible to engage internal and external supervision in any large contract and their unit cost of inspection are assumed to be nearly equal. Following Kofman et al (1993), it is assumed that internal supervisor is likely to collude with the contractor and the second independent supervisor/auditor serves only to perform the audit and collusion free. Let λ = mean no. of inspections per unit time conducted by internal unit and p is the ratio of inspection conducted by external technical unit and internal unit. Theoretically, our model is somewhat close to Belhaj (2012) and Vara et al. (2017). However, our work is concerned with quality failure costs and considers the risk of contractor's opportunism and collusion as well whereas these risks are not incorporated in the analysis in these models and project value is analyzed as a function of quality failure costs.

Let V denotes the value of asset created in the project. The project value among other thing can be considered a function of cost of quality failures. The solution of contractor's problem defined by (2) provides following incentive – compatibility constraints. The probability of auditing in the interval dt is λdt by internal supervision unit. As a result of inspection schedule and consequence of failure detection, contractor under taken effort *e* to improve the quality and resultant change in the mean quality is *Δμxr* is the cost spent by the contractor while taking efforts to improve the quality. Therefore the optimization program of the contractor is derived in Annexure A3 and written as under

$$\max_{e \in \{0,1\}} \left(\frac{1}{2}\sigma^2 c^2 \frac{\partial^2 V}{\partial c^2} - (\mu - \Delta\mu e)c\frac{\partial V}{\partial c} - xre\right) = 0$$

……………………………………..(5.19)

The contractor's problem defined by (5.20) provides following incentive – compatibility constraints.

$\Delta\mu.\ c.(\delta V/\delta c) \geq x\ r$ ……………………………………..(5.20)

From (5.20) it is seen that when cost of quality failures increases, the instantaneous loss of project value is higher than contractor's good quality management cost. It would be optimal for contractor to choose for good quality management. When Δμ is less i.e. contractor is not able to improve the quality due to it's capability constraint, it would be optimal for contractor to not to take efforts for improving the quality.

To ensure value of assets created on higher side and prevent collusion between contractor and internal supervision unit, owner undertakes supervision of quality of work through supervision unit and independent technical audits. Independent technical audits are conducted by third party / external supervisor engaged by owner for the purpose. If λ is the mean number of inspections per unit time conducted by supervision unit and Independent technical auditor also carries out checks (Let us say p. λ where $0 < p \leq 1$) per unit time, then probability of detection of poor quality work would be λ (1+ p) dt

$\lambda' = \lambda\,(1 + p)$

Let $c_{ins}\,r$ is the cost of continuous inspection per unit time and β $c_{ins}\,r$ is the cost of random technical audit/ inspection where β is a cost coefficient which shows that cost of random inspections are proportional to the cost of continuous inspection. Owner exercise his discretion to undertake continuous inspection for a period t_1 ($0<t_1<T$) in the project cycle time T. Owner may exercise the option of abandonment of the project if project value reaches value below V_L (lowest acceptable value). In this case owner's monitoring costs would be given as

$$TC_{ins} = (1+\mathrm{p})[\int_0^{t_1} e^{-rs} C_{ins}.rU_{\{0\le t\le T,\mathrm{V}\ge \mathrm{V}_L\}} ds + \beta\int_{t_1}^{T} e^{-rs}\lambda r C_{ins}.rU_{\{0\le t\le T,\mathrm{V}\ge \mathrm{V}_L\}} ds] \qquad \ldots\ldots\ldots\ldots\ldots\ldots (5.21)$$

$U_{\{0\le t\le T,\mathrm{V}\ge \mathrm{V}_L\}}$ is an indicator function that takes the value 1 when the cost of quality failures does not fall below the critical value corresponding project value fall below V_L during the project cycle and value zero when it reaches. However, we are interested in analyzing monitoring mechanism in this section. The optimization program of contractor would become as follows;

$$\underset{c\,\in\{0,1\}}{\max}\left(\frac{1}{2}\sigma^2 c^2\frac{\partial^2 V}{\partial c^2} - (\mu-\Delta\mu e)c\frac{\partial V}{\partial c} - xre + (e-1)\lambda^{'}\,\mathrm{V}\right) = 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.22)$$

and corresponding incentive compatibility constraint becomes

$$-\Delta\mu c\frac{\delta V}{\delta c} + \lambda^{'} V \ge xr \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.23)$$

Value of project V depends on two state variable I and C i.e. investment and cost of quality failures. V denotes the value of owner's opinion to invest in the project and accept the work. We follow Dixit and Pindyck (1999) to explore the analogy of financial option to model quality failure costs by introducing the contingent claims which will have different payoffs in two eventualities i.e. cost may go up or down. A portfolio of these contingent claims can be constructed to replicate the risk characteristics. From contingent claim analysis, it is known that imputed real option value would be equal to value of replicating portfolio.

Since project completion takes significant time, k is the maximum rate at which firm can invest. Investment is irreversible and non stochastic in nature. Let I denotes the investment rate which includes both capital and operating cost. The dynamics of I are given by

$dK = -Idt$ .... (5.24)

Now therefore consider a portfolio containing the option to invest and a short position in V_c units of project. The value of this portfolio is

$\phi = V(\mathrm{K}, c) - \mathrm{V}_c\, c$ .... (5.25)

The short position requires a payment flow of $\delta.V_c.c.dt$ on quality failure and investment of *I.dt.*

Hence total return on portfolio is

$d\phi - I.dt - \delta.V_c.c.dt$ .... (5.26)

From (5.25)

$d\phi = dV - \frac{\partial^2 V}{\partial c^2} c - \frac{\partial V}{\partial c}(dc) - \frac{\partial V}{\partial K} dK$ .... (5.27)

($\frac{\partial^2 V}{\partial c^2} c = dV^{'}[c].c$ can be omitted as we have assumed V'[C] is constant over dt)

Further from Ito's Lamma we may final

$dV = \frac{\partial V}{\partial c}.dc + \frac{1}{2}\frac{\partial^2 V}{\partial c^2}(\mathrm{dV})^2 + \frac{\partial V}{\partial K}.\mathrm{dK}$ .... (5.28)

From (5.24) & (5.27) we get total

$$= \frac{\partial V}{\partial c}.dc + \frac{1}{2}\frac{\partial^2 V}{\partial c^2}(dc)^2 + \frac{\partial V}{\partial K}.dK - \frac{\partial V}{\partial c}(dc) - I.dt - \delta.V_c.c.dt$$

$$= \frac{1}{2}\frac{\partial^2 V}{\partial c^2}(dc)^2 - I.dt - \delta.V_c c.dt - I\frac{\partial V}{\partial K} dt$$

$(dc)^2 = \sigma^2 c^2 dt$ .... (5.29)

At this portfolio is risk free, this must equal $r\phi dt$

$$\frac{1}{2}\sigma^2 c^2 \frac{\partial^2 V}{\partial c^2}.dt - I.dt - \delta.V_c.c.dt - I\frac{\partial V}{\partial K}.dt = r[V - \frac{\partial V}{\partial c}.c]dt$$

$$\frac{1}{2}\sigma^2 c^2 \frac{\partial^2 V}{\partial c^2} + (r - \delta)\frac{\partial V}{\partial c}.c - rV - I\frac{\partial V}{\partial K} - \mathrm{I} = 0$$

$$\frac{1}{2}\sigma^2 c^2 \frac{\partial^2 V}{\partial c^2} + (r-\delta)c\frac{\partial V}{\partial c} - rV - I\frac{\partial V}{\partial K} - \mathrm{I} = 0 \qquad \text{.................................... (5.30)}$$

For simplicity, its assumed that investment is observable and delay caused due to reduced investment can be tackled by owner through suitable intervention i.e. the effect of I is ignored in the evolution process of project value.

$$\frac{1}{2}\sigma^2 c^2 \frac{\partial^2 V}{\partial c^2} + (r-\delta)c\frac{\partial V}{\partial c} - rV = 0 \qquad \text{.................................... (5.31)}$$

Thus owner optimization problem is defined by following set of equations and conditions

$$dc = \mu c dt + \sigma c dW_t$$

$$\frac{1}{2}\sigma^2 c^2 \frac{\partial^2 V}{\partial c^2} + (r-\delta)c\frac{\partial V}{\partial c} - rV = 0$$

subject to

$$-\Delta\mu c\frac{\delta V}{\delta c} + \lambda' V \geq xr \qquad \text{.................................... (5.32)}$$

and following boundary conditions:

(i) V(0, 0) = V_{max}

(ii) V(K, 0) = 0

(iii)V(0, c) = Max (I-c, 0)

5.3.3 ANALYTICAL SOLUTION

Above problem can be approached from several angles. These methods need to be elaborated. It is to be noted that exponential partial differential equation of real valued stochastic process includes state space where state space is also n-dimensional Euclidean space having n vectors. When interpreting with time variable the index set has definite countable elements having both time dependent and time independent elements. Solution set of c(t, w_t , A, B, ….) = 0

Considering w_t is dominant over 't'. Considering Bernoulli process of finite and infinite sequences of independent random variables $w_{t_1}, w_{t_2} .....w_{t_i}$ for each i the values may be defined success fail over = {0, 1}. But the passage of time and associate notions of 'past' and 'future' are not necessary. However, Most generally w_{t_i} and w_{t_j} in this process of simple random form that form a set of random variable indexed by {1,2,…n} and {1,2,3….. ∝} sets. This may give rise to two kind of solution, viz. strong interpretation and weak interpretation

In case of strong interpretation, we have

$c = e^{aw_t + bt} + A + B$ Where A, B are the primary independents or zero.

$$dc = e^{aw_t + bt}.d[aw_t + bt] + 0 = c[adw_t + bdt]$$

Where a = μ and b= σ

In case of Weak interpretation, the time evolution of this system [mainly a set of canonical Co-ordinates c= (p,q)] is unique i.e. c=c'{p, q, t} subspace c' may be provided.

Then $\frac{dp}{dt} = -\frac{\partial c}{\partial q}, \frac{dq}{dt} = \frac{\partial c}{\partial P}$

This approach is the one this at used in Lagrangian equation i.e. with Legendre transformation. when holding q (t fixed) and defining P as duel. This is the only trial for the given differential form of equation.

i.e. $c = c^{'}[dc_t / \mathrm{d}F] = adt$ and

$$c = c^{'}[\mathrm{d}^2 c_t / \mathrm{d}F^2] = b^n dt$$

when F may be the disturbance component and dc_t / F and $\mathrm{d}^2 c_t / \mathrm{d}F^2$ are the probabilistic approach of interruption [both success of failure trials are included] again 3rd and higher order trials may be ignored if the duration of interruption →0, and the inspection time duration may be neglected for higher order PDE otherwise a, b cannot be predicted. In both cases disturbance of noise component may be predicted zero (or delay may be pre-assigned). Again introducing uncertainty factor

$dc_t = a(c_t, t)dt + b(c_t, t)dw_t$ where a→μ, b→σ

This is a standard Brownian approach with the behaviour of continuous time stochastic process. c_t as the sum of ordinary non negative integral function of closed domain. Failure or delay may be neglected as there is no inspection time domain in the early propagation of work i.e. work dependent function of time and probabilistic failure approach may be neglected.

Then $\int_t^{t+s} \mu(c_t,t)dt + \int_t^{s+t} \sigma(c_t,t)dw_t = \int_t^{t+s} cdt$

But this process of obtaining the solution is not guaranteed to be optimal or perfect but sufficient for immediate goal (termination or rejection process in between the time domain is neglected). Thus this method tantamount to thumb rule of educated guess (past knowledge and skill of supervision unit becomes important), and profile of common sense driven by heuristic search. However, existence and uniqueness of the solution of the problem under consideration, following is required (i) Using deterministic and partial differential equation (PDE) (ii) SDE trial has definite root and may be unique or heuristic solution and (iii) must include real Cartesian coordinates of real space (R^n) of same dimensions. This must provide n dimensional (R^n) space with standard Euclidian structure of real (c_t, t) sets of values.

Now, T>0, $\mu : R^n x[0,T] \rightarrow R^n$

$\sigma : R^n x[0,T] \rightarrow R^{n+m}$

$dc_t = \mu(c_t,t)dt + \sigma(c_t,t)dw_t$ for $t \in [0,T]$ and $E\left[\int_0^T |X_t|^2 dt\right] < +\infty$

i.e. $dC_T = [a(t) + c(t)]dt + [b(t)c_t + d(t)]dw_t$

$$C_t = \phi_{t=(0,T)}\left(C_{T_0} + \int_t^{t+s} \phi'_{s,t}\left(C'(s) - b(s)d(s)\right)ds + \int_t^{t+s} \phi_{s,t} d(s)\,dw_s\right)$$

$dw_t \rightarrow dw_s$ during the period of t to t+s

$$\phi = e^{\left(\int_t^{t+s}(a(s) - \frac{b^2(s)}{2})^2 ds + \int_t^{t+s} b(s)dw_s\right)}$$

The above equation requires exponential trial solution. It approaches to the function

$$d\phi(c_t,t) = \partial_c\phi(c_t,t)\,ds_t + \frac{1}{2}\partial^2{}_c\phi(c_t,t).ds_t{}^2 + \partial_c\phi(c_t,t)dt$$

i.e. $d[A+B+ke^{\sigma W_t}] = A_t e^{\sigma w_t} dt + \sigma A_t e^{\sigma w_t} dw_t + \frac{1}{2}\sigma^2 A_t e^{\sigma w_t} dt$ where t+s→s and t→0

where A, B are the primary conditions (A,B are non zero constants). If we have to consider quality failure cost from the beginning, another approach i.e. failure theory with the application of Super symmetry approach that may be considered which can allow greater adjustment of constants. There may be a greater adjustment of constraints as well as intermittent process as the work may be both continuous as well as a failure theory may be incorporated. For this, Basic simulation of super symmetric approach which consider following:

1. Scale free statistical structure.
2. c approaches limit of probability and independent of path i.e. multiple path approach may be incorporated.

Thus

$$\int_0^s \left(a(s) - \frac{b^2(s)}{2} \right)^2 ds \to 0 \qquad \text{for Brownian symmetry}$$

and $\int_0^t \phi'_{s,t} d(s) dw_s = \lim_{n\to\infty} \int_0^s \phi^n dw_t$

and $E\left[(\int_0^t c_{s,t} dw_s)^2 \right] = E\left[\int_0^t H_s^2 ds \right]$

$b(s)dw_s \to k$

Time line integral

$$c_t = c_0 + \int_0^t \sigma_s dw_s + \int_0^t \mu_s dt \qquad \sigma_s \to \text{b} \qquad \mu_s \to \text{a}$$

σ is predictable integral and μ_s is heuristic search integral unit is $\int_0^t \left(\sigma^2 + |\mu_s|\right) ds < \propto$ which means finite process neglecting interruption.

At this stage, it is tried to find the solution of stochastic differential equation. The solution has been detailed in Appendix D. It may be seen from Annexure D that there may be four possible scenario or cases

Case one involves consideration of specific scalar- linear SDE's where solution is given by

$\therefore S(o) = S_o$

The mean is E[S(t)]=μt + S_0 and variance Var [S(t)=σ^2t. S(t) processes a behaviour of fluctuations around the straight line. Thus, S=S_0+μt. the process is normally distributed with the given mean and variance. However, this case will not consider probabilistic search to optimize various combination of parameters.

Second Case involves scalar- linear SDE with close domain period of time

$E\left[s(\mathrm{t})\right] = S_0 e^{\mu t}$ and $V_{ar}\left[S(t)\right] = S_0{}^2 e^{2\mu t}\left(e^{\sigma^2 t} - 1\right)$

The first property is that S(t)>0, for all t$\in$[0,T] and second is that all future returns are in scale with current values. This process has a log-normal probability density function and close domain function of time.

Third case involves non linear phenomenon where non linearity is introduced by the constant k

$$ds(t) = K\left[\mu - S(t)\right]dt + \sigma S(t)dw(t,w), S(0) = \mathrm{S}_0$$

Now μ=0,

$$E\left[\mathrm{S(t)}\right] = \mu - \left(\mu - S_0\right)e^{-kt}$$

We have introduced after function k to take into account the non-linearity

$$V_{ar}\left[S(t)\right] = \frac{\sigma^2}{2k}\left(1 - e^{-2kt}\right)$$

In the long run, $\lim_{t\to\infty} E\left(S(t)\right) = \mu$

$$\lim_{t\to\infty} V_{ar}\left(S(t)\right) = \frac{\sigma^2}{2k}$$

This analysis shows that the process fluctuations takes place around mean value μ and has a variance of $\frac{\sigma^2}{2k}$ which depends upon k, higher the k, lower the variance i.e. higher the k, faster the process returns back to its mean value. This process is a stationary process which is normally distributed.

$\therefore S(t) \geq 0,$ if $S_0 \geq 0$, μ>0, K>0,

Considering Die out system which work on feed back, we have

$$A(t) = \begin{pmatrix} 0 & 0 \\ 0 & k \end{pmatrix} \; a(t) = \begin{pmatrix} \mu \\ k\phi \end{pmatrix} \; B_i(t) = \begin{pmatrix} 0 & 1 \\ 0 & \sigma, p \end{pmatrix}$$

$$B_2(t) = \begin{pmatrix} 0 & 0 \\ 0 & \sigma.\sqrt{1-p^2} \end{pmatrix}$$

$$\therefore x(t) = \left(\mathrm{P}(t), \sigma(t)\right)^T$$

P(t) depends upon σ_0, For instance, μ=0.1. k=2 ϕ=0.2, σ_1 =5, P=0.5, σ_0 =0.1 or 0.8

The evolution m(t)= $= \phi + (\sigma_0 - \phi)e^{-kt}$ and variance depends on σ_0.

Above case does not consider the second order term. However fourth case involves second order term of failure and described by

$$dS(t) = K\left[\mu - S(t)\right]dt + \sigma\sqrt{s(t)}dw(t), S(0) = S_0$$

This is applicable for less failure process (less volatile) and considering for short term process.

$$dS(t) = \mu S(t)dt + \sigma\sqrt{s(t)}dw(t), \mathrm{S}(0) = \mathrm{S}_0$$
$$E\left[S(t)\right] = S_0 e^{\mu t}$$

$$V_{ar}\left[S(t)\right] = \frac{\sigma^2 S_0}{\mu}\left(e^{2\mu t} - e^{\mu t}\right)$$

The function S_t can be considered dependent upon various parameters like material inventory, labour force, Inspection, project governance, etc. Therefore it would be very difficult to predict the value. Hence we can consider other approaches like deterministic case or dynamic programming method.

In Deterministic case, we consider that all the parameters are well defined. It implies that we are ignoring the effect of uncertainty parameters.

$$dc(\mathrm{t}) = \mu\,\mathrm{c}(\mathrm{t})dt + \sigma\,\mathrm{c}(\mathrm{t})dw(\mathrm{t}).$$

Considering continuous process $W_t - W_s$ is N (0, t-s) for $0 \le s \le t$

Then $dw(t) = \in \sqrt{dt}$

For maximum investment case:

$$V(x,t) = \max E\left[\left(\mathrm{I} - \mathrm{c}(t)\right)e^{-rt}\right]$$

r - discount rate, I– *c(t)* discounted to present value,

now $dc = \alpha c(t)dt, \mathrm{c}(t) = c_0 e^{\alpha t}$

$$c_0 = c(\mathrm{t}=0), \therefore V(\mathrm{c}^*, t) = \left(I - c_0 e^{\alpha t}\right)e^{-rt}$$

When $\alpha \le 0, C_0 e^{\alpha t}$ is decreasing or fixed

$$\therefore V\left(c^*, t\right) = \max\left\{I - c_0 e^{rt}, 0\right\}$$

Now for $0 < \alpha < r$, the point of most optimal conjunction phase

$\dfrac{dV(\mathrm{c}^*, t)}{dt} = (\alpha - r)\,\mathrm{c}_0\, e^{(\alpha - r)t} + rIe^{rt} = 0$ (Conjunction phase if we stop working even than owner has to carry some expenditure till the point as the process does not get stabilized). Solving, we find the time period for which continuous inspection is to be carried out:

$$t = \frac{1}{\alpha}\ln\frac{rI}{\left(r-\alpha\right)c_0}, \qquad \text{.................................. (5.33)}$$

$$t^* = \max\left[\frac{1}{\alpha}\ln\frac{rI}{\left(r-\alpha\right)c_0}\right]$$

When $\ln\dfrac{rI}{\left(r-\alpha\right)c_0} > 0 \quad \therefore \dfrac{rI}{\left(r-\alpha\right)} > c_0$

$\therefore$ Response strategy for optimal analysis of suggestive function V.

$$V\left(c^*, t^*\right) = \frac{I\alpha}{r-\alpha}\left\{\frac{\left(r-\alpha\right)c_0}{rI}\right\}^{\frac{r}{\alpha}} \quad \text{if } c_0 \le \frac{rI}{r-\alpha}$$

$$\left|I - c_0\right| \text{ if } c_0 > \frac{rI}{r-\alpha}$$

Now considering $E\left\{d\left(V\left(\mathrm{c},t\right)\right)\right\} = rV\left(\mathrm{c},t\right)dt = 0$

$$\therefore E\left[dV(\mathrm{c},t)\right] = \frac{\partial V\left(\mathrm{c},t\right)}{\partial c}\alpha x dt + \frac{1}{2}\frac{\partial^2 V(\mathrm{c},t)}{\partial c^2}\sigma^2 c^2 dt = rV(c,t)dt$$

$$\therefore \frac{1}{2}\sigma^2 C^2 \frac{\partial^2 V(\mathrm{C},t)}{\partial C^2} + \left(r-\delta\right)C\frac{\partial V\left(C,t\right)}{\partial C} - rV(c,t) = 0 \text{ where } \alpha \to \gamma$$

Time independent equation when there is no dependence on time, it implies V(c) : = V(c, t).

At boundary condition V(0)=0 and optimal solution V(c^*)= I- c^* which means the optimal breaking point . For any inspection process, breaking point is the point of ceasing the inspection process as it would not affect the project value anymore. However, this method does not help in resolving the issue of optimal inspection frequency, we would now therefore attempt the dynamic programming method.

DYNAMIC PROGRAMMING METHOD

Dynamic programming is also known as backward induction method. It is used to solve numerically challenging sequential decision problems. This method is applicable to both discrete time and continuous time settings. Here, the optimal solution is obtained by combining optimal solutions for sub-problems. The solution steps are detailed below;

Now let's assume V(c)=$Ac^{-\beta}$

$$\frac{1}{2}\sigma^2\beta\left(\beta-1\right)-\left(\gamma-\delta\right)\beta-\gamma=0$$

Considering finite zeros,

$$\beta = -\frac{1}{2} - \frac{\gamma-\delta}{\sigma^2} \pm \sqrt{\left\{\left(\frac{\gamma-\delta}{\delta^2}\right)+\frac{1}{2}\right\}^2 + \frac{2\gamma}{\delta^2}}$$

Considering the complementary solution

$V(\mathrm{c}) = A_1 c^{\beta_1} + A_2 c^{\beta_2}$ $A_2 = 0$ when $\beta_1 < 0$

$V(\mathrm{c}) = A_1 c^{\beta_1}$

Thus stochastic variable investment parameter or opportunity depends upon the parameter value of sensitivity analysis. Now γ may be constant but depends upon the decision for setting a value of contingent claim.

From using pre condition, $\dfrac{dV(\mathrm{c}^*)}{dc^*} = -1 = -A_1\beta_1 c^{*-\beta_1-1}$

Critical value of c^* will be

$$\therefore c^* = \frac{\beta_1}{\beta_1 - 1}.I$$

Where $\beta_1 = -\dfrac{1}{2} - \dfrac{\gamma - \delta}{2} + \sqrt{\left\{\dfrac{\gamma-\delta}{\delta^2} - \dfrac{1}{2}\right\}^2 + \dfrac{2\gamma}{\delta^2}}$

Again using incentive constraint:

$-\Delta\mu.\mathrm{c}\dfrac{\partial V(t)}{\partial c(t)} + \lambda' rx \geq \alpha r$ where $\lambda' = \lambda\left(1+\rho\right)$

$-\Delta\mu.\mathrm{c}\dfrac{\partial V}{\partial c} + \lambda' V \geq xr$

$-\Delta\mu.\mathrm{c}\left(-\beta.\dfrac{V}{c}\right) + \lambda' V \geq xr$

$\lambda' V \geq xr - \beta V \Delta\mu$

$\lambda' \geq \dfrac{xr}{V} - \beta\Delta\mu$

For optimality we find that

$\lambda' = \left\{\dfrac{xr}{Ac^{-\beta}} - \beta\Delta\mu\right\}$

On simplification we get

$$\lambda' = \left\{ \frac{xrc^{\beta}}{A} - \beta\Delta\mu \right\} \quad \text{.................................} \ (5.34)$$

The above characterize the optimal inspection frequency in the problem under consideration as well as the quality failure costs function. However it is to be noted that this approach ignore the effect of any unforeseen event or uncertainty like labour strike, natural disaster etc.

Now, again using abandonment option:

$\frac{dc(t)}{\mathrm{c}(t)} = \mu dt + \sigma dw(t)$ when subjected to abandonment option

$-\Delta\mu.\mathrm{c}\frac{\partial V(t)}{\partial c(t)} + \lambda' V \geq xr$ when $\lambda' = \lambda\left(1 + p\right)$

We have

$$\mathrm{L(c,t)} = \frac{1}{2}\sigma^2 c^2 \frac{\partial^2 V(\mathrm{c},t)}{\partial c^2} + rc\frac{\partial V(\mathrm{c},t)}{\partial c} - rV(c,t) + \frac{\partial V(\mathrm{c},t)}{\partial t} \leq 0$$

Where pay off options;

$$\max\left\{I - c(t), 0\right\} = V(\mathrm{c},t)$$

the project should be abandoned or terminated immediately. Hence, from the point of justification $\frac{1}{2}\sigma^2 c^2 \frac{\partial^2 V(\mathrm{c},t)}{\partial t^2} + \left(\gamma - \delta\right)c\frac{\partial V(\mathrm{c},t)}{\partial c(t)} - rV\left(\mathrm{c,t}\right) + \frac{\partial V(\mathrm{c},t)}{\partial k} - L(\mathrm{c},t) = 0$ for a case of finite historic condition. The solution to above equation can be attempted in future research work by considering various uncertainty parameters.

5.3.4 NUMERICAL SIMULATION FOR QUALITY FAILURE COSTS

A simulation experiment is constructed to demonstrate the validity and the effectiveness of the proposed model. Assuming quality failure degradations follow the random-effects GBM process model. In the simulation, the parameter settings of the GBM process are carefully chosen in order to show the effects of various combinations of performance parameter μ, σ and *w* in on quality failures cost. The model parameters are detailed in Table 5.1 and 5.2. The simulation exercise aims to show the effects of quality failures' mean, its variance and Wiener process random terms. Therefore, we choose different value of w_t constant in all the datasets of first simulation and examine the relative effect of various combinations of mean and variance. Table 5.1 describes the set of model parameters used for first simulation.

Table 5.1 Simulation Dataset-1

Sl No	Data-Set	Parameter Details
1	Data Set 1	μ =0.044, σ varies from 0.05 to 0.14, w_t =5
2	Data Set 2	μ =0.048, σ varies from 0.05 to 0.14, w_t =5
3	Data Set 3	μ =0.048, σ varies from 0.05 to 0.14, w_t =5
4	Data Set 4	μ =0.052, σ varies from 0.05 to 0.14, w_t =5
5	Data Set 5	μ =0.056, σ varies from 0.05 to 0.14, w_t =5
6	Data Set 6	μ =0.060, σ varies from 0.05 to 0.14, w_t =5
7	Data Set 7	μ =0.064, σ varies from 0.05 to 0.14, w_t =5
8	Data Set8	μ =0.068, σ varies from 0.05 to 0.14, w_t =5
9	Data Set 9	μ =0.072, σ varies from 0.05 to 0.14, w_t =5
10	Data Set 10	μ =0.076, σ varies from 0.05 to 0.14, w_t =5

Simulation results are depicted in Figure 5.1. The simulated paths for various datasets show that cost of quality failures turns to be on higher side when mean quality failure is higher. It indicates that mean quality failure cost is the important factor which needs to be controlled during the work execution. It seems to be logical as the project value would deteriorate with higher value of quality failure costs. Another useful implication is that lesser the value of μ, more risk neutral is the simulated path. Further, the randomness in these paths is quite negligible as these are mean path lines of quality failure cost function. What it indicate is that failure costs are relatively less for data set 1 & 2 which reflect the risk neutral project conditions. It implies that if we are able to control uncertainty in project execution it is easier to control the quality failure costs. In other words, owner is required to chart out the some standard programs to control the risk in the execution phase. This is more relevant for multi project organization as has been suggested by Maylor et al (2006). Table 5.2 contains the set of model parameters used in second simulation.

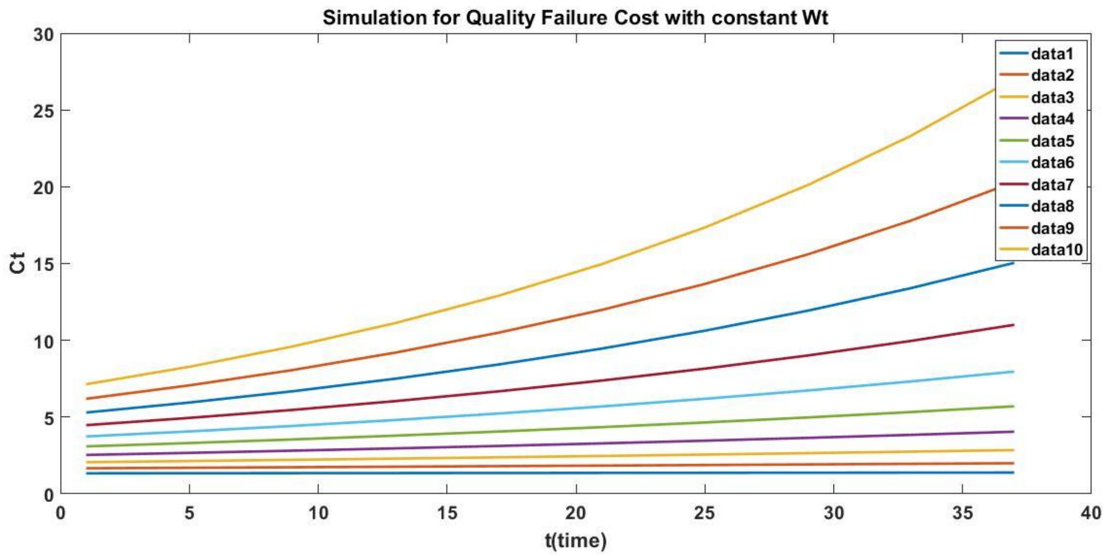


Figure 5.1: Simulation for Quality Failure Cost with constant w_t

This exercise aims to show the effects of mean quality failures and its variance where Wiener process term is non constant. Parameter *w* is defined as d*w* = sqrt(dt)*randn(1,N); where N= 500 and *w* = cumsum(d*w*); Therefore, all the datasets in this simulation are chosen to examine the relative effect of various combinations of mean and variance with varying random term. The corresponding simulation results are shown in Figure 5.2. The simulated paths for various datasets show that randomness is quite significant in comparison to first simulation results which depicts higher uncertainty in the project performance.

Table 5.2 Simulation Dataset-2

Sl No	Data-Set	Parameter Details
1	Data Set 1	μ =0.044, σ = 0.05
2	Data Set 2	μ =0.048, σ = 0.06
3	Data Set 3	μ =0.052, σ = 0.07
4	Data Set 4	μ =0.056, σ = 0.08
5	Data Set 5	μ =0.060, σ = 0.09
6	Data Set 6	μ =0.064, σ = 0.10
7	Data Set 7	μ =0.068, σ = 0.11
8	Data Set 8	μ =0.072, σ = 0.12
9	Data Set 9	μ =0.076, σ = 0.13
10	Data Set 10	μ =0.080, σ = 0.14

It also indicates that effect of random fluctuation is smoothened out in cases where value of mean quality failure cost is less. It further support the earlier finding that owner has to be more concerned about mean value of quality failure costs and thus the capability of the contractors as the in-capable contract would bring more risks in the work execution.

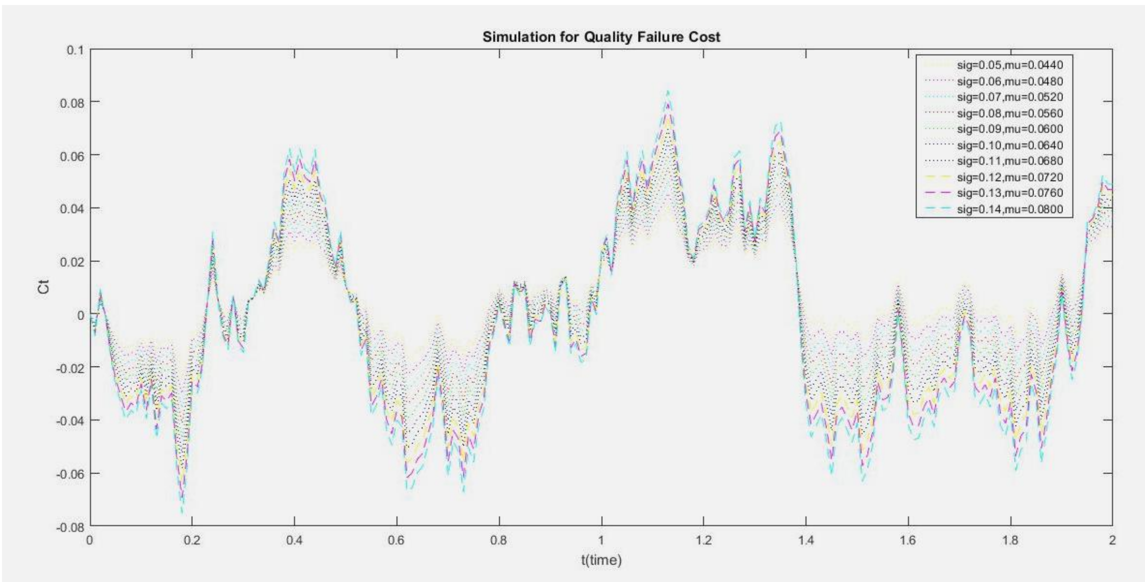


Figure 5.2: Simulation for Quality Failure Cost with non-constant w_t

The above simulation graph reflects that variation in quality failure costs are non-monotonic in nature i.e. high to low quality or low to high quality . It would therefore be useful to consider the effect of monitoring policy that is dependent upon these switching frequency displayed by contractor during project execution. It has been developed in the following section.

5.3.5 DYNAMIC INSPECTION SCHEDULE MODEL

Most of the monitoring policies classified into two categories: random inspections with positive hazard rate of an inspection at most times, or deterministic inspections (Marinovic et al, 2016). In the previous part of this chapter, we have worked with random inspections but with deterministic or constant frequency. However, it is considered that if contractor is delivering quality work then conducting inspection at a fixed frequency would not be optimal use of supervision resource. It may result in avoidable wastage of resources and hence leading to higher monitoring costs. In this section, we therefore analyze monitoring strategy involving dynamically sccheduled inspections in the construction project setting. the basic underlying theme of this type of strategy is to increase the frequency of inspections in accordance with the quality fluctuations. Put simply, we conduct more inspections if quality turns poor from higher and vice-versa. The assumptions made in the this analysis are given below:

a) Cost of quality failures fluctuates and would depend upon contractor efforts and his capability
b) In the independent time intervals, increment in quality failure cost are considered as independent quality change with the contractor's effort a_t such that at $a_t \in [0,1]$, the cost of quality efforts is xa_t.
c) When owner arrange to inspect the quality of work, c_t becomes public information. To ensure truthful disclosure and aware dance of collusion between supervision unit and contractor, Owner used two supervision units as discussed earlier.

A monitoring policy can be specified as increasing sequence of inspections $(T_n)_{n>1}$ times. Let $N_2 \equiv Sup\{n : \mathrm{T}_n \leq t\}$ is the associated counting process with $(\mathrm{T}_n)_{n>0}$. It actually signifies a natural filtration process $\sigma(\mathrm{C}_{T_n}, N_s : \mathrm{s} \leq \mathrm{t})$ by $F = (F_t)_{t \geq o}$

The time elapsed between two inspection is represented as $T_n - T_{n-1}$. Consequently, monitoring policy is represented by a sequence of cumulative density functioning $F_n : R_+ U\{\alpha\} \rightarrow [0,1]$ measurable with respect to $F^P{}_{T_{n-1}}$. That is to say, monitoring decision would depend upon information decision revealed by inspection. Let reputation at time t is given by $K_t = E^a(\mathrm{C}_t \mid \mathrm{F}_t^p)$. If marginal cost of effort is x, then firm's expected payoff is $\Pi_{ft} = E^a\left[\int^{\alpha} c^{-r(s-t)}(\mathrm{K}_s - xa_s)\,\mathrm{ds} \mid \mathrm{F}_t\right]$.

Let $N_t^{LH} = \sum_{s \leq t} 1\{c_{s^-} = L, \mathrm{C}_S = H\}$ and $N_t^{HL} = \sum_{s \leq t} 1\{c_{s^-} = H, \mathrm{C}_S = L\}$ be a counting process denoting switches from low to high quality and from high to low quality respectively. These process are defined as under. Let q be switching frequency displayed by contractor. Now , we define dw_t in the equation :

$$W_t^{LH} = N_t^{LH} - \int_0^t (1-c_s)\,\mathrm{q.ds}$$

$$W_t^{HL} = N_t^{HL} - \int_0^t c_s(1-a_s)\,\mathrm{q.ds}$$

The above two process are martingales. Letting $W_t = W_t^{LH} - W_t^{HL}$ and applying the equation $dc_t = dN_t^{LH} - dN_t^{HL}$, following is obtained.

$$dc_t = q(a_t - c_t)dt + dW_t$$

thus when w_t is a Brownian motion, cost of quality failure follows an Ornstein-Uhlenbeck process if owner adopt dynamic inspection schedule protocol. Now we assume that cost of quality of failure follows more general form of Ornstein Uhlenbeck process as given below:

$$dc_t = q(a_t - c_t)dt + \sigma dW_t$$

Characteristic of Ornstein-Uhlenbeck process driven Brownian motion

$dc_t = -\mu c_t\,\mathrm{dt} + \sigma dW_t$ where we assume $x = (x_t)_{t \geq o} = c$ therefore

$dx_t = -\mu x_t + \sigma dW_t$

C_t is the cost of failure at time 't' and m be the reference value.

$$dc_t = -\mu(c_t - a_t)dt + \sigma dW_t$$
$$e^{\mu t} dc_t + \mu e^{\mu t} = \sigma e^{\mu t} dW_t$$
$$d(\mathrm{e}^{\mu t}\, c_t) = \sigma e^{\mu t} dW_t$$

and

$$\lambda_{t=} c_t - a_t$$
$$dy_t = c_t$$

$$\Rightarrow d(e^{\mu t} y_t) = \sigma e^{\mu t} dW_t$$

now $Z = e^{\mu t} y_t$

$$z_t = (c_0 - m) + \int_o^t \sigma c^{\mu s} dW_s \qquad z_o = c_o - a$$

$$c_l = e^{-\mu t} + a = c^{-\mu t}[(c_o - a) + \int_o^t \sigma c^{\mu s} dW_s$$

$$= e^{-\mu t}(c_o - a) + c^{-\mu t}\int_o^t \sigma c^{\mu s} dW_s + a$$

Finally $c_t : N(\text{a} + e^{-\mu t}(c_o - a) + e^{-\mu t}\int_o^t \sigma c^{\lambda s} dW_s)$, i.e. $c_t : N(\text{a} + e^{-\mu t}(c_o - a); \frac{\sigma 2}{2\mu}(1 - e^{2\mu t}))$ when $t \to \propto$. The Stationary distribution $N(\text{a}, \frac{\sigma 2}{2\mu})$

This probability distribution approaches equilibrium distribution called stationary distribution. Thus, it is an another time changed Brownian motion.

$$c_t = (\text{a} + e^{-\mu t}(c_o - a) + \sigma e^{-\mu t}$$
$$E_t(c_t) = e^{-\mu t} + a(1 - e^{-\mu t})$$

$$\text{Var } (c_t) = \frac{\sigma^2}{2\mu}(1 - e^{2\mu t})$$

One of the main feature of the geometric Brownian motion with Ornstein-Uhlenbeck process is proportionate of the drift term itself. Thus the process can be interpreted as a process to be re-pulled from starting point as explained earlier in section 5.2.3. The idea of re-pulling / attracting point can be easily generated by an arbitrary equilibrium level O and percentage drift μ>o and then this process can be used to model mean reverting behaviour. Now if λ approaches zero, there is a less deviation between Brownian motion to Ornstein-Uhlenbeck line and both the process moves towards to linear trend $\mu_0 + a_t$.

Monitoring is a Key function of financial management and technical supervision. Building upon above analysis, one can also be used to formulate time based monitoring functions

now $\text{dc}_t = \mu c_t dt + \sigma dW_t$

where c_t refers to cumulative cost of failures and dwt is a standard Brownian motion on the complete probabilistic space λ ∈[o, ∝). Brownian motion is a time varying drift and □> o is a constant volatility. In addition, to the Brownian shocks, the contractor is exposed to an exogenous failure risk governed by a Poisson point process {N} with a constant greater than zero. Upon its arrival at time t, $dN_t = 1$, the contractor is not able to perform satisfactorily when $s \geq t$. This might be either project contractor is not able to organize the resources or behaving opportunistically. Thus, considering OU process, we would write

$$dc_t = [-q(c_t - a_t)dt + \sigma dW_t] \quad \{N_t = o\}$$

Where c_t is observable and is given by

$F = \{F_t, t \geq o\}$ where $F_t - \sigma(c_s, N_s, o \leq s \leq t)$

Now, we begin to analyze the case in which principal monitoring pay off is linear (for a self regulating organization). But under these linear pay off is incentive provision i.e. no shock or sudden fund allocation is usually expected to occur (i.e. non volatile case). It implies that any other challenge associated with project execution is neglected. Thus, the optimal monitoring policy prescribes as constant monitoring intensity. In this context, we conjecture, incentive gets compatible with creating any excess of monitoring.

This n = inf $\{n : T_n > t\}$.

Full effort is incentive compatible when $t \in [T_{n-I,}T_n]\ \frac{1}{r+q} E_t[e^{-(r+q}) (T_n - t)] \geq \frac{x}{q}$

This case is simple and play a role that spans of inspection are close to each other. This holds when

$dc_t = -q(c_t - a_t)dt + \sigma dW_t$ and we consider $E_t[e^{-(r+q})(T_n - t)] = u_t$

where expectation is taken over the possible random monitoring time considering contractor is risk neutral and payoff rate >o.

$$\frac{1}{r+q} E_t[e^{-(r+q}) (T_n - t)] \geq \frac{x}{q}$$

$$\frac{1}{r+q}.u \geq \frac{x}{q} \quad \text{for min } u_{t,} \left(u_t\right)_{\min} = u_{\min}$$

$$\frac{u_{\min}}{r+q} = \frac{x}{q} \qquad\qquad u_{\min} = \frac{x(r+q)}{q}$$

u_t is an implicit discounted rate that the firm uses to access the benefit of hiring high quality during continuous evaluation. Considering quality depreciation rate and estimated monitoring time, monitoring policy would be optimal when cost of monitoring is least subject to incentive compatibility starting from t = 0 to time t,

where t, -t is a fixed time line

$$E_t[e^{-(r+q)\bar{T}rand}] = \mu$$

$$\text{where } T_n - t = Trand$$

$$Then\ u = \frac{\lambda}{r+q+\lambda} \quad \text{where } \frac{dF_s}{I-F_s} = \lambda^* \qquad \text{.............................. (5.35)}$$

Thus the principal monitoring payoff may be

$$\prod_o(t) = \prod_H - \prod_L = \int_t^x e^{-r(s-t)} c_s Hds - \int_t^x e^{-r(s-t)} c_s Lds = \frac{1}{r+q}$$

and for some value m : [o, ∝) → [o, ∝) at any point of discontinuity

$$\lambda^* = \frac{(r+q)\,u}{I-u} \quad \text{where } u = \frac{x(r+q)}{q} \qquad \text{.............................. (5.36)}$$

The equation 5.36 actually characterizes the optimal condition of inspection frequency which emerges to be very simple one similar to Vara et al (2017) as it is governed by constant random inspection frequency. It seems to be because the dynamic policy would itself control the opportunistic behaviour of contractor which is witnessed from the fact that quality failure cost evolution process alters from GBM process to a mean-reverting Ornstein-Uhlenbeck. However, it would be interesting to consider the effects of other performance uncertainties in the analysis of various strategies and monitoring costs.

5.4 CONCLUSION

This research studies monitoring policies in the construction projects. In the project settings, contractors and suppliers work and their actual capability are not known to owner. Similarly, their private effort is also not easily observable. These conditions are conducive to moral hazards i.e. collusion and opportunism and therefore they warrant study of monitoring strategy. Initially, we begin with basic analysis of random inspection, continuous inspection and their combined inspection strategy. This analysis shows that owner can effectively reduce the risk of under-performance by opting for strategy combining continuous and random inspection and engaging internal and external supervision agency. Thereafter, project work quality characteristics were studied which revealed that 'future asset value states' depend on present state of quality. In addition, quality failure costs variations over non overlapping time intervals are independent. This illustrates that quality failure cost to be Markovian in nature and evolves through contractors' effort by following GBM. Building on these findings, we attempt to develop a model for study monitoring strategy by modelling quality failures costs as GBM in the projects. A barrier is also introduced which occasion the project execution to discontinue when project value reaches predetermined threshold. It is particular useful, as investing in a project is subject to both resource constraints and standards of quality of work. It shows that when instantaneous loss of project value is lesser than good quality management cost for contractor, it would be optimal for him to not to take effort to ensure quality. This situation may arise when contractor is not able to improve quality because of his capability constraints. In essence, this study put forth the idea that modelling of quality failures along with their economic implications on the project value can provide a consistent basis for risk management by integrating the owner monitoring policy with decisions on the contractual means. This in-turn would address the most crucial but neglected aspect of project governance. Our assertion is validated through a mathematical model and numerical simulations that facilitate risk mitigation decisions by providing information about current state of quality failures and project value. In this model we consider the interaction of monitoring as frequency of inspection by combining random and continuous inspections by both internal and independent supervision unit, quality failure costs and project value. It then characterize circumstances yielding optimal monitoring by using dynamic programming method which prescribes the time period of continuous inspection and frequency of inspections. Analytical findings shows that time period of continuous inspection would depend upon investment amount and frequency would vary with contractor capability, cost of quality failures and improvement achieved by contractor. Numerical simulations are also presented to illustrate the applicability of this model which reveals that risk of quality failures can be reduced under different combination of parameters. Thus, it implies that this model can also help owner to address the problem of underperformance arising from collusion and opportunism to considerable extent. It also facilitates the solving owners' option problem i.e. problem of making decisions of when to spend money to accept the work or reject.

The study also analyze the dynamic monitoring policy with a view to promote contractors effort in achieving project work quality. This policy involves dynamic scheduling of inspections where inspection frequency will be dependent upon quality level i.e. depend upon the result of the past inspections. When we adopt dynamic scheduling, quality failure cost evolution process transitions from GBM process to a mean-reverting Ornstein-Uhlenbeck process. It implies that following dynamic scheduling monitoring policy would reduce the fluctuations in quality failure costs. Thereafter, we deduce conditions for optimal monitoring in terms of inspection frequency. In this research work, modeling quality failure costs and project worthiness make it possible to analyze various inspection strategies for reducing risk of underperformance and provide input for timely decision making. This study is expected to provide a theoretical model to present an economic basis for timely decision making for improved project management. However, future research is necessary to generalize this analysis to characterize optimal monitoring policy and project value.

CHAPTER

6

CONCLUSIONS AND FUTURE SCOPE OF RESEARCH

6.1 INTRODUCTION

This research work concentrates on several issues related to risks present in Public procurement, their causes and effects. The prime interest of this research is to develop an organizational perspective for procurement risks, establish an risk assessment method and identify the policy implications for improving the performance of the organization. A systematic risk analysis approach is developed by combining well established risk analysis techniques of Fault tree and Failure Mode Effects and Criticality Analysis with the Grounded theory method for identifying procurement risks and finding their potential contributors and ranking them. It then formulates Game theory and Evolutionary Game theory models by incorporating characteristics features and particularities of project execution phase for mitigating underperformance risk by making efficient choices in public procurement. Finally, it analyzes various monitoring strategies by modelling quality failure costs and make suggestions for reducing the monitoring costs.

This chapter summarizes the observations and conclusions of the research effort undertaken. In this chapter, the author has further mentions the specific contributions of the research work, and catalogued the areas in which research can be carried out in future.

6.2 GENERAL FINDINGS

In-depth study of PP process various harmful and counter-productive work practices in PP and their role in poor procurement outcome, have been carried out throughout this research work. It is observed that the modeling and analysis of procurement risks as a whole is critically important because of the following reasons:

(i) Public procurement is an important and key business function of government affecting both private and public sector organization. As procurement is highly susceptible to various risks like wastage, time and cost overrun, quality failures, etc., reforming procurement process is considered essential for mitigating these risks. However, it is experienced that each phase and sub-systems of procurement systems are connected in such a manner that problem in one phase may lead to poor procurement outcomes and failures. Thus, a comprehensive modelling of public procurement, operationalizing the interrelationship among various risk elements is a prime necessity. An appropriate method for risk identification and finding their potential contributors along with modelling of procurement risks, based on empirical data, insights are required to be developed.

(ii) Existing methodologies and models in relation to procurement risk analysis practices are still in developing stage. Although, in recent times, several types of survey, case studies, audit and indicators based method and scenario logic and probabilistic models have been developed. However, their usefulness and applicability in many real-life situations have not yet been proved with satisfactory results. First of all, these models do not help in uncovering the risk factors embedded in various processes which is essential for realistic risk scenario planning. Another major shortcoming is that they do not provide adequate information for risk mitigation and therefore immediate research attention on PP is the prime necessity .

Considering the above-mentioned aims, a basic structure for the risk analysis of procurement corruption in tendering, contract award and execution phase of public procurement as a whole has been proposed. Further, contract execution phase has been found to be under-researched. Therefore, literature, dealing with various counterproductive and unethical practices and problems associated with execution phase, are studied by adopting supply chain perspective to develop a systemic view for formulating models by incorporating various unethical behavioral strategies, monitoring and penalty structure. In addition, modelling of monitoring strategies and quality failures' cost has been proposed in the present research work so as to provide an economic basis for timely decision making and improving project performance.

In order to build up a comprehensive methodology for risk modeling, relevant data was selected using sampling techniques of grounded theory method from the publicly available resources on the unethical practices and reports pertaining to public procurement activities. The data search was made from the publicly available resources by selecting the cases where topic of interest was observable. A total of 69 cases related to public procurement was selected for grounded risk analysis. The cases were picked from different sectors such as construction, infrastructure, health, power, oil, gas and port, and goods and services sectors. In the sample, 27 cases were found from 26 countries and remaining 47 cases were based on real occurrences but did not contain country names and taken from multiple organizations. This data has several important features and characteristics with which several kinds of analysis may be undertaken. The important findings of this research are listed below.

(i) The literature on procurement risk is not adequate and therefore an extensive literature review was undertaken to develop an organizational perspective of PP risks. Since past research has acknowledged some definitional ambiguity in respect of PP, the review elucidates the PP's core elements along with their role. A process map is also developed to identify the major steps and decisions and understand their interrelationship in a workflow of PP. As unethical practices also adversely affect the procurement outcomes, the literature dealing with unethical behaviour in PP and organizational corruption is also systematically reviewed. These findings were then combined to develop a conceptual model of vulnerability to unethical behaviour in the organization. The review also analyzes various harmful and counter-productive work practices prevailing in PP, and examine existing risk assessment techniques to identify useful risk analysis techniques

(ii) The public procurement is a complex exercise involving multiple activities and its processes are not very robust. Mixed methods involving qualitative and quantitative analysis would help in developing a systemic view of procurement problems and risk mitigation measures. The risk model, developed in this study, offers varied insights and rich information about wide spectrum of risks present in the PP. It also provides a general pattern of counter-productive and unethical work practices by identifying a comprehensive list of influencing factors from the entire procurement cycle. GT application facilitated qualitative analysis of the sample data from multiple aspects. By using minimal cut set method, 45 combinations of risk elements were identified that may lead to unfair contract award.

(iii) Also, the GT-FTA-FMECA model uncovers the process level vulnerabilities, find their potential contributors and quantifies the criticality of the risk factors to rank them. The discretion abuse, absence of verification, presence of intermediary and conflict of interest emerges as top-ranked factors. Poor procurement plan, low decision monitoring, change order abuse, sharing confidential information, absence of standard codes & criteria, complexity and abusing choice of procurement procedures feature as sixth to twelfth ranked risk factors, respectively.

(iv) No open bidding norm emerges as relatively lower ranked risk factor. It is because procurement manager may practice unethical strategies even with following open bidding norms. However, if unethical practices are facilitated in an organization because of absence of open bidding, it would turn to be more critical. This shows that procurement corruption risk profile may alter and need continuous monitoring. Organizations can monitor procurement process without much cost implications with increasing use of computerization. Various intermediate risk events and/or risk factors uncovered in this study can serve as risk indicators for facilitating such monitoring.

(v) The wide array of risk factors and their widely dispersed location indicates that efforts in addressing procurement corruption should include wide ranging measures. The various identified risk mitigation measures are reforms in procurement process, methods and streamlining organizational policies and controls. For example, to improve the objectivity and facilitating traceable records in procurement procedures, organizations may define various intended outcomes such as timelines, and value for money while crafting urgency and accelerated procurement procedures. The incidences of timeline failures in urgency procurements can then be audited to find out abuse and correcting procedures deficiencies.

(vi) On the basis of characteristics of construction projects, Game theory model is applied to analyze problem of underperformance in the execution phase and found that owner’s cost of ensuring adequate supervision is one of the main factors that affect the optimum probability of collusion between supervision unit and contractor, and hence, there exists risk of underperformance. It depends on 5 other important risk factors, viz. project complexity, supervisor capacity deficit, rework cost, penalty structure, benefits. As several harmful and counterproductive work practices give rise to risk of underperformance, these work practices were reviewed and categorized in a simple but useful framework. It provided two important insights. First, it highlights the need of introducing differential penalty structure as an organizational control policy. Secondly, it underscores the need of incorporating the non-collusive counterproductive practices like contractors’ opportunism in the game analysis. Game theory model, developed here, would facilitate more effective conceptualization of risk scenarios in analyzing contractual underperformance and inferring policy correctional measures. The analysis suggests that owner should focus on addressing the issue of staff capacity deficit and rationalize the penalty structure by adopting differential fines for more serious lapses and minor failures.

(vii) Evolutionary analysis gives important findings and identifies the different situations where it becomes optimal to engage in collusion or opportunistic behaviour despite monitoring and provisions of cost recovery and penalty. For instance, when owner’s monitoring cost outweighs the recovery made through penalty and rework cost taken together a collusive income is more than the non-collusive income, the model indicates that stable strategy for the contractor and supervision unit is to collude. It is interesting to observe that

CSC turns out to be a bistable system in such a scenario. However, this result does not mean that all the construction projects will continue to suffer from lack of control and resultant contractual underperformance. Rather, it implies that performance conscious owners to focus on reducing the monitoring cots and rationalizing penalty structures. It shows that steady state of collusion behaviour depends on 5 key factors, viz. an owner's cost of adequate supervision; rework cost, penalty structure, collusive and non collusive income. The results further reveal that non collusive income earned by contractors through underperformance and procurement system characteristics may affect the stability state and project performance.

(viii) In this research work, the authors also have analyzed various monitoring strategies. This analysis shows that combining random and continuous inspection would help in reducing monitoring cost and risk of collusion. By adopting dynamic inspection scheduling, it is seen that fluctuations in quality failure cost can be controlled by linking inspection timing with quality failures. It also concludes that underperformnce risk increases with contractor capacity deficit. It is, therefore, suggested that past performance should be formalized as evaluation criteria for tender awarding decisions.

6.3 CONCLUSIONS

This research work on the procurement risks has contributed significantly to the field of knowledge in risk modeling in public procurement based on real-world data and theoretical background. In particular, the following contributions are significant:

(i) Risks are present in varying degrees in multi-phased process of public procurement. The systemic literature survey with significant evaluation of the available PP risks as well as risk concepts and assessment methods from other areas presents a complete range of the important aspects on risk identification and assessment. This study also provides theoretical foundation of public procurement risk and integrates earlier research findings into meaningful themes that provide useful direction for the conducting a comprehensive risk analysis.

(i) The proposed procurement risk analysis method integrates GT with FTA and FMECA techniques. Considering the importance of unethical behaviour in PP, this unique approach is successfully applied to procurement corruption for strengthening organizational controls and improving procurement processes. The results identify several risk factors and rank them according to their criticality. This unique approach may be utilized to (a) streamline and well planned public procurement system more effectively, (b) identifying risk factors and operationalizing their interrelationship (c) simulating the possible combinations of risk elements that may lead to the undesired procurement outcomes like unfair contract award, and (d) deduce relevant practical insights about prevalence of multiple unethical strategies and improvement opportunities

(ii) Integrating GT, FTA and FMECA allows for identification, description, and analysis of the key risk factors thereby it helps in prioritizing the risk mitigation efforts. Analysis of this kind has resulted in thorough and in-depth understanding of functioning of procurement systems. A unique and new empirical foundation based risk modeling, as proposed, is an application for general purpose methodology that may be followed to study and analyze important issues in other fields like organizational and contractual underperformance, project failures, inefficiencies in Joint Venture, PPP or activities like concession and licensing.

(iii)The risk assessment exercise has helped in indentifying seven core categories of procurement risk consequences at organization level. These are namely; financial loss, reputation loss, wastage, undue private gain, potential safety hazards, unfair contract awards and sub optimal performance. While constructing fault tree, it uncovered 17 risk factors and 16 intermediate risk events, which portray unethical mediating strategies for unfair contract award. The fault tree developed in Figure 3.8 presents an overview of interrelationships among various risk elements. FMECA ranks the risk factors according to criticality scores. For instance, criticality score for the first three top ranked factors, viz., discretion abuse, absence of verification, and corrupt exchanges found to be 16.53553216, 3.393637427 and 15.80873099. The findings regarding most critical factors seem to be fairly relevant as discussed in detail under section 3.4. This research also yields several practical implications and suggests useful measures for improving organizational controls and procurement processes. FMECA also brings out important information and performance parameters that can be quite useful for reducing the wastage in PP.

(iv) Analysis of contract execution phase is a very important aspect of public procurement for finding factors responsible for poor performance in the projects. Authors used socio-technical system concepts to find the factors influencing the project performance and then built simplified Game theory model to analyze the strategic interactions between three key stakeholders, viz. owner, supervision unit and contractor for application in the construction industry. The Game analysis identifies six important risk factors, viz. cost of ensuring adequate supervision, project complexity, supervisor capacity deficit, rework cost, penalty structure, undue benefits which may affect the project performance. Several important policy inferences are also drawn. For instance, the analysis shows that optimum probability of collusion between supervision unit and contractor depends on two important factors i.e. complexity and supervision capability limitation. The probability of collusion and consequent underperformance would increase with supervision unit capability limitation. Stated simply, contractor would find it easier to collude with supervision unit when supervision unit suffers from capability limitation. Thus, owner should focus on issue of capacity deficit in their supervision units. Another key insight pertains to enlarging control policies i.e. owner should include choice of differential fines for more serious lapses and minor failures. It implies that owner can reduce the optimum probability of collusion in those aspects which can endanger safety in the projects by setting higher fines for those unethical practices which have adverse safety consequences. This simplified model offers a more reliable and easy to implement quantitative method for finding an appropriate strategy or the optimal sequence of decisions.

(v) Analysis of execution phase is further extended by drawing knowledge from supply chain management in projects. Construction supply chain study reveals that behaviour of contractors and suppliers in large construction project is dynamic in nature and characterized by lack of complete information. They may learn from others or through trial and error to opt for more successful strategy. Such strategy adjustments would lead to existence of multiple equlibria. These practical insights were incorporated in the modelling for a closer approximation of the actual project execution situations. Evolutionary games easily model this dynamism through replicator mechanisms in mathematical forms. Thus, evolutionary modelling enabled this work to discover important new insights into the dynamics of unethical behaviors. Evolutionary model explains as to how the project work environment can be altered from undesirable equilibrium states to more desirable states. It, thereby, helps in designing required measures and/or actions to facilitate these changes. Numerical examples are also presented to illustrate the applicability of model and simulate the evolutionary strategy in different initial conditions. It shows that despite monitoring and presence of penalty structure, extent of prevalence of unethical practices may differ as different construction project organizations can get trapped in different equilibria. At evolutionarily stable points, players opt their strategies on the basis of their learning or information acquired. As a result, the information available in the form of penalty structure, quality norms, response to quality and time line failures can be manipulated or modified for achieving desired procurement outcomes. The Evolutionary analysis describes a macro environment of execution phase and reveals how the project work environment can be altered from undesirable states to more desirable alternative equilibrium states and thereby, assists in devising measures for promoting these shifts. Use of evolutionary modelling has resulted in identification of five critical factors that affect the equilibria and drawing several important countermeasures to prevent unethical behaviour in the execution phase. Cost of adequate supervision, rework cost, penalty structure, collusive and non collusive income would affect the players' choice. Based on these factors, the model identifies different situations where it becomes optimal to engage in collusion or opportunistic behaviour despite strict monitoring and having provisions of cost recovery and penalty. For illustration, when cost of adequate supervision is more than the cost of rework and collusive income is less than non-collusive income, owner will choose not to exercise adequate supervision. At the same time, contractor shall become rational not to collude with the supervision unit as a stable strategy. Using evolutionary analysis, this research explicitly identifies several useful policy inferences for different risk scenarios. As a result, the model also contributes to literature on effective monitoring of project performance, as it may be utilized as a helpful framework for improved decision making by simulating efficient choices for possible adjustment actions for mitigating these risks.

(vi) Modeling quality failure costs and project worthiness make it possible to analyze various monitoring strategies and finds conditions characterizing the optimal monitoring for reducing the risk of underperformance arising out of collusion, opportunism and capability constraints. This unique approach may lead to develop a theoretical model to provide an economic basis for timely decision making and improved project management.

6.4 SCOPE FOR FURTHER RESEARCH

Several relevant issues on public procurement in organization, particularly procurement risks, has been investigated by the author and this may opens up new prospects to carry out similar type of studies in future. This is true predominantly for PP performance, whose various aspects are now attracting researchers and managers. Hence, scope of future research in this area appear to be quite enormous. However, based on experience and research in this area, the author identifies some of the important areas, or issues of significance, which need further addressed for research:

(i) In order to lessen the effect of subjectivity in the tools developed in this study, surveys and case studies can be undertaken on the subject for modelling the detailed procurement risk scenario and building organization specific inventories of control deficiencies and possible manipulations. Further, a fuzzy-based modelling approach may be employed for reducing subjectivity, enhancing the applicability, and usefulness of research.

(ii) The magnitude of resources involved in public procurement compels research attention to minimize waste and loss. The complexity and multiplicity of intended objectives make it further necessary to clearly articulate and analyze the public procurement processes. Process definition language like Little JIL can be used to precisely describe the process with the help of risk factors identified in this research for developing automated models which can be used to derive fault tree or generate FMEA information for identifying risk conditions efficiently and iteratively for improving the procurement process. It can also facilitate simulating bidding process to study the collusive behaviour of procurement official and bidders and uncovering potential vulnerability in the existing processes.

(iii) The game and evolutionary game models proposed in this are generic in nature. These models can be improvised by incorporating other variables like costs of delays, time over run and performance deficits etc as potential strategic costs.

(iv) On-line optimization techniques may also be used for simulating the proposed methodology for real-time decision making to optimize monitoring cost for hedging the underperformance risks.

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MATERIAL TRANSACTIONS, COUNTER PRODUCTIVE WORK PRACTICES AND REVIEW DETAILS

Table A.1 : Material Transactions Array

Sl No	Type of Material Transactions
1	Normal stock receipt – from previously issued purchase orders and transfers
2	Unexpected stock receipts- Supply for some project work,
3	Emergency procurement requisitions
4	Sales – Orders to be delivered and to be picked up
5	Stock Transfers to other units, depots or maintenance facilities
6	Assembly/ Machinery orders
7	Bin to bin transfers within warehouse
8	Returns of stock material
9	Returns of non stock material
10	Returns of damaged material
11	Returns to supplier
12	Returns of Unusable /Scrap material

Table A.2: Forms of Harmful and Counterproductive Work Practices

S.N.	Authors	Procurement Phase	Practices
1	Tanzi and Davoodi (1998)	Bidding & tendering execution aspects	Corruption is linked with higher cost and poor quality
2	Zarkada et al. (1998)	Bidding & tendering	Contractors accept money in order not to tender for contract has been invited to tender.

3	Lo et al. (1999)	Bidding & tendering	Setting up high prequalification requirements to restrain competition.
4	Ray et al. (1999)	Bidding & tendering	Disclosure of confidential project baseline, Withdrawal of tender
5	Zarkada-Fraser et al. (2000)	Bidding & tendering	Submission of cover prices and inflated bidding price.
6	Tella et al. (2003)	Tendering	Difference in prices of standardized products
7	Vee and Skitmore (2003)	Bidding & tendering,	Divulging more tender information to preferred bidders and bias evaluations for unfair contract award.
8	Pearl et al. (2005)	Tendering & execution phase	Illogical request for time extensions, theft of materials, Collusive tendering.
9	Zou (2006)	Bidding & tendering	Corruption may occur in different forms and at any phase during the procurement of construction projects,
10	Bowen et al. (2007)	Design, bidding & tendering, construction	Leaking of tender price in return for payment. Hidden fees and commissions, compensation of tendering costs to unsuccessful bidders.
11	Olken (2007)	Execution phase	Uses independent engineers to audit road projects for determining the quantity and value of missing inputs to find out corruption.
12	Sohail and Cavill (2008)	tendering	Tailoring project requirements to fit the preferred tenderer.
13	Alutu and Udhawuve (2009)	Bidding & tendering	Chief executive may award a contract to his/her preferred company in an unfair manner.
14	Hartley (2009)	Bidding & tendering	Collusive bidding, lack of honesty and fairness.
15	Wang et al. (2009)	Tendering and Construction	Supervising engineers may collude with contractors and conceal their illegal activities.
16	Ma and Xu (2009)	Bidding and tendering	Obtain unlawful the qualifications during bidders and/or tender and to raise prices or reduce the quality of engineering standards during construction

17	Ameh and Odusami (2010)	Bidding & tendering	Issuing the certified works falsely.
18	Tabish and Jha (2011)	Tendering	Collusive behaviour in bidding stage
19	Auriol et al. (2011)	Tendering	Use of exceptional type of procedures
20	Olusegun et al. (2011)	Tendering	Bribery and corruption to high and management officials in Government offices during contract award
21	Tabish and Jha (2011)	Conception, bidding & tendering	Inadequate publicity, pre-qualification not done as per notified criteria, and unfair evaluation.
22	Adnan et al (2012)	Execution	Illogical request for time extensions and theft of materials
23	Bowen et al.(2012)	Bidding & tendering	Corruption appears to be widely prevalent, most notably in the form of conflicts of interest, but substantially also in terms of tender rigging and collusive pricing.
24	Goldman et al. (2013)	tendering	Political connections of winning companies.
25	Osei-Tutu et al. (2014)	Execution	Artificial claims, unjustified variations and extensions of time
26	Ballesteros-Pérez et al (2013)	Bidding & tendering	Unethical tenderer to reap an illicit profit
27	Shittu et al. (2013)	Execution phase	Poor quality and substandard material may lead to adverse safety consequences
28	Moodley (2014)	Execution	Bribery, dangerous practices, poor quality, etc.
29	Lenfle et al,(2015).	Tendering and execution	Underbidding- bid aggressively and then work inflexibly asking for more compensation with every change

Table A.3 : Criteria for Selection and Exclusion

A. Selection Criteria	
Sl No	Criteria
1	Time period between 2005-2015

2	Conceptual review
3	Article dealing corruption with Micro perspective
4	Journal articles, Conference papers and work of International bodies engaged in anticorruption work searched electronically by following search terms : a) corruption risks, b) risk of corrupt practices, c) corruption vulnerability, d) identifying corruption risks, e) assessing corruption risks, f) corruption scheme g) fraud scheme h) fraud risk assessment
B. Exclusion criteria by theoretical relevance	
1	Studies in which the primary focus is not micro-perspective. However exceptions were made for certain "foundation" articles.
2	Articles unavailable electronically or by other reasonable means.
3	Book reviews.
4	Non-English language articles with no suitable translation available.

Table A.4: Analysis Protocol

A. Data Organization	
Sl No	**Criteria**
1	Arrange papers in chronological order from 2005 to 2015.
2	Prepare Excel workbook for recording and comparing coding the information
B. Data Analysis	
Sl No	**Analysis steps**
1	Literature was searched using selection criteria to select the articles and papers were excluded by using exclusion criteria.
2	Full content of each paper was reviewed to develop theoretical sensitivity.
3	Papers are selected from 'theoretical relevance' perspective for further analysis
4	Information from selected papers was coded for extracting information, taking into account the author(s)' focus in application domain, research design used to determine the phenomena(on), key findings.
5	Advantage and disadvantage of methods used in earlier research were documented.
6	Factors that make organizations vulnerable to corrupt practices were identified

	and organized into groups on the basis of thematic similarity.
7	Risk assessment literature was reviewed from other established disciplines to borrow and integrate the concepts for vulnerability conceptualization.
8	Inferences from review learning are combined for capturing risk causality and risk consequence in a comprehensive manner for inclusion in PP risk analysis.

Table A.5 : Frequency of use of research methods in Academic research articles and International Agencies' research publication

Methods	Frequency in (International Agencies' research publication)	Frequency in (Academic research)	Total Frequency
Indicator	7	1	8
Survey/Interview	4	10	14
Case Study/ Analysis	0	2	2
Data Mining	0	1	1
Co-relation study	1	1	2
Audit	1	0	1
Logic and probabilistic model	0	1	1
Theoretical	13	19	30
Business game	0	2	2
Value chain analysis	2	0	2
Qualitative meta analysis	0	1	1
Mixed	6	10	16
Total	34	48	82

Table A.6 : Authors by type of Research Methods

Methods	Name of the Authors/Publication
Indicator	Savona, E. U. and Martocchia, S., (2006).
	Fazekas, M., Toth, I. J. and Peter, l., (2014), Kenny, C., (2007), Stanley, K. D., Loredo, E. N., Burger, N., Miles, J. N. V. and Saloga, C. W., (2014), TI (2013b), Ware, G. T., Moss, S., Campos, J. E. and Noone, G. P., (2007), World Bank (2010), Wensink, W. and Jan, M., (2013).
Survey/Interview	Collins J. D., Uhlenbruck K. and Rodriguez P. (2009), Frost, J. and Tischer, S., (2014), Gbadamosi, G. and Joubert, P., (2005), Gopinath C. (2008), Heywood, P. and Meyer-Sahling, J., (2013), Karmann T., Mauer R., Flatten T. C. And Brettel M. (2014), Lindgreen A. (2004), Rama M., (2012), Schultz, J. and Søreide, T., (2008), Wu X., (2009).
	Buromensiky M, Serdiuk O, Osyka I, Syrotenkos, Shekhovtzov T, Volianska O, Kalchenko S and Company MAConsulting (2009), Ewins, P., Harvey, P., Savage, K. and Jacobs, A. (2006), ICAC (2011), Pashov, K., Valev, N. and

	Pasheva, (2010).
Case Study/ Analysis	Ojha, A. And Palvia, S., (2012), Zyglidopoulos, S. C., Fleming, P. J. and Rothenberg, S., (2009), Zyglidopoulos, S. C., Fleming, P. J. and Rothenberg, S., (2009).
Data Mining	Balannik, R., Besciere, P., Mazer, E. and Cobbe, P., (2012).
Co-relation study	Lopez, J. A. P. and Santos, J. M. S., (2014).
	Mulcahy S., (2012).
Audit	Khan, M. A., (2006)
Logic and probabilistic model	Solojentsev, E. D., (2006).
Theoretical	Arjoon S., (2006), Ashforth, B. E., Gioia, D. A., Robinson, S. L. and Treviño, L. K., (2008), Aguilera R.V. and Vadera A. K., (2008), Bager, G., Korbuly, A., Pulay, G., Benner, H., Haan, I. , Vos-Schellekens, J., Van E. D., (2008), Bishara N. D. and Schipani C. A. (2009), Chhralkovska, J., Jansky, P., and Mejstrik, M., (2012), Galang, R. M. N., (2012), Georgiev, V., (2013), Hess D., (2009), Hannah S. T., Avolio B.J. and May D. R., (2011), Hansen, H.K., (2011), Moore, C., (2007), Misangyi, V. F., Weaver, G. R. and Elms, H., (2008), Mackevicius, J. and Kazlauskiene, L., (2009), Martin, A. W., S. H. Lopez, V. J. Roscigno and R. Hodson, (2013), Nieuwenboer, N. A. and Kaptien, M., (2008), Pinto, J., Leana, C. R. and Pil, F. K., (2008), Petkoski D., Warren D. E. and Laufer W. S.,(2010), Vian, T., Brinkerhoff, D. W., Feeley, F. G., Salomon, M. and Vien, N. T. K., (2012).
	ADB (2011), Cohen, J. C., (2006), DGHL (2010), Halpern, J., Kenny, C., Dickson, E., Ehrhardt, D., and Oliver, C., (2008), Kenny, C., (2006), McDevitt A., (2011), Savage, A. (2007), TI (2013a), UNGCO (2013), World Bank (2009), Williams, A. (2014), World Customs Organization (2015), Willems and Theodorakis (2016).
Business game	Rabl, T. and Ku¨hlmann, T. M., (2008), Rabl, T., (2011)
Value chain analysis	Patrion, H. A., and Kagia, R., (2007), Plummer, J. and Cross, P., (2007).
Qualitative meta analysis	Tenbrunsel A. E. And Smith-Crowe K., (2008)
Mixed	Bager G. (2011), Bowen, P. A., Edwards, P.J. and Cattell, K., (2012), Biswas M., (2015), Cover, O. and Mustafa, S., (2014), Geetanee, N., (2006), Maxwell, D., Bailey, S., Harvey, P., Walker, P., Sharbatke-Church, C. and and Savage, K., (2012), SÖÖt, M., (2012), Smith-Crowe, K., Tenbrunsel, A. E., Chan-Serafin, S., Brief, A. P., Umphress E. E. and Joseph, J., (2014), Voliotis, S., (2011), Zou, P. X. W., (2006)
	Blundell, A. G. and Marwell E. E., (2010), Døssing, H., Mokeki, L. and Weideman, M., (2011), Trivunovic, M., Johnsøn, J., Mathisen, H., (2011), AFP (2013), World Bank (2007), Zuleta, J. C., Leyton, A. and Ivanivic, E. F., (2007).

MINIMAL CUT SET ANALYSIS AND INVENTORY DATA BASE PARAMETERS

B.1 MINIMAL CUT SET ANALYSIS

The minimal cut sets are determined by using Top- down algorithm and Boolean algebra. The analysis begins with top events and represents each gate as a Boolean expression of basic events and/or other gates. These expressions are then combined, expanded, and simplified into an expression which mathematically expresses the top event in terms of the basic events without using any gates. As a result, all intermediate events have been eliminated that results in the minimal cut sets. In Boolean algebra AND gate is REPRESENTED by symbol . or ∩ and OR gate is represented by symbol + or U. For example, an event O is attached to the OR gate with two input events A and B. Then we can express mathematically O = A + B. Similarly, if an event O is attached to the AND gate with two input events A and B . We can express an AND gate mathematically O = A.B. The fault tree developed at Figure- 5 is reduced by using Boolean algebra. As Top event is connected with G1 and G2 through an AND Gate, T is expressed as T = G1.G2. Further, five events G3, G4, G5, G6 & G7 connect together with OR gate to G1. Similarly, G2 is joined with X_{15}, X_{16} and X_{17} by OR gate. G1 and G2 are therefore replaced by G1 = G3+G4+G5+G6+G7 and G2 = $X_{15}+X_{16}+X_{17}$.

In a similar manner, other intermediate events are also mathematically expressed as below;

G3 = X_1 +G8+G9+G10+G11, G4 = $X_5.X_8$, G5 = X_9+X_{10} , G6 = $G_{12}+G_{13}$

G7 = G14+G15 = $X_8+X_{13}+X_{14}$, G8 = X_2+X_3 , G9 = X_4+X_5 , G10 = X_2+X_6

G11 = X5.X7, G12 = $X_2+X_{11}+X_{12}$, G13 = X_2+X_9

Now substituting G1 = G3+G4+G5+G6+G7 in Boolean expression for Top even T,

T = (G3+G4+G5+G6+G7).G2 and on further substituting G3 = X_1 +G8+G9+G10+G11,

we find T = (X_1+G8 +G9+G10+G11+G4+G5+G6+G7).G2

Finally we substitute the value of G8, G9, G10, G11, G12, G13 and find

T = X_1.G2+ (X2+X3).G2 + (X_4+X_5).G2 + (X_2+X_6).G2 + ($X_5.X_7$).G2 + ($X_5.X_8$).G2 + (X_9+X_{10}).G2 + (G12+G13).G2+ (G14+G15).G2

$T = X_1.G2 + X_2.G2 + X_3.G2 + X_4.G2 + X_5.G2 + \underline{X_2.G2} + X_6.G2 + X_5.X_7.G2 + X_5.X_8.G2 + X_9.G2 + X_{10}.G2 + \underline{X_2.G2} + X_{11}.G2 + X_{12}.G2 + \underline{X_9.G2} + \underline{X_2.G2} + X_{13}.G2 + X_{14}.G2$

(Putting G2=X15+X16+X17) and eliminating redundant sets to avoid double counting

$T = X_1.X_{15} + X_1.X_{16} + X_1.X_{17} + X_2.X_{15} + X_2.X_{16} + X_2.X_{17} + X_3.X_{15} + X_3.X_{16} + X_3.X_{17} + X_4.X_{15} + X_4.X_{16} + X_4.X_{17} + X_5.X_{15} + X_5.X_{16} + X_5.X_{17} + X_5.X_7.X_{15} + X_5.X_7.X_{16} + X_5.X_7.X_{17} + X_5.X_8.X_{15} + X_5.X_8.X_{16} + X_5.X_8.X_{17} + X_6.X_{15} + X_6.X_{16} + X_6.X_{17} + X_8.X_{15} + X_8.X_{16} + X_8.X_{17} + X_9.X_{15} + X_9.X_{16} + X_9.X_{17} + X_{10}.X_{15} + X_{10}.X_{16} + X_{10}.X_{17} + X_{11}.X_{15} + X_{11}.X_{16} + X_{11}.X_{17} + X_{12}.X_{15} + X_{12}.X_{16} + X_{12}.X_{17} + X_{13}.X_{15} + X_{13}.X_{16} + X_{13}.X_{17} + X_{14}.X_{15} + X_{14}.X_{16} + X_{14}.X_{17}$

Therefore here we find following minimum cut sets here

Two element minimum cut sets: $\{X_1, X_{15}\}$, $\{X_1, X_{16}\}$, $\{X_1, X_{17}\}$, $\{X_2, X_{15}\}$, $\{X_2, X_{16}\}$, $\{X_2, X_{17}\}$, $\{X_3, X_{15}\}$, $\{X_3, X_{16}\}$, $\{X_3, X_{17}\}$, $\{X_4, X_{15}\}$, $\{X_4, X_{16}\}$, $\{X_4, X_{17}\}$, $\{X_5, X_{15}\}$, $\{X_5, X_{16}\}$, $\{X_5, X_{17}\}$, $\{X_6, X_{15}\}$, $\{X_6, X_{16}\}$, $\{X_6, X_{17}\}$, $\{X_8, X_{15}\}$, $\{X_8, X_{16}\}$, $\{X_8, X_{17}\}$, $\{X_9, X_{15}\}$, $\{X_9, X_{16}\}$, $\{X_9, X_{17}\}$, $\{X_{10}, X_{15}\}$, $\{X_{10}, X_{16}\}$, $\{X_{10}, X_{17}\}$, $\{X_{11}, X_{15}\}$, $\{X_{11}, X_{16}\}$, $\{X_{11}, X_{17}\}$, $\{X_{12}, X_{15}\}$, $\{X_{12}, X_{16}\}$, $\{X_{12}, X_{17}\}$, $\{X_{13}, X_{15}\}$, $\{X_{13}, X_{16}\}$, $\{X_{13}, X_{17}\}$, $\{X_{14}, X_{15}\}$, $\{X_{14}, X_{16}\}$ & $\{X_{14}, X_{17}\}$

Three element minimum cut sets: $\{X_5, X_7, X_{15}\}$, $\{X_5, X_7, X_{16}\}$, $\{X_5, X_7, X_{17}\}$, $\{X_5, X_8, X_{15}\}$, $\{X_5, X_8, X_{16}\}$ & $\{X_5, X_8, X_{17}\}$

Checking presence of Minimal cut sets in Fault tree for validation: FT can be validated by obtaining the minimal cut sets of the fault tree and identify the smallest order cut sets and check if these are indeed valid failure paths to the top event (Stamatelatos et al 2002). Let's take one example $\{X_6, X_{15}\}$, this MCS implies that urgency procedure have been abused (G10) because of conflict of interests (X_{15}) to avoid public call (G3) for unfair contract awards (T). Thus, this MCS is present in our FT. Similarly other MCSs were checked.

B.2 INFORMATION PARAMETER FOR INVENTORY DATA BASE

As the purchase process is found to be tightly intertwined with inventory control and management for procurement of goods as well as works, inventory management process was studied to find the risk mitigation measures. It is found that an efficient inventory management would not only be helpful in an efficient material planning but also facilitate streamlining the controls in procurement process by generating traceable records and need estimation more objective. In addition, it can timely provide updated and objective information about material on hand and requirement and its correct description which will reduce the chances of passive waste such as excess material or arising from poor procurement planning. With the invent of Information Communication Technology, it is easy to maintain an updated data base of inventory status of various items which are lying in various stages. The data base or inventory system can be customised with particular characteristics and features to provide with a focus to provide required information and generating records of material transactions that can be traced later on. FMECA of various risk factor leading to waste reveals that following information and performance parameters can be quite useful for reducing the wastage;

(1) Inventory status of various supply items and their past consumption pattern – It would be helpful to generate annual demand for various items.

(2) Purchase orders: In case of automated inventory systems, they may be provisioned with the features to store the purchase orders details or may be provided the interface with purchase order data base. An alarm may be generated, if a purchase order is placed even when sufficient quantity is available on-hand.

(3) Information about past procurement rates and suppliers; It would be helpful in preparing the cost estimates and evaluating the rates offered by bidders in the bid evaluation stage.

(4) List of frequent purchased items- It would facilitate inclusion of these items in the category requiring regular procurement. Consequently, decision regarding maintaining their inventory and finding regular vendors will be taken.

(5) Urgent Demand/ procurement: The information about urgency procurements can be a valuable source of information for improving the procurement planning to timely initiate action for such needs in future. At the same time, inventory system can suggest existing orders where change orders can be placed for immediate supply.

(6) Specifications: The inventory data base can be developed with the features to store the specification details that can readily provide this information while procurement process is initiated.

(7) Rejected items; If the detail about items rejected during quality inspection and use due to quality defects and deviation from specification, it can be used for improving the quality and evaluating the vendor performance.

(8) Failed supply order and delivery time lines: The information about failed orders and delivery time line can serve as an important input for timely intervention to prevent it effect on operations.

(9) Change order: Details of change orders would help in analyzing the pattern of change orders and designing corrective actions like improving the estimation and need estimate or segregating the instances of active waste where further auditing may be required.

(10) Unused Items: Inventory system can be customized to generate periodic list of idle inventory that can be used to prevent its further procurement or given to unit or section which is planning it procurement.

(11) Product with shelf life: Items having shelf life like pharmaceutical products need special attention so that they are received sufficient valid period and consumed before them

(12) Product with warranty period; certain products have stipulated warranty period for various quality failures. Such warranty claims can be timely raised if inventory data base provide this information in case of failures.

B.3 Data Sources

During the research work, a data search is made only from the publicly available resources by selecting the case studies by following the principles of theoretical sampling and theoretical saturation. The concepts of theoretical sampling and theoretical saturation are explained in detail in Chapter 3 of this thesis. Essentially data search is governed by the simple principle of theoretical sampling which involves selecting the cases where topic of interest was observable. The data source details are given in Table B.1.

Table B.1 : Data Source Reference Details

S. N.	Data Source Name	Data Source Web Access details	No of Cases
1	ICAC (1998)	ICAC (1998). Managing Integrity & Striving for Excellence; Corruption prevention package for construction industry. http:// www.hkedc.icac.hk/english/files/publications/PG012.pdf .. / Accessed 16.04.16.	**3**
2	Corruption Research Center Budapest: (2013)	High-level corruption in Spain. Available@ http://www.crcb.eu/ *February 2015, Budapest*	**3**
3	Centre for co-operation with non-members Directorate for Financial, Fiscal and Enterprise Affair (2001)	Centre for co-operation with non-members Directorate for Financial, Fiscal and Enterprise Affair (2001). OECD Global Forum on Competition Summary of Cartel Cases Described By Invitees. http://www.oecd.org/ .../publicdisplaydocumentpdf/?cote=CCNM/GF/COMP(2001)4...En/ Accessed 22.02.15.	**1**
4	OECD (2007)	OECD (2007). Bribery in Public Procurement: methods, actors and counter-measures. https://www.oecd.org/daf/anti-bribery/anti-briberyconvention/44956834.pdf/ Accessed 21.03.14	**6**
5	Passas (2007)	Passas, N. (2007).*Corruption in the procurement process/outsourcing government functions: Issues, cases studies, implication*. Boston: Institute for Fraud Prevention. http://www.theifp.org/research-grants/procurement_final_edited.pdf/ Accessed 15.04.16	**2**
6	Global Infrastructure Anti-Corruption Centre (2008);	Global Infrastructure Anti-Corruption Centre (2008). Examples of Corruption in Infrastructure. https://www.giaccentre.org/documents/GIACC.CORRUPTIONEXAMPLES.pdf/ Accessed 25.03.16.	**10**
7	World Bank (2010).	World Bank (2010). Fraud and corruption awareness handbook: how it works and what to look for-a handbook for staff. Washington, DC: World Bank 2010. http://siteresources.worldbank.org/INTDOII/Resources/INT_inside_fraud_text_090909.pdf/ Accessed 23.02.15.	**10**

S. N.	Data Source Name	Data Source Web Access details	No of Cases
8	TI (2006)	Preventing Corruption On Construction Projects Risk Assessment And Proposed Actions For Funders http://www.giaccentre.org/documents/TI-ACFREPORTRISKASSESSMENTFUNDERS.pdf	**6**
9	Bribery and corruption – case studies overview (2012)	Bribery and corruption – case studies overview (2012). Ashurst Publication. https://www.ashurst.com/doc.aspx?id_Resource=491/ Accessed 22.01.16.	**1**
10	European Union (2013);	European Union (2013). Study on Corruption in the Healthcare Sector. http:// *ec.europa.eu/.../20131219_study_on_corruption_in_the_healthcare_sector_en.pdf* Accessed 23.02.16 Anti- corruption risk mitigation for organizations working with third parties Is out of sight out of mind?. https://www.transparency.nl/wp-content/uploads/2016/12/Siyer_-_Anti-corruption_risk_mitigation_strategies1.pdf	**2**
11	European Union (2013) & S Iyer (2012-14)	European Union (2013). Study on Corruption in the Healthcare Sector. http:// *ec.europa.eu/.../20131219_study_on_corruption_in_the_healthcare_sector_en.pdf* Accessed 23.02.16 Anti- corruption risk mitigation for organizations working with third parties Is out of sight out of mind?. https://www.transparency.nl/wp-content/uploads/2016/12/Siyer_-_Anti-corruption_risk_mitigation_strategies1.pdf	**1**
12	Summaries of Foreign Corrupt Practices Act (2013) . Steps taken OECD anti-bribery convention.	Summaries of Foreign Corrupt Practices Act Enforcement Actions by the United States January 1, 1998 – February 22, 2013 https://www.justice.gov/sites/default/files/criminal-fraud/legacy/2013/03/19/2013-02-25-steps-taken-oecd-	**4**

S. N.	Data Source Name	Data Source Web Access details	No of Cases
		anti-bribery-convention.pdf or file:///G:/Article%202/GT%20Final%20merged%20cases/REPORT%20FOR%20CASES/Ref%20Volvo%20case%20%20steps%20taken%20oecd%20anti%20bribery%20convention.pdf	
13	Hong Kong Business Ethics Centre cases study;	Hong Kong Business Ethics Centre cases study. http://www.hkbedc.icac.hk/english/publications/case_studies.php?andor=and&area=19&pg=2 / Accessed 22.02.16.	1
14	Pre-contract procurement fraud and corruption	Pre-contract procurement fraud and corruption Guidance for prevention and detection. (2013). www.hacw.nhs.uk/EasySiteWeb/GatewayLink.aspx?alId=39680	**4**
15	Glenn T. Ware, Shaun Moss, J. Edgards Campas and Gregary, p Noone (2006)	Corruption in public procurement in Campos J. and Pradhan S.(eds.) The many facts of Corruption : Tracing the vulnerability at sector level	**1**
16	Moron T. H. (2006).	How Multinational Investors Evade Developed Country Laws (Page 5) Available @https://www.cgdev.org/files/6113_file_WP_79.pdf	**1**
17	OECD (2009)	Typologies on the role of intermediaries in international business transactions. (page 26-27) Available @http://www.oecd.org/investment/anti-bribery/anti-briberyconvention/43879503.pdf	**4**
18	Varinac & Ninić (2014)	Varinac, S. & Ninić, I. (2014). Public Procurement Corruption Map in the Republic of Serbia. Belgrade, 1 Španskih: Boraca Organization for Security and Cooperation in Europe Mission to Serbia. http://www.osce.org/serbia/126843?download=true./ Accessed 23.02.16	**9**

Table B.2 : Risk factors associated with procurement process.

Sl No	Risk factors	Explanation/Example
1.	Knowledge deficit	Lack of technical capacity among staff, is committee members and supervision unit.
2.	Weak dispute resolution mechanism	Dispute resolution procedures that provide efficient and fair process to resolve disputes and ensure neutrality of arbitrators.
3.	Weak monitoring of change orders	Low or no monitoring of post tender changes resulting in contract lengthening and changing contract conditions pertaining to price, quantity or scope of work.
4.	Unjust engagement of intermediaries	Intermediaries are sponsors or middlemen and consulting or engineering companies, or joint ventures, who may be engaged in a non-transparent manner and without any justified or real need and realist fees.
5.	Non updated/Absence of rate reference	Non availability of appropriate information for determining reasonability of procurement price.
6.	Inadequate record keeping	Public notices, bid documents, bid opening and evaluation records, Change requests and outcomes, signed agreements and supplementary agreements, execution progress, test and audit findings, claims, dispute resolution and final payment details.
7.	Absence of Quality Standards & Procurement Codes	Relevant and comprehensive quality standards and procurement codes do not exist for ensuring quality assurance and fair procurement procedures.
8.	Inadequate/Absence of Verification	Verification of bidder capability certificates, bank guarantees, consultant credentials.
9.	Project complexity	Complex nature of the product and works involving diverse skill and multiple phases which may lead to contract completeness.
10.	Technical complexities	Complexities of the technology involved in

Sl No	Risk factors	Explanation/Example
		the product and work.
11.	Procurement size	Size reflected through large number of people and huge financial investment.
12.	Absence of Separation of function	Separate the functions of approval of operations, execution, control and accounting to reduce the risk of errors, not discovering improper procedures, and enable avoiding waste and effective reviews. Independence of procurement functions, audit agency and supervising engineers.
13.	Poor procurement planning	If organization does not undertake procurement planning where requirements are reliably determined, appropriate contract strategies are developed and economy of scales are used to ensure procurement at the right time and at the right price.
14.	No open bidding norm	Norm of not following open bidding procedures in procurement.
15.	Absence of rotation among staff	Absence of rotation of staff on sensitive position may lead to gradual accretion of acquisition and personnel management authorities.
16.	Subjective/ Inadequate bid evaluation	Poorly justified disqualification and rates, unusual scoring of bids,
17.	Weak Control	Independent supervision of works, quality testing provision, contract administration, provision of auditing, procedures to regulate and review change requests, budgeting and expenditure cost checks, provision of termination and penalty against non performance of contractors.
18.	Absence of need analysis	Absence of established routines for needs assessment and market analysis and insufficient clarification of procurement needs.
19.	Unregulated discretion	Specification framing, describing work, defining eligibility criteria, setting up

Sl No	Risk factors	Explanation/Example
		delivery conditions, planning procurement quantity, using urgency provision, making choice of procurement procedures, undervaluing the estimate, inflated price estimation and bid document obscuration, contract lengthening and changing contract conditions pertaining to price, quantity or scope of work.
20.	Inaction on corrupt practice such as using false credential	No action is taken aginst the bidders for using false credentials for winning the contract.
21.	Weak regulation of relationship with external entities	Absence of regulation (through appropriate mechanism like code of ethics and belief systems) of interpersonal relationship and transaction between organizational members and external entities.

As seen from the section 5.32 of chapter 5, cost of quality failures during project execution phase evolves through a GBM process. Hence, cost of quality failures can be expressed as

$$\frac{dc}{c} = \mu dt + \sigma dW_t$$

Let $p_t(c)$ denotes the density of c and by using a binomial approximation, we can view the Brownian motion as satisfying

$$p[\mathrm{W}_{t+\Delta c} = W_t + \Delta c] = [\mathrm{W}_{t+\Delta t} = W_t - \Delta c] = \frac{1}{2} \qquad \text{……………................ (1)}$$
$$Var[W(t+\Delta t) - W(t)] = \sigma^2 c^2 \Delta t$$

Where $\Delta c = \sqrt{\Delta t}$. In the approximation to be at c at time $t + \Delta t$, one must be at c+ Δc at time t which give

$$p_{t+\Delta t}(c) = \frac{1}{2} p_t(c - \Delta c) + \frac{1}{2} p_t(c + \Delta c)$$

By using $\Delta t = (\Delta c)^2$ this implies

$$\frac{p_{t+\Delta t}(c) - \mathrm{p}_t(c)}{\Delta t} = \frac{p_t(c+\Delta c) + \mathrm{p}_t(c - \Delta c) - 2\,\mathrm{p}_t(c)}{2(\Delta c)^2} \qquad \text{……………................ (2)}$$

Let $\Delta t \to 0$, then $\lim\limits_{\Delta t \to 0} \dfrac{p_{t+\Delta t}(c) - \mathrm{p}_t(c)}{\Delta t} = \partial_t p_t(c)$

The right hand side of equation (2) is re-written as

$$\frac{1}{2\Delta c}\left[\frac{p_t(c+\Delta c)}{\Delta c} - \frac{\mathrm{p}_t(c) - p_t(c-\Delta c)}{\Delta c}\right]$$

$$= \frac{1}{2}\left[\frac{\partial_c p_t(c) - \partial_x P_t(c - \Delta c)}{\Delta c}\right] \qquad \text{……………................ (3)}$$

Now we assume

$$f(c) = p_t(c)$$

$$\partial p_t(c) = \frac{\sigma^2 c^2}{2} \partial_{cc} p_t(c)$$

Where $O(\in^2)$ term is defined as follows,

$$\lim_{\in \to 0} \frac{O(\in^2)}{\in^2} = 0$$

Then $f(c+\in) + f(c-\in) - 2(f(c)) = f''(x)\in^2 + O(\in^2)$

Then expession (3) becomes as under

$$\frac{1}{2}\partial_{cc} p_t(c)$$

and finally equation(2) can be expressed as

$$\partial_t p_t(c) = \frac{1}{2}\partial_{cc} p_t(c) \qquad \text{…………................ (4)}$$

If the Brownian motion has variance σ^2 and change in c is expressed as proportion of *c* then binomial approximation is

$$\mathrm{P}[\mathrm{W}_{t+\Delta t} = W_t + \sigma c \Delta c] = P[\mathrm{W}_{t+\Delta t} = W_t - \sigma \Delta c] = \frac{1}{2}$$

Where $\Delta c = \sqrt{\Delta t}$. The factor σc is put then Varian becomes as under

$$Var[W(t+\Delta t) - W(t)] = \sigma^2 c^2 \Delta t$$

Following above, we can write as below

$$\partial p_t(c) = \frac{\sigma^2 c^2}{2}\partial_{cc} p_t(c) \qquad \text{…………................ (5)}$$

As Brownian motion has drift μ, the equation (5) would get another term i.e. deterministic component. For sake of brevity, we assume that motion of *c* does not have any variance then it's density can be expressed as

$$p_{t+\Delta t}(c) = p_t(c + \mu \Delta t)$$

Because particle at C at time t +Δt must have been c + mΔt at time t. then

$$\frac{p_{t+\Delta t}(c) - p_t(c)}{\Delta t} = \frac{p_t(c + \mu c \Delta t) - p_t(c)}{\Delta t}$$

$$= \mu c \frac{p_{t+\Delta t}(c + \mu c \Delta t) - p_t(c)}{\mu c \Delta t}$$

When $\Delta t \to 0$ $\qquad \partial_t p_t(c) = \mu c \partial_c p_t(c)$ …………................ (6)

If Brownian motion has both drift μ and variance σ^2 then by considering (5 & 6) we get

$$\partial_t p_t(c) = \mu c \partial_c p_t(c) + \frac{\sigma^2}{2} \partial_{cc} p_t(c) \qquad \text{.............................. (7)}$$

Now we define A linear operator L which is a function from function to function satisfying L(xf+yg) = x L(V) + y L(T) where x and y are constants and V & T are functions. Let us say that a function V: R→R is C^2 if it's twice differentiable and the derivative are continuous functions of C

For any μ & σ^2, we may define

$$L.V(c) = \mu c V^{'}(c) + \frac{\sigma^2 c^2}{2} V^{"}(c) \qquad \text{.............................. (8)}$$

By combining (11) & (12) heat equation becomes as under:

$$\partial_t p_t(c) = L.V(c) = \mu c V^{'}(c) + \frac{\sigma^2}{2} V^{"}(c) \qquad \text{.............................. (9)}$$

ANALYTICAL SOLUTION

As seen from section 5.3.3 of Chapter 5, the existence and uniqueness of the solution of the problem under consideration, three condition were required namely; (i) Using deterministic and partial differential equation (PDE) (ii) SDE trial has definite root and may be unique or heuristic solution and (iii) must include real Cartesian coordinates of real space (R^n) of same dimensions. It implies that it must provide n dimensional (R^n) space with standard Euclidian structure of real (c_t , t) sets of values.

Now, T>0, $\mu : \mathrm{R}^n\, x[0,T] \rightarrow R^n$

$\sigma : \mathrm{R}^n\, x[0,T] \rightarrow R^{n+m}$

$dc_t = \mu(c_t, t)dt + \sigma(c_t, t)dw_t$ for $t \in [0, \mathrm{T}]$ and $\mathrm{E}\left[\int_0^T |X_t|^2\, dt\right] < +\infty$

i.e. $dC_T = [a(t) + c(t)]dt + [b(t)\,\mathrm{c}_t + d(t)]dw_t$

$$C_t = \phi_{t=(0,\mathrm{T})}\left(C_{T_0} + \int_t^{t+s} \phi'_{s,t}\left(C'(s) - b(s)d(s)\right)ds + \int_t^{t+s} \phi_{s,t} d(\mathrm{s})\,\mathrm{dw}_s\right)$$

$dw_t \rightarrow dw_s$ during the period of t to t+s

$$\phi = e^{\left(\int_t^{t+s}(a(s) - \frac{b^2(s)}{2})^2 ds + \int_t^{t+s} b(s)dw_s\right)}$$

As stated previously in section 5.3.3 , above equation requires exponential trial solution. It approaches to the function

$$d\phi(c_t, t) = \partial_c \phi(c_t, t)\,\mathrm{ds}_t + \frac{1}{2}\partial^2{}_c \phi(c_t, t).ds_t{}^2 + \partial_c \phi(c_t, t)dt$$

i.e. $d[A + B + ke^{\sigma W_t}] = A_t e^{\sigma w_t} dt + \sigma A_t e^{\sigma w_t} dw_t + \frac{1}{2}\sigma^2 A_t e^{\sigma w_t} dt$ where t+s→s and t→0

where A, B are the primary conditions (A,B are non zero constants). To consider quality failure cost from the beginning, we will now consider super symmetry approach. It may allow a greater adjustment of constraints as well as intermittent. For this, basic simulation of super symmetric approach which considering (i) scale free statistical structure. (ii) c approaches limit of probability and independent of path i.e. multiple path approach may be incorporated. Thus, we can write

$\int_0^s \left(a(s) - \frac{b^2(s)}{2}\right)^2 ds \rightarrow 0$ for Brownian symmetry and $\int_0^t \phi'_{s,t} d(s) dw_s = \lim_{n\to\infty} \int_0^s \phi^n dw_t$

and $E\left[(\int_0^t c_{s,t} dw_s)^2 \right] = E\left[\int_0^t H_s^2 ds \right]$

$b(s) dw_s \to k$

Time line integral

$c_t = c_0 + \int_0^t \sigma_s dw_s + \int_0^t \mu_s dt$ $\sigma_s \to$b $\mu_s \to$a

σ is predictable integral and μ_s is heuristic search integral unit is $\int_0^t \left(\sigma^2 + |\mu_s| \right) ds < \propto$

[finite process neglecting interruption]

For solving Stochastic Differential Equation, Let's now assume c_t is given by following ordinary differential equation

$\mathrm{dc(t) = f(t, c)\, dt}$ when t=0, $\mathrm{c(0) = c_0}$

$\mathrm{c(t) = c_0} + \int_0^t f(s, c(s)) ds$ where, $c(t) = c(t, c_0, t_0)$

$\frac{dc(t)}{dt} = f(t).x(t)$ $\mathrm{c(0) = c_0}$

$f(t) = \lambda(t) + h(t)\xi(t)$ $\to \xi(t)$ =true noise process or initial propogative process independent of path

Now $dw_t = \zeta(t) dt$

$\mathrm{dc(t)} = \lambda(t) c(t) dt + h(t) c(t) dw_t$

Or, $dc = \mu c dt + \sigma c dw_t$

Now $dc(t, w) = f(t, c(t, w)) dt + h(t, c(t, w)) dw(t, w)$

where c(t)=c, λ(t)=μ, h(t)=σ, w→ inspection function

and c=c(t, w) is actually a random process with expectation value given by following;

$dc(t, w) = \mu(t) dt + \sigma(t) dw(t, w)$

$f(t, c(t, w)) \in R, h(t, c(t, w)) \in R$ at $w(t, w) \in R$

$$\mathrm{c(t,w)} = \mathrm{c}_0 + \int_0^t f(s, c(\mathrm{t,w})ds + \int_0^t h(sc(s,w))dw(s,w)$$

During calculating this stochastic integral $\int_0^t h(s, c(s,w))dw(s,w)$, we assume h(t, w) only change in discrete time duration, $t_i(k = 1, 2, 3....n-1)$ when we have

$$0 = \mathrm{t}_0 < t_1 < t_2 ..... < t_{n-1} < t_n < T$$

$\therefore S = \int_0^T h(t,w)dw(t,w)$ as Riemann Integrable under the bonneted function [a, b] which implies adisjoint, non empty compact subinterval with a deterministic pattern.

If $P = \{I_1, I_2, ...I_n\}$ is the partition of Integral I then P denotes the finite well definite path function with max, min value of each subinterval integrals.

Then $Upper(f; p) = \sum_{k=1}^{n} M_k |I_k| = \sum_{k=1}^{n} M_k (c_k - c_{k-1})$ where M defines the path max and

$$\mathrm{Lower}(f; p) = \sum_{k=1}^{n} m_k |I_k| = \sum_{k=1}^{n} m_k (c_k - c_{k-1})$$

Then $m(b-a) \le L(f; p) \le U(f; p) \le M(b-a)$

Thus $\mathrm{S}_N(w) = \sum_{k=1}^{\infty} h(t_{k-1} w)\left(w(t_k, w) - \mathrm{w}(\mathrm{t}_{k-1}, w)\right)$

Where $S \to I_t$ \$integral of a stochastic process h(t, w) with respect to the Brownian motion w(t, w) where, $\lim_{n\to\infty} E[(s - \sum_{k=1}^{n} h(t_{k-1}, w) - w(t_{k-1}, w))]$

This indicates that expectation vector →0 means the stochastic integral is in mean-square sense. The sense is only applicable for finite data output. This stochastic integral is random and depends upon the path W(t, w)

Now $\int_0^T c dw(t,w) = c \lim_{n\to\infty} \sum_{k=1}^{n} (\mathrm{w}(t_{k-1}, w) - w(t_{k-1}, w))$

$$= c(w(T, W) - W(o, w))$$

W(T,w) and W(o,w) are standard Gaussian random variable

If h(t,w)=W(t,w) = domination propagation function

Then $\int_0^T w(t,w)dw(t,w) = \lim_{n\to\infty}\sum_{k=1}^{n}(\mathrm{w}(t_{k-1},w)(w(t_{k-1},w)-\mathrm{w}(\mathrm{t}_{k-1},\mathrm{w}))$

$$= \lim_{n\to\infty}\left[\frac{1}{2}\sum_{k=1}^{n}(w^2(t,w)-w^2(t_{k-1},w)) - \frac{1}{2}\sum_{k=1}^{n}(w(t_k,w)-w(t_{k-1},w))^2\right]$$

$$= \frac{1}{2}w^2(T,w) - \frac{1}{2}\lim_{n\to\infty}\sum_{k=1}^{n}(w(t_k,w)-w(t_{k-1},w))^2$$

[Simplified form]

Now, $E\left[\lim_{n\to\infty}\sum_{k=1}^{n}(w(t\ ,w)-w(t_{k-1},w))^2\right] = \lim_{n\to\infty}E\left[\sum_{k=1}^{n}(w(t\ ,w)-w(t_{k-1},w))^2\right]$

$$= \lim_{n\to\infty}\sum_{k=1}^{n}(\mathrm{t}-\mathrm{t}_{k-1}) \ = T$$ E→Expectation

$$Var\left[\lim_{n\to\infty}\sum_{k=1}^{n}(w(t\ ,w)-w(t_{k-1},w))^2\right] = \lim_{n\to\infty}Var\left[(w(t,w)-w(t_{k-1},w))^2\right]$$

$$= 2\lim_{n\to\infty}\sum_{k=1}^{N}(\mathrm{t}-\mathrm{t}_{k-1})^2$$

Reducing the partitions, $t_k - t_{k-1} \to \infty$ then

$$\lim_{n\to\infty}\sum_{k=1}^{n}(\mathrm{t}_k-\mathrm{t}_{k-1})^2 \le \max(\mathrm{t}_k - t_{k-1})\lim_{n\to\infty}\sum_{k=1}^{N}(t_k - t_{k-1})$$

$$= \max(\mathrm{t}_k - t_{k-1})T = 0$$

$$\therefore E\left[\lim_{n\to\infty}\sum_{k=1}^{n}(\mathrm{t}_k-\mathrm{t}_{k-1})^2\right] = T \qquad \mathrm{Var}=0$$

$$\therefore \sum_{k=1}^{n}(W(t,w)-W(t_{k-1},w))^2 = T$$

Then stochastic Integral $\int_0^T N(t,w)dw(t,w) = \frac{1}{2}w^2(T,w) - \frac{1}{2}T$

Now considering again from the property of $It\acute{o}$ integral

$E\left[\int_0^T h(t,w)dw(t,w)\right] = 0$ and $Var\left[\int_0^T h(t,w)dw(t,w)\right] = \int_0^T E\left[h^2(t,w)dt\right]$

This calculation shows

$$E\left[\int_0^T (h(t,w)dw(t,w))^2\right] = \int_0^T E\left[h^2(t,w)dt\right]dt < \infty$$ finite frame

and $\int_0^T [a_1 h_1(t,w) + a_2 h_2(t,w)]\,dw(t,w)$

$$= a_1\int_0^T h_1(t,w)\,dw(t,w) + a_2\int_0^T h_2(t,w)dw(t,w)$$

a_1, a_2 are the stochastic functions of $h_1(t,w), h_2(t,w)$

Thus

$$dc = \mu c dt + \sigma c dw_t$$
$$dc = (\mu - \frac{\sigma^2}{2})dt + \sigma dw_t$$

and $C_{ins} = \left(1 + p\int_0^T e^{-rs} C_{ins} r I ds + (1+p)\int e^{-rs}\lambda\alpha C_{ins} ds\right)$

$$S(t) = S_0\, e^{(\mu - \frac{1}{2}\sigma^2)t + \sigma w t_0}$$ when $c(t) = \ln S(t)$

Now if we Consider Stochastic differential equation

$$ds(t) = \mu s(t)dt + \sigma s(t)dw(t)$$

Here Y related to s, $Y(s) = \phi(t,s) = \ln(s(t))$

$$\frac{\partial\phi(s,t)}{\partial s} = \frac{1}{s},\quad \frac{\partial\phi(s,t)}{\partial s} = \frac{1}{s}, \frac{\partial^2\phi(s,t)}{\partial s^2} = -\frac{1}{s^2}$$ and

$$\frac{\partial\phi(s,t)}{\partial t} = 0$$ Y – is another prediction function

$$dY(t) = \left(\frac{\partial\phi(s,t)}{\partial t} + \frac{\partial\phi(s,t)}{\partial s}\mu s(t) + \frac{1}{2}\frac{\partial^2\phi(s,t)}{\partial s^2}\sigma^2 s^2(t)\right)dt + \left(\frac{\delta\phi(s,t)}{\partial s}\sigma s(t)\right)dw(\mathrm{t})$$

(same from Ito's Lamma)

$$\therefore dY(t) = (\mu - \frac{1}{2}\sigma^2)dt + \sigma dw(t)$$

Since RHS of above is independent of Y(t),

$$\therefore Y(t) = Y_0 + \int_0^t (\mu - \frac{1}{2}\sigma^2)dt + \int_0^t \sigma dw$$

$\therefore S(t) = S(0).\mathrm{e}^{(\mu - \frac{1}{2}\sigma^2)t + \sigma w(t)}$

Again we have to consider two more functions $X_1(t)$ & $X_2(t)$

$$U(t) = X_1(t).X_2(t) where$$
$$dX_1(t) = f_1(t, X_1)dt + g_1(t, X_1)dw(t)$$
$$dX_2(t) = f_2(t, X_2) + g_2(t, X_2)dw(t)$$

and $dU(t) = dX_1(t)X_2(t) + X_1(t)dX_2(t) + g_1(t, X_1).g_2(t, X_2)dt$

$$\therefore dU(t) = \left[X_2(t)f_1(t, X_1) + X_1(t)f_2(t, X_2) + g_1(t, X_1).g_2(t, X_2)\right]dt + \left[X_2(t)g_1(t, X_1) + X_1(t)g_2(t, X_2)\right]dw(t)$$

This equation contains two large groups, linear SDEs and non-linear SDEs. Now we consider only the linear SDEs. These may be of two groups scalar linear, and vector-valued linear.

$$dX(t) = f(t, X(t))dt + g(\mathrm{t}, X(t))dw(t)$$

Where f(t, X(t)) and g(t, X(t)) are affine functions of X(t) and W(t) $\in R^m$ i.e. m-dimensional Brownian Motions.

$\therefore$ Solutions

$\mathrm{X(t)} = \phi(\mathrm{t})\left(x_0 + \int_0^t \phi^{-1}(s)\left[a(s) - \sum_{i=1}^m B_i(s)\right]ds + \sum_{i=1}^m \int_0^t \phi^{-1}(s)b_1(s)dw_i(s)\right)$ a form of standard solution ignoring all the valuable concept n-brownian motion.

where $\phi(t)$ and $\phi^{-1}(s)$ are the fundamental matrix and universe matrix.

$$\phi(t) = \exp\left(\int_0^t \left[A(s) - \sum_{i=1}^m \frac{B_i^2(s)}{2}\right]ds + \sum_{i=1}^m \int_0^t B_i(s)dw_i(s)\right)$$

Similar to ordinary differential equations

assuming $W(t) \in R$, $A(t)=0$, $b(T)=0$

$A(t)=A$, $B(t)=B$

$dx(t)=AX(t)dt+BX(t)dw(t), X(t)=x_0$

$$\therefore \phi(t) = e^{\left(A - \frac{1}{2}B^2\right)t + BW(t)}$$

$$\therefore X(t) = \phi(t)x_0 = x_0 e^{\left(A - \frac{1}{2}B^2\right)t + BW(t)}$$

Now considering specific scalar linier SDEs leads to four different cases where mean is E[S(t)]=μt + S_0 and variance Var[S(t)] =σ^2t. S(t) processes a behaviour of fluctuations around the straight line. Thus, S=S_0+μt. that is governed by the process which is normally distributed with the given mean and variance. However, this case will not consider probabilistic search to optimize various combination of parameters.

Second Case includes scalar- linear SDE with close domain period of time

$E\left[s(\mathrm{t})\right] = S_0 e^{\mu t}$ and $V_{ar}\left[S(t)\right] = S_0{}^2 e^{2\mu t}\left(e^{\sigma^2 t} - 1\right)$

The first property is that S(t)>0, for all $t \in [0,T]$ and second is that all returns are in scale with current values. This process has a log-normal probability density function.

Third case considers non linear phenomenon where non linearity is introduced by the constant k

$$ds(t) = K\left[\mu - S(t)\right]dt + \sigma S(t)dw(t,w), S(0) = \mathrm{S}_0$$

Now μ=0,

$$E\left[\mathrm{S(t)}\right] = \mu - \left(\mu - S_0\right)e^{-kt}$$

$$V_{ar}\left[S(t)\right] = \frac{\sigma^2}{2k}\left(1 - e^{-2kt}\right)$$

In the long run, $\lim_{t\to\infty} E\left(S(t)\right) = \mu$

$$\lim_{t\to\infty} V_{ar}\left(S(t)\right) = \frac{\sigma^2}{2k}$$

This analysis shows that the process fluctuations takes place around mean value μ and has a variance of $\frac{\sigma^2}{2k}$ which depends upon k, higher the k, lower the variance. It implies that higher the k, faster the process returns back to its mean value. This process is a stationary process which is normally distributed.

$\therefore S(t) \geq 0$, if $\mathrm{S}_0 \geq 0$, μ>0, K>0, Considering Die out system

$$A(t)=\begin{pmatrix}0 & 0\\ 0 & k\end{pmatrix}\ a(t)=\begin{pmatrix}\mu\\ k\phi\end{pmatrix}\ B_i(t)=\begin{pmatrix}0 & 1\\ 0 & \sigma, p\end{pmatrix}$$

$$B_2(t)=\begin{pmatrix}0 & 0\\ 0 & \sigma.\sqrt{1-p^2}\end{pmatrix}$$

$$\therefore x(t)=\left(\mathrm{P}(t),\sigma(t)\right)^T$$

P(t) depends upon σ_0, μ=0.1. k=2

ϕ=0.2, σ_1 =5, P=0.5, σ_0 =0.1 or 0.8

The evolution m(t)= $=\phi+\left(\sigma_0-\phi\right)e^{-kt}$ and variance depends on σ_0.

The fourth case involves second order term of failure and described by

$$dS(t)=K\left[\mu-S(t)\right]dt+\sigma\sqrt{s(t)}dw(t),S(0)=S_0$$

This is applicable for less failure prone process and considers short term process in its scope.

$$dS(t)=\mu S(t)dt+\sigma\sqrt{s(t)}dw(t),\mathrm{S}(0)=\mathrm{S}_0$$

$$E\left[S(t)\right]=S_0e^{\mu t}$$

$$V_{ar}\left[S(t)\right]=\frac{\sigma^2S_0}{\mu}\left(e^{2\mu t}-e^{\mu t}\right)$$

The function S_t can be considered dependent upon various parameters such as material inventory, labour force, inspection frequency. It would therefore be difficult to predict its value. Thus it would be useful to consider other solution approaches.

Annexure-I

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E Thesis Metadata Form

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Annexure-II

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Consent Form for Digital Archiving

Name of the Author (Research Scholar)	SUNIL KUMAR SHARMA
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