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"RISK SHARING IN TRADITIONAL CONSTRUCTION CONTRACTS FOR BUILDING PROJECTS. A CONTRACTOR'S PERSPECTIVE IN THE GREEK CONSTRUCTION INDUSTRY."

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DECLARATION OF ORIGINALITY

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SUMMARY

The primary process in a traditional construction contract is based on a buy/sell dipole between candidate contractors and project clients. The decision driver of a client is to accept the best offer on the basis of the minimum bid and the decision driver of a contractor is to win the tender by maximizing as much as possible the profit element. Primary (market) processes are supported by managerial processes.

Successful project management (PM) aims at achieving the triple-constraint (time, cost and quality) target for both contractors and project clients. PM activities are often supported by a Risk Management (RM) system based on which contractors identify, assess, monitor and control any type of risk that may emerge in any stage of a building project.

It is extensively reported that the traditional procurement remains inefficient as contractors are obliged to submit tenders approximately on a zero-profit limit and are transferred unrealistic cost risk amounts from their clients. In addition poor project cost performance is also a common drawback in traditionally procured projects. This contractual context suffering from legal disputes and compensation claims leads contractors to embody into their estimates contingency reserves. These reserves are supposed to perform three tasks: resolve emergencies, control schedule and improve facility (Ford 2002).

The goal of the study is to reveal improvement opportunities for contractors when they negotiate post-bid risk sharing agreements with their clients.

To present the knowledge body reviewed, the tools deployed and the results achieved in the study, the author briefly discusses each chapter below.

♦ **CHAPTER 1: INTRODUCTION**
This chapter provides general introduction to the reader into the world of the construction industry and the problematic context of traditional procurement. The research gap is mapped while providing a practical case wherein contractors and clients enter into disagreement regarding sharing of cost risks in the post-bid period. The example is grounded for the case of the Greek construction industry. The structure of the report is outlined too.

♦ **CHAPTER 2: RESEARCH DESIGN**
In this chapter the author initially discusses some observations on the preference of Design-Bid-Build (DBB) contracts, highlights the client-contractor market dynamics which shape procuremet decisions and indicates the low satisfaction of contractors due to unfair risk allocation towards them. The problem statement is summarized into a research proposal section, describing also the next steps of the chapter. The author based on the mode of *selection* examines only building projects during the actual construction phase and traditionally procured. The mode of *refinement* led the author to choose only the cost side as problem scope. Thereafter the two dimensions; technical and behavioral, of the problem are illustrated coupled with the three research components (predictive, exploratory, and control). The research framework and the survey specification provide a helpful representation of the factors that the study will quantify or assess. The chapter proceeds to the presentation of the research model which visualizes the sequence of theories, focus, tools and deliverables of the study. The research goal and the research questions conclude this chapter.

♦ **CHAPTER 3: LITERATURE REVIEW**
The goal of this chapter is to provide firstly comprehensive understanding of some fundamental terms such as uncertainty, risk, risk perception, contingency, etc. Two extensive appendices are dedicated on the definition of "risk" (Appendix 3) and "RM standards" (Appendix 4) for interested readers. A special section is written for specific key-terms such as "uncertainty", "cost contingency", "RM in the construction industry", "Risk sharing" so to establish the motivation of the author to investigate the selected research area. These sections are highlighted with a *pin* icon. The author deployes the tool of systematic literature review to obtain further information on: (a) RM frameworks, (b) on-site risk

events, (c) industry approaches on RM and (d) risk assessment techniques. This chapter assisted the author firstly to identify a generic risk list which was further tailored to on-site conditions; for this purpose 109 references were reviewed (Table 7), secondly to decide which quantitative tool is appropriate for performing the risk analysis (i.e. the Monte Carlo simulation) and lastly to ground strong incentives on the investigation of risk sharing decisions and their impact on project cost performance.

♦ **CHAPTER 4: MODEL DESIGN**

The discussion of the applicability of Hobbs model (Hobbs 2010) for enabling the author to perform cost risk analysis and further contingency estimation is provided in this chapter. The specific model was chosen as it is constructed for small to medium construction projects and also combines probabilistic and simulation-based cost analysis tools. The author tailored the existing model to a specific risk list which consists of 27 individual risk factors, and added some columns in the excel sheet so to draw additional conclusions. In addition, the chapter presents the distributions used to model experts' opinion, discusses the interdependency among the individual risks, and shows an example of computing the minimum required number of iterations for performing Monte Carlo (MC) simulation. In the end, a short explanation of the working method of @RISK is provided. The applied methodology for contingency estimation is outlined, the input and output values of the model are tabulated and a screenshot of the constructed model is presented.

♦ **CHAPTER 5: SURVEY DESIGN**

To collect all the qualitative and quantitative data required for performing all palnned analyses the author constructed a questionnaire-based survey with four sections (namely: "Organisation Profile", "Project Profile", "Direct Rating of Risk Drivers & Risk Factors", and "Contact Information"). This chapter initiates with extensively reviewing the use of survey instruments in construction Project Risk Management (PRM) studies and argues on the necessity for also using a survey instrument in the study. The planning of the survey follows by presenting all the psychometric (validity and reliability) and statistical (precision and accuracy) concepts measured. The descripitive statistics analysis for the first section is presented with the use of pie charts and descriptive summary tables. Validity and reliability tests are performed with the aid of SPSS software. The results showed a satisfactory content validity with an Item-CVI value of 0.80. In respect to reliability: a satisfactory instrumental reliability was obtained with contingency coefficient C equal to 0.546 and regarding response reliability a satisfactory average intraclass coefficient correlation was obtained with ICC equal to 0.758 and Cronbach's alpha had a satisfactory value of 0.758.

♦ **CHAPTER 6: DATA ANALYSIS**

The results obtained from the execution of the Monte Carlo simulation are firstly collected for the five cost elemental categories (namely: "land preparation", "foundations", "substructure", "superstructure" and "finishes") and afterwards descriptive statistics are deployed in order to draw observations regarding the data behavior. A case project is examined (i.e. the 10th project) and the same observations are drawn for the whole portfolio of the 22 projects. Interesting findings were derived on a portfolio-level such as that: (a) all cost elemental data are approximately symmetrically (with an average kurtosis value of 3.0), (b) the minimum and maximum values of the simulated costa data are outliers; a sign of possible overestimation and (c) the data normality test indicated normality for all cost categories.

A swicht to Project Case 14 was decided as the specific respondent was the only one capable of providing realistic values for the AHP, which will be later discussed. When correlations were assumed a positive and strong correlation was found among all cost categories, verifying in parallel a monotonicity and linearity pattern.

The simulation results obtained with @RISK for the Case Project 14 were plotted with the aid of MATLAB so to enable comparisons between two scenarios; "with (including) correlations" and "without (excluding) correlations". The two scenarios' Probability Density Functions (PDFs) and the two corresponding Cumulative Density Functions (CDFs) were compared on the same graph. It was found that when correlations are included the probability of meeting the base estimate is increased by +7% and the mean estimate value is slightly decreased by -0.09%. The scenario of "excluding correlations" produced a higher estimate by +3.39% at the desired confidence level (p=71.57%); a sign of underestimation if correlations are not considered. Both standard deviation and variance were underestimated when correlations were excluded; a very important finding verified by previous studies.

The chapter concludes with an extensive analysis of the risk assessment process for all individual risk factors and their cost risk drivers. The comparative scatter plots showed that "substructure" cost risks influence mostly the project final cost with scoring the highest standard deviation (SD=€15018.91) and "land preparation" cost category has the least influence on the project final cost with the smallest standard deviation (SD=€1536.28). All five cost elements were found positively and strongly correlated to the final project cost. The author ranked all 27 individual risk factors both on the basis of their change provoked on mean and on the basis of their change provoked as % of the mean for each cost category.

The direct rating of the four cost risk drivers is presented with a detailed presentation of the Analytical Hierarchy Process (AHP). For readers not familiar with performing AHP an extensive overview of the procedure is presented in Appendix 18. The ranking of cost risk drivers derived from the MC simulation was in agreement with the one derived from the AHP. Schedule cost risk drivers were found as the most important, second the quantity ones, followed by unit cost and last were the global risk drivers.

♦ CHAPTER 7: CONCLUSIONS & IMPLICATIONS

This chapter concentrates all the improvements achieved throughput the logic proposed and the model applied by the author. Fistly, on a project-specific level (Case Project 14) it was found that: (a) the probability meeting the base estimate was decreased by -0.61% and the revised estimate was smaller by -0.02% comparing to the intial one, and (b) the total project's contingency was decreased by -2.82%, the revised contingency was very slightly smaller by the initial one as a percentage of the estimate by 0.07% and "finishes" and "substructure" cost categories scored the highest contingency amounts.

The efficiency of the traditional procurement was evaluated, on a project-specific level (Case Project 14), based on three measures: (a) the degree of risk transfer, (b) the project delivery inefficiency and (c) the Cost Performance Index (CPI). A simple geometrical representation method was used to visualize the cost improvements achieved from the pre-ΔM to the post-ΔM condition. After plotting the pair co-ordinates (ΔM, ΔP), an improvement was achieved for all cost categories apart from the "superstructure". This improvement is expressed in € 401.40 less cost risks transferred to the client side and an average reduction in project delivery inefficiency by -2.70%. The case project's CPI was very slightly increased by +0.02%. On the contrary, the average cost performance improvement achieved for the entire portfolio was equal to +2% for the 14 out of the 22 examined projects.

On a portfolio-level the model (a) delivers an average increase of incentive profits by € 6707.42 which represents the 1.91% of the average portfolio's value (€ 349994.32) and (b) requires an average reduction of contingency by -3.68%.

All research questions, as formulated in the second chapter, are finally answered one by one. All questions were addressed on project-specific level (Case Project 14) and where was possible on a portfolio-level. In respect to the fisrt and second research question the cost risks transferred were computed and an opportunity for average reduction by -35.65% was revealed, linked to an average increase by +5% in probability of meeting the estimate. This is a very fundamental finding as it uncovers an important benefit for the contractor; the improvement of meeting his/her intial estimate. The second fundamental finding is that if a contractor reduces on average the contingency reserve by -4.32%, he/she will be benefited by an increase of +6.17% in the incetive profit element.

It is not surprising that contingencies and profits follow an inversely proportional relationship on a project-specific level. The study concludes with an interesting result that this relationship still holds for the entire portfolio as strong negative correlation was found between incentive profits and contingencies in both conditions (pre-ΔM and post-ΔM). The incentive profits in both conditions and contingencies in both conditions were found strongly and positively correlated.

♦ **CHAPTER 8: STUDY LIMITATIONS & FURTHER WORK**

The study is limited by three main industrial factors which are discussed as: (a) the small sample, (b) the industry's structure and character, and (c) the industry's declining performance. The technical limitations are related to the lack of model's verification and validation and the scale used in the AHP. For further research the author proposes a pseudo-code for optimal contingency setting by contractors with the aid of @RISK and a recommendation for the client in order to achieve a transparent and collaborative comparison of contingencies in the post-bid phase with the awarded contractor.

ABSTRACT

Abstract:

Purpose

To investigate the effect of risk sharing decisions of contractors on traditionally procured building projects' cost performance. The behavioral side, explaining how contractors set contingencies in order to share more or less cost risks and the technical side, explaining how contractors quantify on-site risks will reveal improvements in DBB contracts.

Design/Methodology/Approach

A systematic literature review provided input for the construction of a tailored list with 27 on-site risk factors. A four-sectioned questionnaire-based survey was developed for enabling data collection. The organizational data were analysed with the aid of the SPSS software and partially plotted in OriginPro. The project-specific data were simulated with MC method (in @RISK) to obtain risk-adjusted estimates.

Findings

Organizational and project characteristics were analysed from 22 building projects. The survey scored a response rate of 63%. If a contractor applies the porposed cost risk analysis model and revises his/her profit-related decision (ΔM), the base estimate and the risk sharing ratio then the following results are obtained. The results are distringusighed in three categories, as follows:

Predicitve (on project-level)	Base estimates	-2.50%
	Actual costs	-2.52%
	Contigencies	-4.32%
	Cost risks transferred to client	-35.65%
Exploratory (on project-level)	<u>Riskiness of:</u>	
	Cost categories	"Substructure" most risky, "Land preparation" least risky
	Cost risk drivers ranking of importance	1st: Schedule, 2nd: Quantity, 3rd: Unit Cost, 4th: Global
	Project delivery inefficiency	-2.70%
Control (on project-level)	Probability meeting the base estimate	+5%
	CPI	+0.02%
(on portfolio-level)	CPI	+2%
	Incentive profits	+1.91%
	Contigencies	-3.68%

Originality/Value

The study addresses a lack of debate regarding the investigation of risk sharing decisions in traditional procurement from a contractor's view. Its uniqueness is based on two facts: (a) it highlights how risk sharing decisions in the post-bid phase affect project's cost performance and (b) which contingency levels could enhance higher incentive profits. Both facts are influenced by the central profit-related decision based on which the contractor revises his/her estimate and risk sharing ratios correspondingly. The study adds-value especially for the case of the Greek construction industry as no similar study has been previously executed, with all

practical implications derived being generalisable.

Key-words: Risk sharing, contingency estimation, Monte Carlo simulation, AHP, contractor

Type: A questionnaire-based survey

> *"It is better to be roughly right, rather than precisely wrong."*
> *John Maynard Keynes*

ACKNOWLEDGMENTS

This thesis describes my research about the potential of minimizing cost contingencies of contractors and achieving higher cost performance in traditional building procurement. The review of risk management models and risk sharing bibliography was necessary to set a ground for the research development A cost risk analysis model for contigency estimation is adopted from Hobbs (2010) which enabled the author to obtain simulation results.

The idea generation was nurtured from the moment I realized that large Dutch contractors, such as BAM B.V. and Witteveen+Bos B.V. tend to fiercely switch away from traditional procurement to more innovative types contracts. This reality intrigued my interest in extending the research in the behavioral and technical dimension in cost risk estimation and contingency setting in Design-Bid-Build contracts.

The report forms the final piece of my Master's program in Construction Management and Engineering. The moment has come for me to look back on my research efforts and to thank those who contributed to its outcomes.

My gratitude goes first to my academic supervisors; Associate Professor Saad Al-Jibouri and Professor Joop Halman at the University of Twente for their scientific input and helpful criticism. Prof. Saad supported me, as the direct supervisor, during this entire endeavor by providing constant feedback and dealing with my schedule arrangements. Although nobody was 100% certain about the research topic from the beginning, after spending more than 3 months, we achieved to concretize a study leading to practical and theoretical implications. Prof. Joop provided insightful feedback and ideas in draft versions. All his "WHYs?" led to the refinement and the use of updated models, relevant key-terms and practices in the area of risk management.

Secondly, I would like to thank Mr. Dionysios Panagiotopoulos and Mr. Konstantinos Seferiadis, both members of the Technical Chamber of Greece (TCG), who enthusiastically encouraged the development of this study and provided me with input and resourceful connections in the "pursue of participants".

Given that I was asked to keep the anonymity of the survey's raters, I have to recognize the value of their practical guidance. The five senior engineers and members of the Technical Chamber of Greece formed the *Content Evaluation Panel*. The TCG is the public professional body that serves as the official technical advisor of the Greek state and is supervised by the Hellenic Ministry of Environment, Physical Planning and Public Works. The Technical Chamber of Greece is a member of the European Council of Applied Sciences and Engineering (Euro-CASE).

I cannot omit all the 22 participants of this study without whose input this research would have never been implemented. I truly thank them for sharing their cost data, risk perceptions and experiences with traditional building procurement.

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Arnhem, 20/4/2015

Dimitrios Kordas

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ACRONYMS

A	AAA	American Arbitration Association
	AACE	Association of the Advancement of Cost Engineering
	AHP	Analytical Hierarchy Process
	APM	Association for Project Management
	ATOM	Active Threat and Opportunity Management
B	BOT	Build-Operate-Transfer
	BQ	Bill of Quantities
	BPM	Business Performance Measurement
C	CMAA	Construction Management Association of America
	CM@R	Construction Manager At Risk
	CPI	Cost Performance Index
	CPM	Critical Path Method
	CRMS	Construction Risk Management System
D	DB	Design-Build
	DBB	Design-Bid-Build
	DBOM	Design-Build-Operate-Maintain
	DoT	Department of Transporation
F	FERMA	Federation of European Risk Management Association
	FHWA	Federal Highway Administartion
	FIDIC	Fédération Internationale Des Ingénieurs-Conseils
G	GARP	Global Association of Risk Professionals
	GC	General Contractor
	GCW	Government Contract Work
	GMP	Guaranteed Maximum Price
H	HHM	Hierarchical Holographic Model
I	ICE	Institution of Civil Engineers
	IPD	Integrated Project Delivery
	IRM	Institute of Risk Management
	ITA	International Tunneling Association
J	JV	Joint Venture
K	KPI	Key Performance Indicator
M	MC	Monte Carlo
	MRMP	Multi-Party Risk Management Process
O	O&M	Operation and Maintenance
P	PCO	Project Cost Outcome
	PFI	Private Finance Initiative
	PERT	Program Evaluation and Review Technique
	PMI	Project Management Institute
	PMBoK	Project Management Body of Knowledge
	PPP	Private Public Partnership
	PRAM	Project Risk Analysis and Management
	PRINCE	PRoject IN Controlled Environments
	PRM	Project Risk Management
	PRMIA	Professional Risk Managers' International Association

	PUMA	Project Uncertainty MAnagement
R	RADM	Risk Allocation Decision Making
	RAMP	Risk Analysis and Management Process
	RAMPA	Risk Assessment Methodology Property Analysis Ranking
	RBS	Risk Breakdown Structure
	RM	Risk Management
	RFE	Request For Estimates
	RFP	Request For Proposals
	RFRM	Risk Filtering, Ranking and Management
	RICS	Royal Institute of Chartered Surveyors
	RMA	Risk Management Association
	RRF	Risk Ranking and Filtering
S	SRA	Society for Risk Analysis
	SFCA	Standard Form of Cost Analysis
	SHAPU	Shape Harness and Manage Project Uncertainty
	SPM	Stakeholders Perspective Measurement
T	TCC	Target Cost Contracts
	TRAH	Technical Risk Assessment Handbook
	TPRM	Two-Pillar Risk Management
W	WBS	Work Breakdown Structure

ICONS / SYMBOLS

Icon / Symbol	**Explanation**
◊	Primary explanations or definitions of a key-term, method, process, system
□	Decomposition of the primary explanations or secondary definitions
	Important note or further elaboration on a term that will be deployed later in the report. It grounds the author's motivation on the research area.

FIGURES

TABLES

CONTENTS

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INTRODUCTION

Chapter **1**

1.1 Project background

1.1.1 Nature of the construction industry

Construction does not behave as one whole industry but like more a "conglomerate of industries", an industry of industries or a "meta-industry" (Palmers 2003). The building sector is a loosely coupled system which exhibits mainly characteristics of complexity (Dubois & Gadde 2002). This implies that all changes in the backbone of the construction product and process key-areas can have a high-impact on all stakeholders involved during the conceptual planning, the design, the procurement, the execution and the operation & maintenance (O&M) stages.

The nature of the construction industry is changing more than ever. The housing crisis in the US in 2008 proved that the trend towards commoditization of construction services result in margin compression for construction firms. Margin-related decisions are located in the core of this new reality which globally affects the procurement methods followed between clients and contractors and other key-stakeholders such architects, suppliers, and specialized building teams. The industry also is usually fragmented as a plethora of small-size or medium-size enterprises represent a significant proportion of the industry's output while only a small group of large corporations possesses multi-million projects portfolio.

Project initiators when they procure building projects treat construction procurement as a commodity or a buying decision. Building projects, without excluding any type of them, are not very complicated as modern contractors possess the know-how of standardizing designs, prototyping structural components such as roof panels and floor plates, and coordinating efficiently building teams. Thus the construction process becomes part of a highly competitive market. Contractors try to balance their risk-ownership while achieving a winning bid. Contractors when formulating a competitive estimate have to price their risks and inevitably to take into consideration several variables.

Koen (Koen 2003) specified a 'particular rationality' based on the trend of change on which the construction industry operates. All types of engineering and sciences fall under the same heuristic rationality category expressed by Koen as follows:

"At the appropriate point in a project, freeze the design, allocate the resources as long as the cost of not knowing exceeds the cost of finding out, allocate sufficient resources to the weak link and solve problems by successive approximation."

If the aforementioned heuristic could be taken for granted then the construction industry shouldn't have received so much critique on economic, governmental and political level. At least, we wouldn't keep asking the simple "Why is construction so backward?" (Woudhuysen & Abley 2004). This drives towards the in-depth research on the impeding factors affecting the *Triple Constraints* (known also as the Iron Triangle). According to Wysocki (Wysocki 2009), five operating constraints exist for all types of projects: (1) scope, (2) quality, (3) cost, (4) time and (5) resources. For the sake of simplicity and complying with the study's scope the focus is paid on the classic triplet as shown in Figure 1.

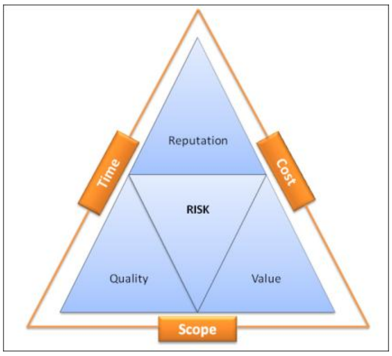

Figure 1: "Triple

1.1.2 Naming the pain

The core deliverable for all contractors is the handing out of projects on time, within budget and achieving other project objectives, such as energy efficiency and multi-functionality. Project control is a complex task undertaken by project managers which involves constantly measuring progress, evaluating plans and taking corrective actions when required (Kerzner 2013). Although the software technology has offered many project control programs and techniques contractors struggle with successfully achieving cost and time objectives (Olawale & Sun 2010). Thus the two principal components in traditional construction projects are very likely to fail regardless the project's type and location.

Many projects are suffering from serious cost overruns; a sign of inefficient risk-sharing agreements. Different scopes have been developed in order to approach the phenomenon of cost escalation. Akinci and Fischer (Akinci & Fischer 1998) developed a knowledge map to visualize the interference of uncontrollable factors and cost overrun variables from the contractors side. Other scholars verified cost overruns throughout extensively studying a series of transport infrastructural projects (Flyvbjerg et al. 2003).

Delays are often characterized as construction risks, too. For the UAE construction industry, Faridi and El-Sayegh (Faridi & El-Sayegh 2006) studied through a detailed questionnaire the top10 causes of delays. They revealed that 50% of the UAE construction projects experience delays.

Regarding cost/time delays in high-rise buildings procured in Indonesia 11 variables were detected as responsible for cost overruns (i.e. design changes, poor labor productivity, inadequate planning, materials shortages, etc.) and 7 variables were observed for driving time overruns (i.e. inaccurate quantity take-off, lack of experience of project type, materials costs increased due to inflation, etc.) (Kaming et al. 1997). A similar study was undertaken by Mansfield, Ugwu and Doran (Mansfield et al. 1994) in Nigeria. This research detected the most significant factors causing delays and cost escalations by carrying out a questionnaire survey among 50 construction professionals.

All these studies above bring into the light that contractors fail to apply or to adapt project control models. The reason behind this reality, according to the author, is behavioral as well as technical inaccuracy of estimates derived from a tendency for setting unrealistic contingencies. Following this logic, I proceed with presenting an approach on the technical side and the behavioral side of risk-related fields which are the grounding motives for this study.

1.1.3 Identifying the research gap

Project initiators and owners, with their suppliers tend to minimize in their agreements the risks they bear. In procurement of construction projects public clients (e.g. state, municipality) usually bear more risks during the execution phase, in contrast to the case of private clients who are more risk averse. In risk management of construction projects, the buyer (owner) has two principal instruments at his disposal: 1) the choice of time and resources put into engineering and design (project specification), thus affecting the level of risk in the project, 2) the sharing of risk as specified by the incentive contract for the contractor (Olsen & Osmundsen 2005). Both tools are cost-driven and imply that the buyer will have to afford the costs of risks.

The market-based cost risk models and the pricing strategies do not seem to be effective in improving risk-sharing agreements. An explanation could be that although there are three major types of setting pricing objectives: (1) cost-oriented, (2) competition-oriented, and (3) demand-oriented, the current pricing strategy in construction is predominantly cost-based (Mochtar & Arditi 2001).

These cost-based estimating models lead inevitably to increased contractual claims and legal disputes (Zaghloul & Hartman 2003). The problematic nature of construction contracts has a negative impact on the formation of fair risk sharing agreements which leads to the frequent malpractice of risk misallocation (Jergeas & Hartman 1994). Lavander (Lavender 1990, p.223) saw also the additional claims as a very expensive element in traditional construction procurement.

In traditional building procurement when cost-based models are applied poor cost performance is frequently reported. Naïve pricing and risk allocation by aversion lead to increased legal claims and disputes (Figure 2). The connection between risk-sharing contractual decisions and poor cost performance was also identified in the Malaysian construction industry (Ramanathan et al. 2012). The traditional contracts favorite clients who on the ground of the lowest submitted bid have to select the most competitive contractor. Contractors, on the other side, have to plan a well-structured cost estimate after having outsourced some work packages, if agreed and calculated their cost/schedule risks. Then contractors submit their offers and compete with "closed books" on a bid round. Clients have to choose the winning bid, then both parties "open their books" in order to agree on the compensation mechanism and finally the selected contractor initiates the actual project's execution.

The problematic situation arises when both parties reach an agreement after the contract award and contractors demand additional compensation from their clients in order to cover unexpected costs occurred during the project's execution or vice versa. The Greek construction industry is not an exception of this vicious relationship. Having the fear of on-site risks and client's risk aversion, contractors tend to design a contingency amount and embody it into their bids so to be covered for unexpected risk events which clients would not be willing to compensate. Contractors almost inevitably will include contingencies in their bids (Figure 3).

If bid models were always effective then contractors should be able to determine and submit optimal and bid prices without the necessity of setting contingencies. The pricing strategies and their numerical bid models such as the Carr's, Friedman's, Gate's model as discussed in Crowley (Crowley 2000) and fuzzy-set models as reviewed by Paek, Lee and Ock (Paek et al. 1993) cannot outline the risk pricing behavior of contractors. Understanding how contractors take risk-sharing decisions and consequently defensive strategies (setting contingencies) will assist to look deeper into the whole cadre of the price-oriented traditional procurement. This study will drive research towards designing proposals for setting optimal levels of contingencies before the biding rounds and achieving an overall improved cost performance (improved Cost Performance Index).

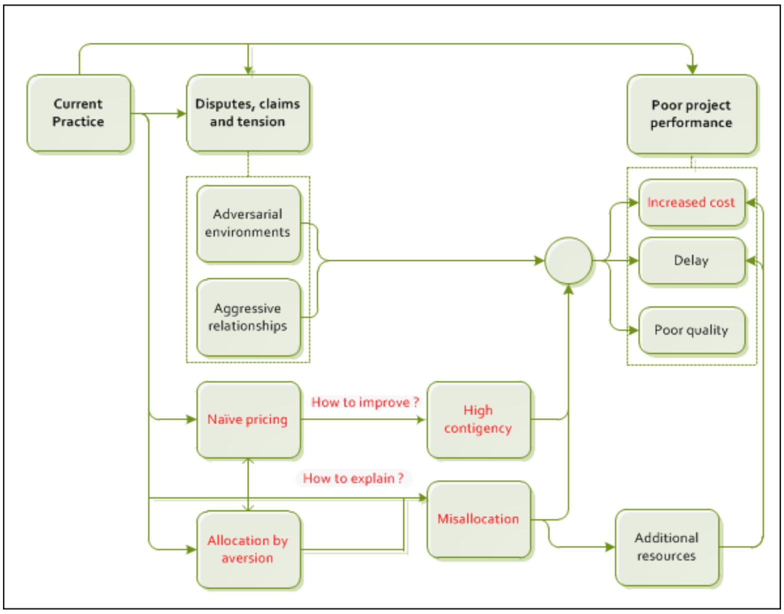

Figure 2: Hypothesized causal factors for poor project performance (AlSalman & Sillars 2013)

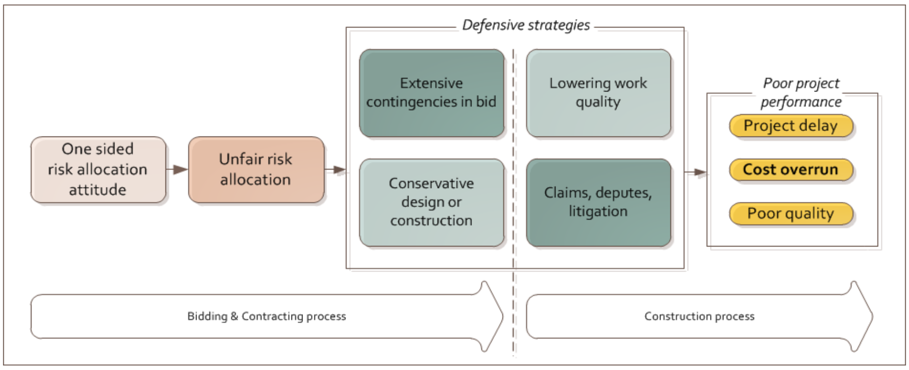

Figure 3: Problematic risk allocation diagram (Pipattanapiwong 2004)

A practical example of this problematic situation is provided below so to enable the reader in interpreting where the research gap is located and how the study will address it.

A practical case in traditional building procurement in the Greek construction industry

In traditional building procurement contractors after receiving the Request for Proposals invitation, design and submit their most competitive offer. In the process of preparing their cost estimates contractors may collaborate with a group of internal or external estimators. When contractors compete on a specific contract do not know the prices, the reductions or the contingencies set by the other competitors. It is thus a "closed book" process so bidding rings and in general collusion phenomena to be avoided.

For the awarded the contract contractor, the price is given as follows:

$$Price\ (Contract\ value) = Fixed\ amount\ (Cost\ estimate) + Incentive\ profit$$

For example if a contractor bids a project for € 1,000,000 (contract value) this means that in this amount a contractor embodies also his/her expected profit. To visualize this practically let's consider a case of a building project with five cost categories: land preparation, foundations, substructure, superstructure and finishes where a contractor sets a pre-determined level of profit, as shown below:

Cost category	*Profit level (% of cost estimate)*	*Profit value (€)*
Land preparation	2	20,000
Foundations	5	50,000
Substructure	5	50,000
Superstructure	2	20,000
Finishes	3	30,000

So it can be deduced that € 170,000 is the contractor's profit in this case; an amount however that the client is not in position to precisely know. The client cannot be aware of the contractor's profit decision and in addition to this; the client cannot assume that in the bid price a contractor will include any contingencies. Consequently the client in order to minimize his/her possible losses due to unexpected risk events that may occur he/she will try to reduce the "profit window" of contractor in a traditional contract. More specifically the client will try to make a mutual agreement with the selected contractor on the *maximum allowance of cost risk*, which according to the more recent clause (2013: no reference can be provided due to lack of an online published source) in the Greek construction industry is equal to 30% of the cost estimate. According to the circular letter of the Technical Chamber of Greece (TCG) the maximum amount of cost risk allowance in 2010 was specified at the 35% of the contract value[1]. Below the relevant legal clause is provided:

(Presidential Decree 696/74) Clause 89. Control and Monitoring of studies during construction
"The additional compensation for the control of the submitted study from the client to the contractor is equal to the 15% of the corresponding cost estimate. The additional compensation for the monitoring of the study during construction is equal to 25% of the corresponding cost estimate. If the compensation agreed is higher than the projected one, then the agreed one is considered."

For the client then, the price is given as follows:

$$Price = Contract\ value\ \pm\ 35\% \times Contract\ value$$

[1] http://portal.tee.gr/portal/page/portal/TEE_HOME/TEE_HOME_NEW/anakoinwseis/egkyklios_TEE.pdf

The formula above does not imply that a client will always make use of this clause. It aims to provide the legal range within; the two parties can claim maximum compensation from each other.

Consequently the client pays to the contractor the fixed amount of € 1,000,000 but if during the project's execution additional costs occur due to unexpected risks he/she may require from the contractor to cover this range of extra costs within the legal limits. If the contractor can legally prove that this "extra money" cannot or should not be compensated by him/her then the client will have to suffer the loss.

A sub-clause is also negotiated between the two parties. The client will often try to motivate the contractor to claim a percentage of the *maximum allowance of cost risk* that he/she could afford based on his/her financial capability. This sub-clause is however a very subjective and arbitrary decision which often contractors deny to take as they will be legally tightly limited and thereafter clients will be able to claim additional compensation de facto.

Considering the described problematic situation between clients and contractors it becomes evident that a contractor will work towards minimizing the amount of *allowance of cost risk* and the client will work towards maximizing the amount of *allowance of cost risk*. Of course the contract agreement would be undisturbed if no risks arise during the actual construction of a building project because simply no risks means no application of the *maximum allowance of cost risk*. Consequently the client pays the € 1 mil. to the contractor and then the process proceeds to the actual construction.

In reality, there is a plethora of on-site risks that may occur and consequently contractor will tend to avoid taking risk ownership, simply will deny compensating their client for the additional costs as they see these unexpected events as out their responsibility area. However contractors to remain competitive in the bidding process minimize their profit elements and apply a contingency amount so to be covered against possible risks. The level of contingencies, set in the pre-bid phase, influences the extent to which contractors will share risks, in the post-bid phase, wherein they co-decide with their client their risk-sharing agreement.

"Negotiating strength has a major impact on my projects cost performance. The project's client has a strong negotiating position pre-bid against a candidate contractor. The contractor usually has the superior position thereafter. The legal framework however enhibits a contractor's actual negotiating power as clients are more than "expected" protected against on-site risks. Thus, as being a contractor I include high contigencies in my offers so to remain both competitive against other bidders and attractive enough for my client by offering considerable margin reductions in some work packages."

(A participant's view)

From this practical example as described above and taking into consideration the legal framework of traditional building procurement within the Greek construction industry, the following logical questions emerged:

- Do contractors prefer setting pre-bid high contingencies or accepting more cost risks post-bid?
- How likely is for a contractor to meet the base estimate without changing his/her profit and how likely if he/she would have revised the profit element and the base estimate?
- How much more or less cost risks contractors will share if they revise their base estimates?
- What are the implications for the contingency levels before and after contractors revise their base estimates?
- Which on-site risks, of the provided list, are perceived by contractors as more important than others?
- Is there any relationship between profits and contingencies?

All the aforementioned questions reveal the research gap in traditional construction procurement regarding risk sharing agreements under the limitation of industry's nature and legal framework.

1.2 Structure of the report

Success of a research project is largely achieved through dedication and a steady methodological approach to the work. Research activities are primarily divided into two types; basic and applied research (Bickman & Rog 1998). The purpose of basic research is to expand knowledge. On the contrary, applied research is realized in an open environment wherein results often deliver a type of a design.

This thesis starts as an initially basic research and continues mainly as an applied research, aiming to improve industry's stakeholders understanding in the risk-sharing problem. The intent of the author is to primarily contribute towards offering a deeper analysis of how contractors decide on contingencies setting in the pre-bid phase and how they take risk-sharing decisions in the post-bid phase. The end-product of the research will reveal that contingencies reduction can guarantee contractors re-winning the contract and increasing the probability of meeting their initial cost estimate by applying slight profit decreases/increases in each of the five cost categories of a building project.

Typically the research process consists of two major processes, "planning" and "execution" (Bickman & Rog, 1998). The planning process consists of a *definition* phase (chapter 1) and a *research design* (*chapter 2*) phase. In the definition phase a broad area of study is defined and the research topic selected is outlined. In the research design phase the research idea will be grounded within a research supporting framework, the problem's scope will be explained and the research model will be designed. The research questions, goal, and objectives will be also included to clarify the direction towards how data will be gathered and utilized. The *literature review* section (chapter 3) is considered as a vital part as it provides practical motives and scientific input for proceeding with the study. The execution process is the actual application of the research design and the reporting of results. *Model design* (chapter 4) initiates the execution process, in which the cost risk analysis form is discussed and explained in detail. The data collection tool is structured in the fifth chapter *(survey design)*. The *data analysis* section follows (chapter 6) and its *results and implications* are discussed (chapter 7) and *further research* and *study's limitations* are discussed in chapter 8.

This thesis is primarily a research report. The report is structured according to the framework described in the book of Kempen and Keizer (Kempen & Keizer 2000). This framework divides the research into four main phases: 1) Orientation, 2) Research, 3) Solution and 4) Implementation. Below, Figure 4 presents an overview of the thesis structure based on the specific framework.

□ *"Orientation phase"*
Chapter 1 introduces the reader to the changing nature of the construction industry, exposes the core drawbacks of time and cost escalations with which contractors usually deal with and outlines how risks shape new trends and needs in traditional building procurement. Subsequently, the second chapter discusses the entire research methodology applied in this study. This chapter states the problem by precisely identifying the research gap in traditional building procurement, clarifies the wide research goal within the subsequent research objectives assigned to the formulated research questions. Lastly the research strategy which is followed is outlined step by step.

□ *"Research phase"*
The theoretical package of published work is aggregated by means of an extended literature study (chapter 3). First a separate search process was conducted concerning the notion of "risk-sharing" followed by key-words such as "schemes", "agreements", "incentives", and "networks" within the construction contracts context. Thereafter, the use of "risk efficiency" and "risk transfer" was examined. Thirdly, the whole spectrum of risk management operations in the procurement of building projects was approached in combination with the most prevalent outcome of inefficient risk-sharing; risk misallocation. Included to this part, qualitative and quantitative risk management models are summarized.

□ *"Solution phase"*
In the beginning a model for line by line cost risk assessment is set up. The research model (chapter 4) utilizes as input data obtained from a questionnaire survey and proceeds with the simulation of them by deploying Monte-Carlo method in excel sheets with @RISK add-in. Interested readers in understanding the simulation process followed and how the input values were transformed into outcome curves (i.e. probability density functions, cumulative curves, tornado graphs) are advised to read this chapter. Chapter 5 ("Survey Design") follows thereafter by designing the survey instrument and collecting necessary input for the three section included, as can be seen in Appendix 8. The output derived from the descriptive statistics analysis, the simulations and the other quantitative methods (AHP) will be presented in chapter 6.

□ *"Implementation phase"*
Then the report proceeds with presenting the improvements achieved and some statements that potentially could provide ground for setting statistical hypotheses and forming mathematical relationships (chapter 7: "Research Findings"). The study concludes presenting some limitations and structuring a future work proposal into a flowchart. Potentially the idea proposed, in this chapter, could lead to the integration of a code regarding contingency minimization within the @RISK based cost risk analysis form (chapter 8).

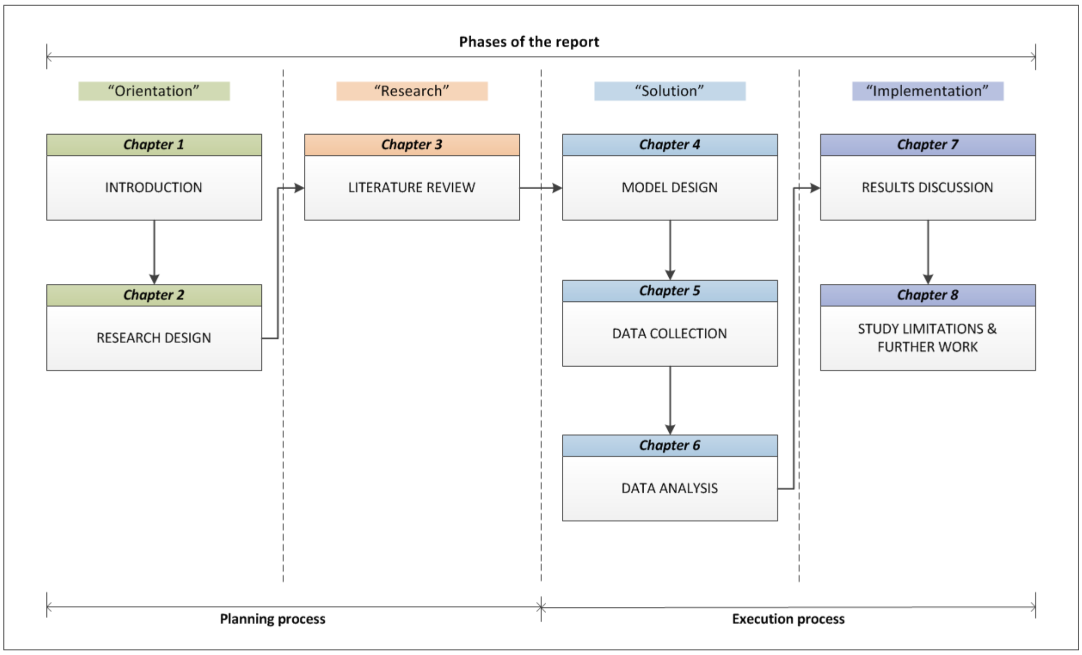

Figure 4: Structure of report

RESEARCH DESIGN

Chapter **2**

2.1 Historical observations on traditional building procurement

Traditional construction procurement became the main route to procure constructed facilities in the UK soon after the industrial revolution of the nineteenth century and to date, it remains the dominant procurement strategy in the UK (Rowlinson & McDermott 1999). As it was logically noted by Akintan and Morledge (Akintan & Morledge 2013), traditional procurement is mostly preferred by one-off clients, who seldom engage in construction. Traditional building procurement is not only favored by clients. In their article, Skitmore and Love (Skitmore & Love 1995) found that program managers opt for the traditional lump sum method to a significant degree of 42%.

In contradiction to the widely use of traditional procurement in recent times, the use of the traditional construction procurement strategy to procure facilities is falling across the UK (CIOB 2010). The adversarial relationships engendered in traditional construction procurement inevitably lead to:

- poor collaboration between clients and contractors, increased conflicts, and failure of contractors to satisfy clients' needs (Eriksson et al. 2008), and
- a logical swift towards other procurement methods such as Design-Build contracts (Ojo et al. 2006; Eriksson et al. 2008).

Other authors develop a more market-dynamics approach for explaining the client-contractor relationship. The competition-cooperation continuum in construction was deployed by Eriksson (Eriksson 2008) to assess the degree to which clients base their procurement decisions on competitive or cooperative choices. It was shown, that clients rely on competitive choices against their contractors in traditional procurement during the entire buying process. However, incompleteness in traditional contracts and inefficiency of risk-sharing clauses lead to a shift towards more integrated procurement packages, such as Design & Construct contracts.

Risk allocation decisions have been taken based on the known principles stating that: "The person best able to manage a risk should bear that risk". In the survey executed for the Australian Constructors Association it was revealed that, in many cases, this principle is no longer followed in Australia. This research uncovers considerable dissatisfaction among constructors as to how risk is allocated in a construction contract, with 61% identifying risk allocation as a pressure point. Evidence suggests that the traditional competitive approaches, which most countries are now moving away from, give rise to systemic problems with market dynamics in the construction sector (Atkin, 2006). It is argued that these traditional competition policies, due to the characteristics of the construction industry, create a business environment that encumbers innovation and dynamic efficiency (Ang, 2011). The traditional procurement system is once again found responsible for the poor image of the industry.

As risk allocation is a very critical part in any contract agreement, the study will explore (in chapter 3) the components affecting risk allocation decisions. These components will be used in an Analytical Hierarchy Process model to indicate which risk drivers are perceived as the most important for contractors in their cost estimates.

Modern construction is governed by a number of different types of procurement routes available for clients to choose from. Each different type of procurement has its own proponents and inherent strengths and weaknesses. Selection of optimal procurement systems is difficult, because even experienced clients cannot know all the potential benefits or risks for each system. Procurement is, therefore, a succession of 'calculated risks' (Tookey et al. 2001).

In the context of traditional building procurement, the study will use a group of 27 on-site construction risks which will be assessed with the aid of a cost risk analysis model (see in chapter 4) and thereafter the contingency levels embodied into cost estimates will be specified (see in chapter 7). This "succession of calculated risks" as discussed above enables the researcher to derive the required contingency amounts and draw practical conclusions.

2.2 Research proposal

The idea generation was built on the query of how and why, the traditional building procurement leads to inefficient contractual risk-sharing. In the beginning of the research proposal, the main obstacle was the unwillingness of contractors to claim their risk-sharing behavior and their perception on profitability change in respect to their post-bidding estimates.

Clients as was seen in the example (discussed in § 1.1) will tend to receive an additional amount by their clients if unexpected risks occur. Contractors often deny accepting risk ownership and will react by either betaking to juridical solutions or embodying contingencies into their estimates. Contractors add simply <u>a 10% 'contingency' onto the estimated cost which is virtually certain to be inadequate</u> and causes delay, litigation, and perhaps bankruptcy (Thompson & Perry 1992, p. 1).

The setting up of risk contingencies was observed in many industry-specific reports as an inefficient mean of enhancing project cost performance; a strategy that will be further discussed in the third chapter.

Objective (i.e. costs) and subjective (i.e. probabilities, impact values) data will be required to be obtained from contractors. The target group of the study consists of contractors who are operating in the Greek building sector and are bidding building projects under traditional contracts. All the contractors participated in the study have experienced cost overruns due to uncovered construction (on-site) risks and have entered into legal disputes with their clients. This section discusses: the problem statement, the project scope, the research model, and the research questions with the research goals and objectives.

The *problem statement* section deals with presenting the "*what"* part of this study. It initiates with the demarcation of the problem, a useful section to narrow down the variables assessed within the research model. Once the *demarcation of the problem* is described, the *scope of the problem* is outlined as in the study the author considers solely the contractors perception on risk-sharing.

The *research model* then follows, with an attempt to construct a conceptual model in respect to contractors pricing strategies when they are involved in traditional construction contracts for building projects. Lastly, the *overall research goal* is exposed and the *research objectives* with their correspondent *questions* are presented.

2.3 Demarcation of problem

A mean of scientific progress is the adoption of the scope of demarcation. Quay (Quay 1974, p.156) defined six modes of progressing scientific knowledge; the modes of (1) multiplication, (2) cumulation, (3) selection, (4) complication, (5) refinement, and (6) assimilation.

The mode of *selection* and *refinement* are deployed in the present study. Towards the *selection* direction two decisions were taken and have to be pointed out. Three choices with regard to the boundaries of the research should be pointed out before continuing: Firstly, the research focuses only on one type of construction projects. Building projects regardless their size (i.e. total surface, number of floors) or function (i.e. civil, defense, institutional) are investigated during this study. Secondly, there is a selection with regard to the project phase of building projects. The construction phase (execution) of building facilities is the stage considered in the study. This implied a very specific set of risks that contractors have to assess in their risk-sharing agreements with their clients. The third choice, already approached, is the traditional building procurement system. A short analysis of how the D-B-B method works and the effect of the bidding process will be provided below.

The *refinement* mode deployed to prove the scientific progress will be fully presented in the following section of "problem scope".

2.3.1 Selection mode

□ *"Why to focus on the construction phase?"*

Designing a traditional contract although seems a usual and simple task, it is a multi-stakeholder process affected by different drivers. Traditional procurement and traditional project management are often accused for limited input by the client's side during the design stages, resulting in a mismatch between project design and project execution (Vrijhoef & Koskela 2000). Contractors are often dealing with on-site risks derived from design variations or scope changes due to miscommunication between the architect and the client. In other cases, due to changes in materials' prices or violation of minimum wages contractors have to bear on-site risks that clients could have foreseen and act proactively so to be avoided. Clients do not want to get involved as they perceive all on-site phenomena being under the contractor's umbrella, although this is an unfair attitude. Consequently the construction phase becomes the process stage wherein the majority of risks are probable to emerge.

In a Design-Bid-Build contract a contractor will have to foresee how to react quickly and cost-efficiently to all potential construction risks. This implies that many negotiations will have to take place during the actual construction and many disputes may arise between contractors and clients leading to delays and poor cost performance.

The Malaysian construction industry experiences this conflictual reality as reported by Kong and Gray (Kong & Gray 2006), who identified serious delays in project delivery due to parties' disputes. They found, through an exploratory survey research, that the most prominent cause of disputes was the frequency of variations, with design and scope changes being a particular source of discontent.

Design variations and scope changes are transformed into cost construction variations. This costly reality implied a deeper view into the actual risk-sharing tactic between the two parties during the execution phase. Thus all these cost variations are set as core elements to investigate their impact on the cost performance of projects.

Lastly, the attention only on the execution phase is paid for effort investment reasons. In the actual construction phase the effort amount dedicated into the whole project life cycle is the largest one, proportionally to the rest stages. In the Professional's Handbook submitted to the Project Management Institute (PMI), it was found that 60% of the production time (Figure 5) involves all execution operations (Stuckenbruck 1981, p. 4).

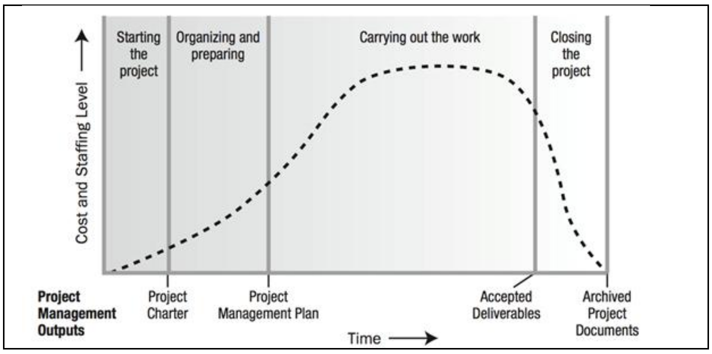

Figure 5: Project life cycle-left (PMI 2013)

□ "*Why to focus on building projects?*"

Two factors led the author towards selecting solely building projects. The availability of more buildings' contractors rather than infrastructure contractors, holding and willing to provide the needed data and secondly the familiarity of the researcher and contractors with elemental cost analysis led towards examining only building projects.

□ *"Why to focus on traditional contracts?"*
The traditional procurement system had been often characterized by lengthy tendering process, separated design & construction tasks, lack of innovative, open communication platform and fierce competition towards the lowest bid price. In particular, the traditional procurement requires a sufficiently lengthy tendering period, to allow for the complexity of the work be documented, bidders to read the documentation, visit the site, and prepare for the tender (Neighbour 2006). The traditional construction tender is a *hard-money* contract (Neighbour 2006, p. 9). Usually conventional procurement is selected by simple small to medium sized projects where time is not a critical factor (Taylor et al. 1991; Masterman 2003). Although this procurement system was the mostly applied in many countries as was seen above in Malaysia or in Australia (Love 2002; Davis et al. 2009) it started losing its favorability.

With time and cost to be increasingly considered as the core drivers, the usage of traditional contracting methods is declining. Past researches have been completed to argue on the decreasing popularity of design-bid-build contracts, such as in Malaysia (Rahman 2009).

The push for the adaptation to new procurement strategies is directly connected to the requirement of clients for higher satisfaction (Mbachu & Nkado 2006). In their paper, the authors showed that clients place premium importance on the accuracy and reliability of cost estimates, feasibility, and risk assessments regarding the quantity surveying services. This finding imposed a closer view to the cost estimates of building phases and their variations within traditional contracts.

The last reason for selecting only traditional procurement is the issue of cost uncertainty. The central proposition in cost uncertainty lies in the fact that only at the beginning stage of the construction phase some cost certainty can be evaluated. No one knows the final price of the construction project until to be completed (Turner 1990). Cost uncertainty is derived from price variations such fluctuations in materials' or labor prices/wages (Akpan & Igwe 2001) and scope growth (Akinci & Fischer 1998). This context of variations as was discussed before increases the contractual disputes and the claims raised from contractors towards their clients (Morledge 2002 p. 185).

This reality proves strongly that the lowest tender price may not lead to the achievement of the minimum overall construction cost and consequently additional costs may be demanded to be paid from contractors to clients and vice versa.

□ *"Analyzing the bidding process"*
A contract document set consists of specifications and bidding documents. Although the risks examined are construction-related, the risk-sharing process between clients and contractors is designed and included in contract preparation with an impact on the completion negotiations. In this sequence of activities for traditional building procurement, it is examined how before the contract award contractors estimate their potential risks and how they draw risk-sharing agreements after winning the bid.

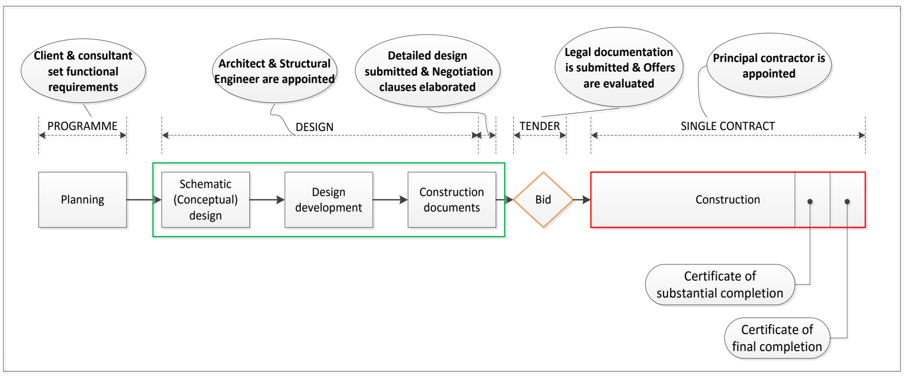

Figure 6: Sequence of operations in the traditional design-bid-build system of project delivery

A significant amount of projects in the construction industry are assigned through what is known as tender or bidding processes (Drew et al. 2001; Christodoulou 2010). Tenders serve as a competition arena for candidate contractors to submit their offers and then clients based on price-related criteria to select the most economically attractive proposal for their project. This price determination mechanism is frequently explained in bibliography (Li & Love 1999; Liu & Ling 2005).

In a usual bidding procedure a number of contractors compete to win and undertake the construction of a project by submitting sealed proposals until a deadline date set by the project owner. Given that all project-related parameters are equal for all candidates, the contract will be awarded to the competitor who submitted the lowest bid (Chapman et al. 2000).

Thus the coin has two sides in a traditional bid round. The easy one is of the client, who has to decide very straightforward upon price and time criteria. The difficult part lies to the contractor's side who has to consider on what price to bid to gain the project. This is probably one of the most difficult decisions management has to face during the bid preparation (Li & Love 1999).

This study does not focus on the manner that contractors follow to formulate their bidding decisions. Competitive bidding has been extensively researched (Shaffer & Micheau 1971; Kim & Reinschmidt 2006; Takano et al. 2014) and is a very popular topic in construction research since the two seminal probabilistic models of (Friedman 1956; Gates 1967), the updated model of Carr (Carr 1982) and the research of Runeson and Skitmore (Runeson & Skitmore 1999) lead to the formulation of the *Tendering Theory*.

The bidding stage is a complex decision stage for all contractors, as the intense competitive pressures in the construction industry often push contractors to substantially decrease their profit margins in order to deliver a competitive bid and win the tender (Drew & Skitmore 1997). It is frequently reported that it is not rare to see the winning bid include a near zero-profit margin (Chao & Liou 2007). This phenomenon of bid underestimation is also highlighted in further studies (Fayek 1998; Yiu & Tam 2006) who tried to establish a relationship between the probability of winning the contract and the level of the profit margin, as a market penetration strategy. Tenah and Coulter (Tenah & Coulter 1999) had identified a similar phenomenon, where contractors were bidding even below their actual costs to win the tender, although this strategy does not guarantee successful results for the contractor.

It should be pointed out that it is out of scope of the present study to investigate the relationship between the probability of winning the contract and the level of profit of contractors. This study is limited to the post-bidding period of a traditional tender (Figure 6).

The reason behind this choice is to introduce the profit-element and enhance a profit-related decision to contractors so to extract the most honest cost judgment when providing their base estimates.

The above context of bid decision-making of contractors implied a necessity to include in the research framework profitability throughout the "reimbursement" dimension as a possible driver in the risk sharing perception of contractors. The supporting framework will be provided in a next paragraph.

2.4 Problem scope

The logic behind all construction procurement models is that each participant wishes to obtain as much as possible from the process in terms of its own financial rewards. Given the fact that the process takes place in a competitive market there is a cycle of fluctuating pressure on prices at all times. A downward pressure thus forces the contracting participant to look to alternative means to recoup its profit (Rowlinson & McDermott 1999, p. 31). This initially implies thinking towards the profitability change as a strategy for winning a bid in a competition. It will be seen below that this strategy will be taken into consideration in the study's scope – as was also stated above when referring to the bidding process.

However contractors often adopt a claims-based behavior as they perceive too much risk to be transferred on them. This climate stimulates reductions in quality and functional performance. The client usually responds to this reality by utilizing an external project coordinator for monitoring the contractor's behavior and foresees possible disputes. This relational arena is a vicious cycle of negative behaviors (Figure 7). As can be seen from the figure this results in a vicious cycle of negative behaviors. One way of avoiding this model, which is based around the traditional strategy, is to adopt alternative contract strategies. The focus on the contractor's perspective is based on the tight interconnections between contractors and his suppliers, sub-contractors and the client's resources shared with him (Figure 8).

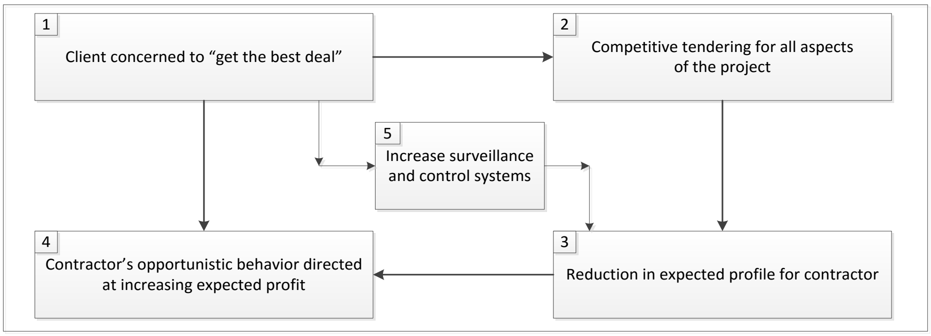

Figure 7: Vicious circles in construction procurement (Curtis et al. 1991)

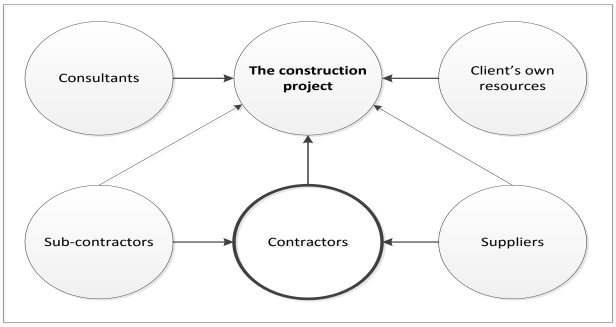

Figure 8: The position of a contractor in traditional procurement

□ *"The cost side in project success"*

The extent to which cost is the central decision-criterion for clients to decide on the selection of their contractors is researched by many scholars. In the pursuit of identifying and ranking the "critical success factors" for pre-qualifying contractors and their bids some research has been already completed. Financial soundness, technical ability, management ability, and HSE performance are ranked as of primary importance (Hatush & Skitmore 1997). Finance, among personnel, technology, and experience is ranked as an influential decision-making factor too (Kumaraswamy 1997). In the same context of prioritizing success criteria, Songer, Molenaar, and Robinson (Songer et al. 1996) found that UK-based clients when judging the overall project success, they rank "delivering on or under budget" the project as the most significant factor for a sample of 137 clients.

Shenhar, Levy and Dvir (Shenhar et al. 1997) proposed that project success is divided into four dimensions (project efficiency, impact on customer, business success, and "within budget?" future preparation) which are time-dependent. Several project success models have been developed in the area of project management in order to clarify measures and key-indicators of project performance while combining it to product integrity requirements. Atkinson (Atkinson 1999) focused on the "Iron Triangle" of Cost-Time-Quality as success-related reference. Lim and Mohamed (Lim & Mohamed 1999) built an approach of project success on two viewpoints: the micro and the macro. Cost is seen as a micro-factor.

Sadeh, Dvir, and Shenhar (Sadeh et al. 2000) divided project success into four separate dimensions. The first dimension is meeting design goals within the budget goals to be met, the second dimension is the benefit to the end user, the third dimension is benefit to the developing organization and the last dimension is the benefit to the national technological infrastructure.

Other authors saw more holistically the project success models. Takim and Akintoye (Takim & Akintoye 2002) set 10 KPIs for assessing project success in the UK construction sector, by distinguishing between 7 project-performance indicators and 3 company-performance indicators. Two of the seven project-performance indicators are the construction cost and the cost predictability and profitability one of the three corporate indicators. Chan and Chan (Chan & Chan 2004) created also a set of Key Performance Indicators (KPIs) to measure both objectively and subjectively the achievement of success.

Consequently the cost dimension becomes vital in project success. Monetary values are the most common and direct factors for judging the satisfaction, the quality, the profitability and the efficiency in contractual relationships. It has to be pointed out however that for producing a completed evaluation of a project's performance the time (schedule) dimension cannot be neglected. This study will utilize only cost data due to the high number of projects examined (in total 22) and due to the complexity of acquiring a full and applicable schedule diagram with all the activities for each project.

For the present study the logic of choosing the cost side is illustrated below (Figure 9).

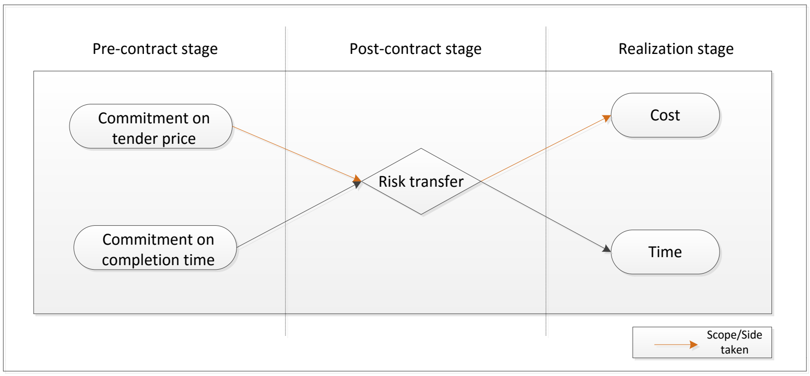

Figure 9: Cost-side as adopted from (Chang & Ive 2002, p. 281)

□ *"Cost estimating"*

Cost estimating is the technical process of predicting costs of construction (CIOB 1983). Cost estimating is one of the most important steps in project management. A cost estimate establishes the base line of the project cost at different stages of development of the project. A cost estimate at a given stage of project development represents a prediction provided by the cost engineer or estimator on the basis of available data. If the cost engineer or estimator is employed by the owner then he responds to a Request For Estimate (RFE).

The accuracy of cost estimates is a pivotal issue in the cost forecast process. Cost estimation, cost control and profitability are three interconnected areas in which contractors compete for winning a project in a bidding process. Cost estimates are distinguished into three groups; design, bid and control estimates[2]. Control estimates are the centre of this study as the author will explore improvement opportunities in risk sharing in the after bidding phase.

The Project Management Body of Knowledge (PMBoK) identifies three cost management processes: cost estimating, cost budgeting, and cost control. It therefore decomposes project cost estimates into five categories: (1) engineering, (2) construction, (3) right-of-way, (4) utilities and (5) environmental. Common methods of cost estimation are the following: (1) historical bid-based, (2) cost-based (top-down: analogous & bottom-up), (3) parametric modeling (4) risk-based (computerized tools) and (5) other methods, such as vendor bid analysis, three-point estimates and expert judgments.

Ntuen and Mallik (Ntuen & Mallik 1987), being in line with the PMBoK, classified slightly differently the cost estimation tools into four main categories: (1) experienced based (2) simulation (3) parametric and (4) discrete state.

[2] http://pmbook.ce.cmu.edu/05_Cost_Estimation.html

Regardless of the estimation technique type, what is crucial to understand is that contractors rely on their intuitive and subjective judgment to proceed with their cost estimations. Thus we are dealing with a dynamic problem with no constant boundaries of values. This indicates the difficulty of structuring a wide and generic method of cost estimating for building contractors. Historically, Law (Law 1994) has documented a general procedure for building cost estimating models. However, he reckoned that in practice, contractors devise their own methods of cost estimating and bidding. This creates a very volatile field in accurately estimating the construction costs of building elements and leads to variations in their cost estimates. In addition to the above, the lack of clear cost-estimating guidelines provokes under or over calculations in the cost estimates. The same observation was noted by Carr (Carr 1989).

The conclusion of this section brings into the light the technical problem of delivering accurate cost estimates. Building contractors when preparing their base estimates do not expect this technically problematic situation. Therefore, we proceed with outlining the procedure of building cost models and utilizing appropriate cost data.

□ "*Objectives and types of cost modeling*"
The development of cost modeling as a cost structure and cost control technique has evolved gradually leading to the known "traditional" techniques. By applying a cost model four points can be achieved as they are stated by (Ferry et al. 1999, p. 111):

- To give confidence to the client with regard to the expected cost of the project.
- To allow a quick and practical representation of building cost with such a way the cost to be analyzed and tested.
- To establish a system for advising the designer on cost that is compatible with the process of building up the design.
- To establish a link between the cost control of design and the manner in which costs are generated and controlled on site.

In the construction industry three types of construction cost modeling exist and these are:

- Traditional models: functional units, superficial-perimeter, conference method[3], storey enclosure, approximate quantities, bill of quantities.
- Non-traditional models: statistical and econometric models (i.e. regression analysis and causal model, risk-simulation models (i.e. Monte Carlo and value management), knowledge-based models, resource-based models, time-constrained models, and life-cycle models.
- New wave models: artificial intelligent systems (i.e. neural networks and fuzzy logic) and other models (i.e. environmentally and sustainable development).

□ "*Building cost models*"
Two kinds of cost models can be built (Ferry et al. 1999):

- A product-based cost model, which can model the completed project
- A process-based cost model, which can model the process of the project's construction

Although the process models is argued that generate more accurate estimates as activities are time-depended, the construction process cannot be modeled until the form of the building has been postulated. In the context of the present study all building projects examined are finished and delivered to their clients. In fact, it should be more appropriate to design and apply a process model but the researcher choice was a product-based cost model.

The <u>product-based cost model</u> was preferred against the process-based one, for the following reasons:

[3] An approach to cost function estimation on the basis of analysis and opinions about costs and their drivers gathered from various departments of a company (Bhimani et al. 2008, p.275).

- No activity networks could be obtained of each of the 22 projects examined. Thus the luck of schedule data implied a focus on a basic elemental cost analysis.
- Contractors are more familiar with the traditional term of "bill of quantities" (BQ) as they can quickly interpret physical resources (e.g. materials, labor, hours) requirements and transform them to cost estimates.
- The client when tenders a DBB contract will be contracting for "finished work" not for a production process (Ferry et al. 1999, p. 121)
- Elemental cost analysis is the most well-known product-based cost modeling method and it is tightly connected to a practical breakdown of cost elements. This simplicity provided by cost elemental analysis led to the selection of a product-based cost model. For example in the UK in 1969 was designed for first time a Standard Form of Cost Analysis (SFCA). Appendix 1 presents the most recent standard form of elemental cost analysis as published by the Royal Chartered Institute of Surveyors (RICS 2014).
- Product-based models were preferred lastly because they are completely compatible with the widely cost measure used in preliminary cost plans, the *elemental cost* (€/m²) for each structural or non-structural element. An example of a cost plan sheet was retrieved from the book of (Ferry et al. 1999, p. 229) and presented also in Appendix 1.

□ "*Determining the cost elements*"
In order to structure an easily understandable and simple cost model there is a need for choosing appropriate cost elements. The cost elements have to represent actual "work packages" which can be estimated in the bill of quantities (BQ) and track their progress during the project's execution.

The elemental Standard Form of Cost Analysis (SFCA) provided in the first appendix is explicitly detailed, a fact that makes the application of the form especially difficult. Moreover the SFCA is structured in terms of quantities and unit costs. This study does not aim to focus on quantity-related terms but more on total and sub costs. Consequently, the survey instrument utilizes the following five cost elements which are seen as tightly interconnected construction phases of building projects. These five elements are:

- Land preparation
- Foundations
- Substructure
- Superstructure
- Finishes

All these five cost elements have been defined as "part of the building which always performs the same functions irrespective of its type (Ferry et al. 1999, p. 125)". The five elements were not only chosen by means of logical sequence and unique functions, but also on the ground of the following criteria:

- Clear definition/description of each element in order to enable all contract parties to agree on breakdown of activities and sub-contracts.
- Each element should have a significant cost importance.
- Each element should be easily separated in terms of technical drawing and BQ analyses.
- The elements chosen should enable comparisons among other project parties' estimates and in-between the specific elements.
- No interdependence of individual cost risks is assumed. Every risk factor assessed, is derived as a cost element-specific characteristic.

The no-correlation assumption among risks lies on the logic that it is highly difficult to separate an indivisible building element from other elements. It becomes evident that some building components of a construction phase may share functions with other building components. For example, external walls' construction may have some effect on insulations, roofs or curtain walls-related construction. This shows a complexity in quantifying interdependences among the construction risks, leading us to the assumption of no interdependence (no correlation mathematically) among all risks assessed in and out of the five cost elements. However correlations will be discussed and applied among the five cost elemental categories. This choice will be discussed in

□ *"Cost data"*

Project cost before distinguished into direct and indirect costs often is ranked under a layers-based hierarchy (Figure 10) to promote the different types of capital (fixed capital, networking capital, total working capital) involved (Ostwald 1984, p. 363). This study deals with the top two cost components, the <u>contingency</u> and the <u>profit</u> because they are both seen as drivers affecting opportunities and threats within the risk-sharing decision making. Short definitions of each cost component will be provided in the third chapter.

□ *"How much accurate is cost data?"*

Nearly all data used in cost planning techniques has been processed in some way, very often with a corresponding loss in accuracy and certainly with some loss of context (Ferry et al. 1999, pp. 152-153). The information provided by the client's consultant from the brief till the tender documents relate a summary of factors affecting the costs. These incomplete specifications are received by the cost planners and bid them in a Request For Proposals (RFP) process.

The contractor, while bidding for a project, passes all the monetary values for the resources (i.e. wages, materials, equipments) to the contract manager who transfers them to the estimator. The estimator utilizes these gathered data and tries to forecast the next tender price and deliver a competitive price. The quantity surveyor then extends the analysis of estimator to a contractual strategy for bidding similar future projects and controlling efficiently the development of the design.

This procedure is the basis of forming a traditional retrieval strategy for cost estimations often executed solely by contractors. Contractors before bidding for a project, have to incorporate, the consequence of risk decisions taken by contract's managers and estimators, into their cost estimations. After a project is awarded, contractors once again have to absorb all the risks deriving from technical or behavioral uncertain conditions. Both are the same coin's sides dealing with cost data in the pre-and post-bidding stage (Figure 11).

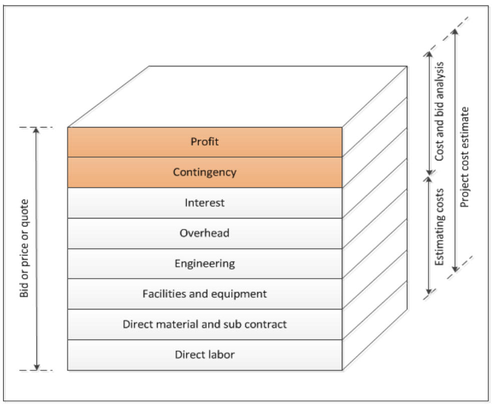

Figure 10: Components of a project cost estimate

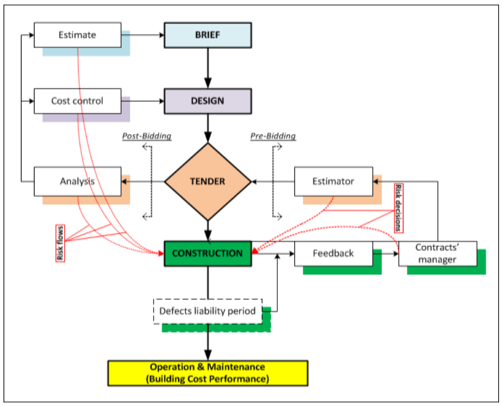

Figure 11: Traditional cost retieval

□ *"(Cost) Performance measurement"*

The present study's scope is grounded on the cost side of performance measurement. Thus *efficiency* and *profitability* will be examined as the driving forces of project cost performance (Figure 12). The reason for referring to performance is because profit-related decisions of contractors influence the project delivery efficiency. The relationship between efficiency and change in profit will be defined and discussed in chapter 7 (see in § 7.2).

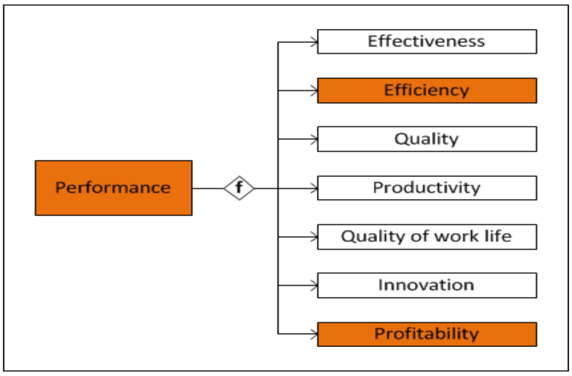

Figure 12: Performance dimensions (Sink 1985)

On the definition of performance many basic approaches are conceptualized to define the term. Among first, Vroom (Vroom 1967) suggested a multiplicative relationship as the first equation indicates. This relationship was modified by Porter and Lawler (Porter & Lawler 1968), who introduced three dimensions affecting an individual's performance. In the construction-related context, performance was slightly changed, since Laufer and Borcherding (Laufer & Borcherding 1981) focused on the effects of financial incentives on productivity. They conceptualized performance as a general multi-parameter issue affected by four variables (Equation 3). Maloney and McFillen (Maloney & McFillen 1983) after raising the topic of the "motivation – performance" connection researched how the expectancy theory model of a worker's performance could be validated in the construction operational environment.

$$Performance = f(Ability \times Motivation) \quad (1)$$
$$Performance = f(Effort \times Ability \times Role\ perception) \quad (2)$$
$$Performance = f(Ability \times Motivation \times Role\ perception \times Uncontrolled\ conditions) \quad (3)$$

Having provided the definition of performance, this study will utilize the first formula's elements ("ability" and "motivation") in the evaluation of the cost risk drivers as will be explained in chapter 6 (see in § 6.3.3). Ability and motivation will be the sub-criteria of the performance criterion for performing the Analytical Hierarchy Process (AHP) when judging the direct rating of participants on the four cost risk drivers as explained in chapter 4 (see in § 4.1). The reason explaining this choice is that ability and motivation are unique behavioral traits of each respondent, thus a unique rating of the four cost risk drivers will be expressed. It would be more objective having average rating values of all managers involved in a specific project but this would be a complex and time consuming procedure.

Performance indicators for industry measures are presented using the delivered recommendations of important UK task forces (Latham 1994; Egan 1998). In all these efforts, cost predictability and project performance are defined in various terms.

Love and Holt (Love & Holt 2000) distinguish performance indicators, performance measures and performance measurement based on a philosophy raising the awareness on switching from the *myopic* Business Performance Measurement (BPM) towards the Stakeholders Perspective Measurement (SPM). In this article Performance Measurement (PM) is the outcome of the combination of BPM and SPM, which embodies many variables. Among this group of variables regarding the assessment of PM, this research effort focuses on three "short-term" measures which represent the role of the "profit center" (Love & Holt 2000, p. 413):

- Performance
- Profitability
- Client/Contractor mutual benefit

Thus, after examining the work on critical success factors and performance measurement it can be argued the need on narrowing down the problem of risk-sharing from a cost perspective. Finally, aiming to frame more precisely the study's scope I refer on the idea of complexity. Examining the problem of risk sharing decisions from a "philosophy of science" viewpoint, I prefer to rather ground criteria than a clear definition of the solving strategy. Beyond the three criteria or components that will be settle down, the problem of defining the notion of complexity is overcome and I approach it throughout two dimensions: the *technical* (knowledge-driven) dimension and the *behavioral* (psychology-driven) dimension.

Three aims are set, following the rhetoric of Chu, Strand, and Fjelland (Chu et al. 2003), and these are:

- *Predictive* aim: to forecast how a base estimate will change after the incorporation of cost risks.
- *Exploratory* aim: to understand how contractors perceive riskiness during actual construction by applying direct rating of cost risk drivers and to explain how contractors tend to share each risk individually.
- *Control* aim: to provide a control methodology for setting optimal contingencies and consequently to improve cost performance index.

Ideally a scientific theory would explain, predict, and facilitate control at the same time. The connection between the problem's dimensions and the three components is presented within a logic sequence of scope delimitation (Figure 13).

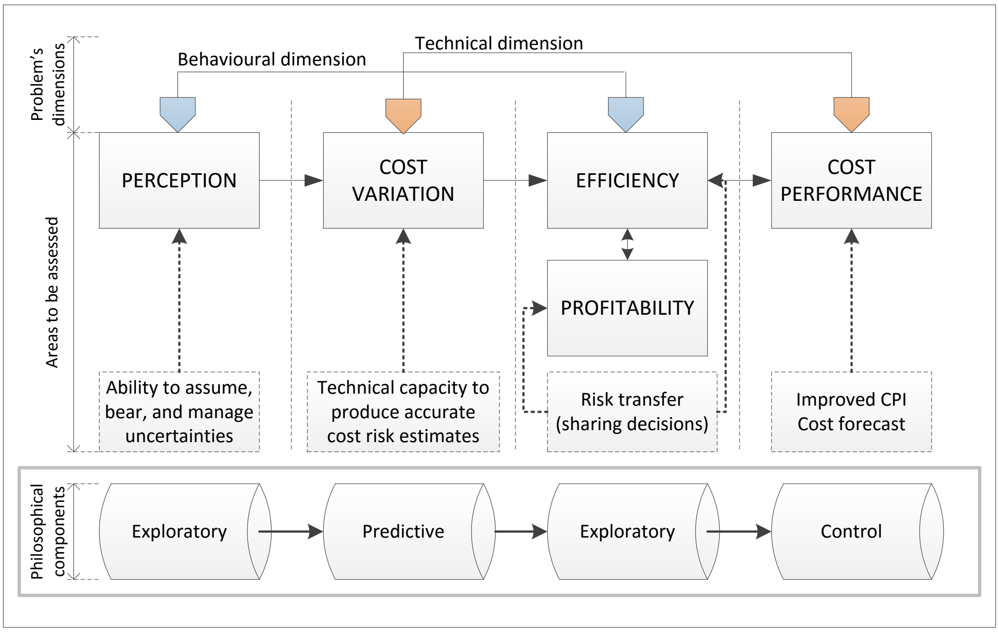

Figure 13: A sequence of scope delimitation

Since the study deepens in the cost performance achieved by the contractor selected the following framework depicts the forces and processes influencing the formation of risk sharing agreement with the client. To construct the research framework presented below, the next key-points were considered.

a. In order to design and negotiate on a contract there always should be present two main forces, the demand and the supply. The demand force is represented by the client (or buyer) as he requires services to be delivered to him. The supply force is represented by the contractor (or seller) as he needs to prepare an offer and bid the package of services in a tender with other competitors.
b. Contractual relations encompass the contractual terms within a governing relationship; typically this comprises: the relationship, the risk apportionment, the division of responsibilities and the reimbursement mechanism (Cox & Thompson 1997). This research includes the 3Rs of the 4Rs, by excluding the **R**elation between client and contractor and considering the **R**esponsibility (or Risk-ownership), the **R**eimbursement (as payment mechanism), and **R**isks (as pricing drivers).
c. The framework should be verified in scientific bibliography. The research model is strengthened by the statement that "the seller's price is the buyer's cost (Ferry et al. 1999, p. 242)."
d. The whole framework in order to be compatible with the entire research is built in a manner to underpin the central research goal, which will be in a following paragraph clarified.

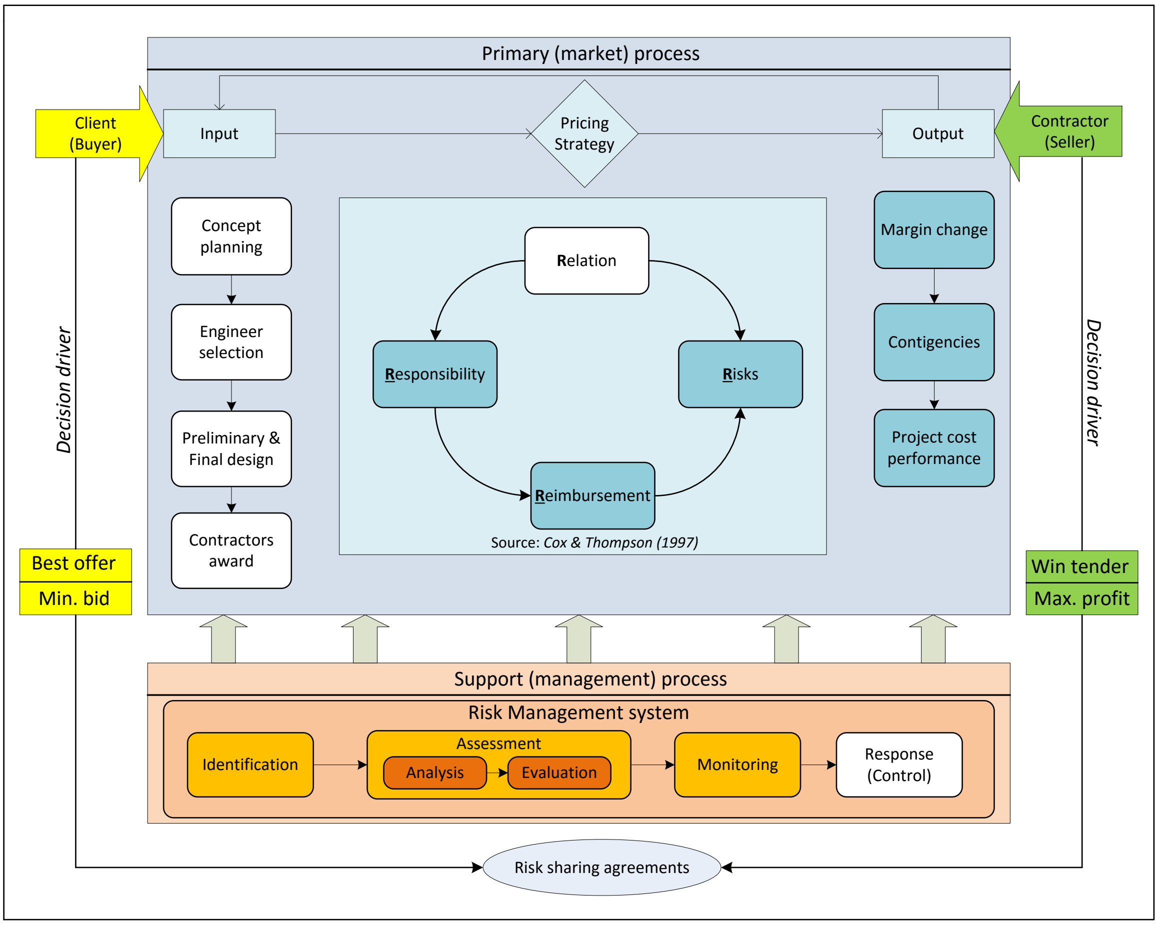

Figure 14: Research framework

The components of the research framework assisted the author to identify the elements that should be collected from the study's participants. A questionnaire booklet was constructed as will be discussed in the fifth chapter and presented extensively in Appendix 8. The reason for not providing the questionnaire to the reader at this point of the study is because some additional terms such as risk-sharing ratio, risk source, risk type, likelihood of occurrence and risk impact are not yet clarified.

Based on the research framework, the author will introduce and explain in the following chapter (*Literature Review*) the following key-terms. Some of them will be required to be filled in by the respondents in the questionnaire delivered by assigning numerical values, other terms will be required to filled in by making a simple choice among alternatives provided. Table 1 summarizes the key-terms of the research framework that have to be expressed and quantified by the contractors who participate in the study. Lastly in order to enable the reader to understand which data will be required from the potential survey's respondents to fill in the "survey specification" will be provided. For readers who are interested in quickly reviewing the survey tool, they are advised to check Appendix 8.

Table 1. Terms of research framework to be obtained from participants

	Key-term	Description	Value to fill in
Primary Processes	Responsibility	Risk ownesrhip	Risk sharing ratio (b %)
	Reimbursment	Payment mechanism	Choice among alternatives
	Risks	• Risk events • Cost risk drivers • Uncertainty source	• No choice provided • Judgement on the drivers • No choice provided
	Margin change	Profitability decision	±ΔM (%)
Support Processes	Identification	Setting a list of on-site risks	No choice provided: 27 risk events identified
	Assessment	• Risk type • Risk probability • Risk impact • Risk importance	• Fixed Vs. Variable • Likelihood of occurence • 3-point rating of cost impact • Direct rating of risk drivers
	Monitoring	Evaluate contingency levels and implications to project cost performance	No choice provided: action area of the author

Survey specification

Dear colleagues,

I am a civil engineer coming from Greece and having studied Civil Engineering inbetween 2004-2011 for the qualification of Master in Engineering (Diploma) at the University of Patras, Greece. After acquiring a 2 years working on-site experience, I decided to pursue my master studies in Construction Management and Engineering at the University of Twente, in the Netherlands. From January 2014 and so on I am working on my master thesis project for which I chose the Greek geographical area to examine the formation of risk-sharing schemes in traditional (Design-Bid-Build) contracts. Two reasons implied this focus: firstly the frequent used practice of competitive bidding for both private and public clients and secondly the high affinity of in Greece-operating construction practitioners with the traditional procurement system.

This introduction aims to briefly inform you regarding the purpose of the present questionnaire form in respect to its practical and scientific importance.

The questionnaire is serving as a survey research tool to gather all the required data for my research graduation project. The study has a twofold goal. Firstly it explores the risk-sharing practices of contractors in a traditional construction contract for building projects. Secondly it aims to map how profit-related decisions are taken and how these decisions could lead to optimal contingency setting, so to remain competitive in a bidding round. In addition to the above, potential hypotheses will be formulated so to explore contractors' perceptions in relation to contingency, riskiness of cost category, incentive profits, change in contingency levels and the probability meeting the base estimate.

In order to achieve the goal described above, the data that the respondents will be asked to fill are the following:

- Organizational characteristics (section A),
- Base estimates of the total project (section B),
- Percentages of the total estimate for each construction phase (section B),
- Range limits for each construction phase (section B),
- Risk ownership or cost risk-sharing rates for the identified construction risks (section B),
- The minimum change in the margin profit of each construction phase (section B),
- The probability and impact estimations of each individual risk factor and the cost risk drivers' importance rating (section C), and
- Details for personal communication (section D).

Scientifically the study will extend the knowledge in risk-sharing agreements by revealing *where* (cost category) and *why* (risk perception) contractors become more or less risk aversive and how risk contingencies are associated to the change of incentive profits. This will lead to the formulation of practical implications explaining how the risk-sharing decisions of contractors influence the total project cost performance.

I would like to thank you in advance for your participation and your valuable assistance for the implementation of this study.

All the data used and the derived results will remain in the possession of the respondents and only with their permission will be used in a possible scientific publication.

For any questions you may have and further needed elaborations, do not hesitate to contact me directly. If case of additional time required and anonymity to be kept, please contact the author.

Yours faithfully,

Kordas Dimitrios

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2.5 Research model

The research model helps to visualize all the components that the study will examine. The model assists as a mean for:

- Ordering the activities to be executed (Table 2)
- Presenting the results to be delivered (Figure 15)
- Connecting all the above with the research questions (as described in text below)

The main difference between the research framework (Figure 14) and the research model (Figure 15) is that the first one serves as an idea-grounding instrument and the second one as a quick schematic overview of the whole set of tasks that have to be executed in this research.

The provided model is conceptualized based on the methodology of (Verschuren & Doorewaard 2007). Four sections can be distinguished (Table 2), which can also be seen in the research questions and objective. The four sections aim to answer the following questions as depicted below (Figure 15).

Table 2. Decomposition of the research model

Sections of research model	Question to answer
A	Which theories to search in?
B	Where to focus?
C	Which research tools to deploy? What should be the outcome of the searching process?
D	What is expected to deliver as a result?

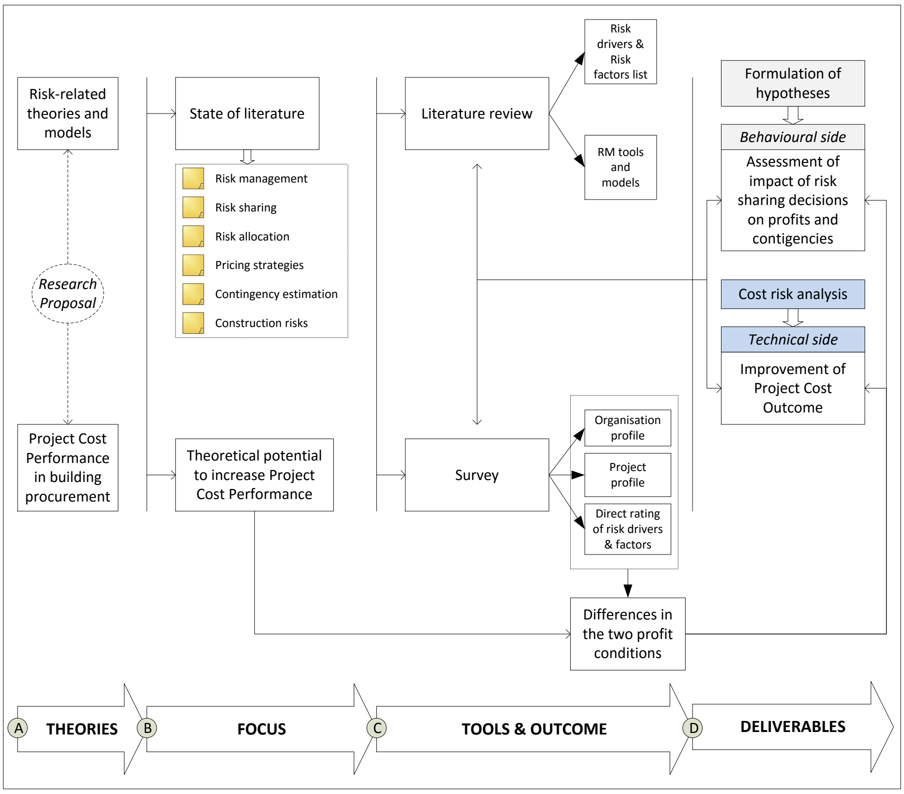


Figure 15: Research model

All the input required for structuring the risk assessment model comes from the section C, as it provides the researcher with the detailed list of the risk factors (and with their drivers too) required to be quantified. The risk management method used in the study is derived after a systematic literature review was performed. In the same section, the data collection instrument, a questionnaire form, was designed. The survey instrument assisted in gathering all the organizational and financial characteristics of each building project. The outcome of the survey gave input for determining the structure of the statistical hypotheses and the structure of the cost risk analysis model.

The last section (section D) is the one which provides answers to all research questions. The behavioral dimension of the problem examined is approached through the test of hypotheses as will be presented in chapter 4. Thus, research sub-question 1a and research sub-question 2a are concisely connected to the behavioral dimension. Similarly, the technical dimension of the problem is investigated by means of constructing a cost risk analysis model and checking its power to deliver higher project cost outcomes. Thus, research sub-question 1b and research sub-question 2b are replied throughout the results gathered after the simulation performed for each building project.

The third research question is the aftermath of the expected deliverables (section D). Project-specific measures will be discussed and an evaluation of the cost performance index will be outlines. Statements will be formulated so to enable further hypotheses testing. Below it is presented the connection between the parts of the thesis's structure and the research model applied.

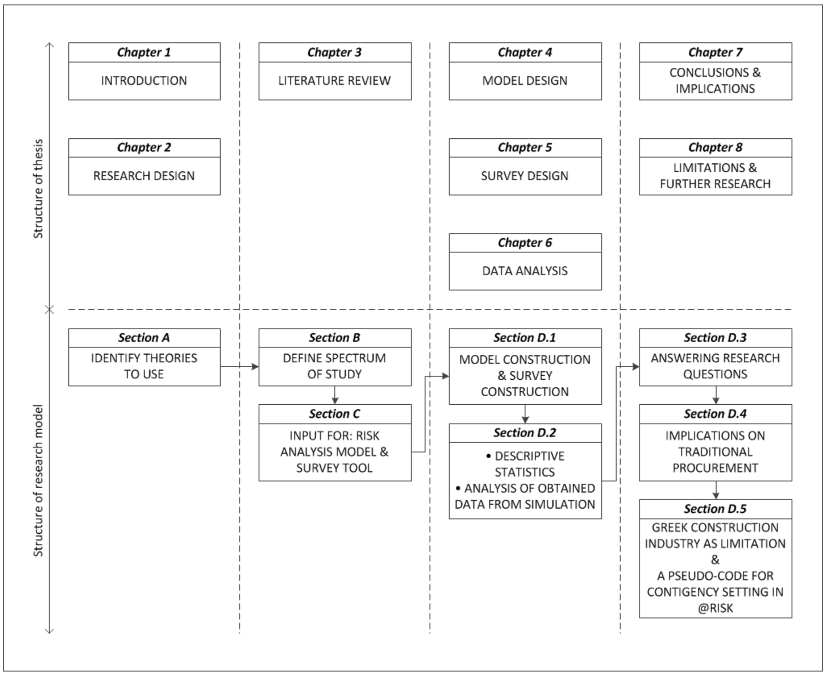


Figure 16: Connecting research model with report's structure

2.6 Research goal

The overall research goal of this study can be summarized as the one of:

Practical relevance:

"Providing insight in how contractors formulate their project estimates pre-bid and how they negotiate on risk-sharing agreements with their clients after been awarded a contract."

Scientific relevance:

"Assessing the effect of risk-sharing decisions taken (in post-bid) by contractors and examine projects' performance in terms of project delivery efficiency and cost outcome."

The results and benefits of such study include:

(1) An improved understanding between contractors and project owners (clients) regarding:
- The range of potential cost values of construction phases for building projects.
- The actions related to profit-making decisions affecting the estimated values within the range.
- The impact of these decisions on the project delivery efficiency efficiency and project cost performance.

(2) Contractors (as decision-makers) will gain a more thorough understanding of the range of cost outcomes and the drivers of those outcomes in the negotiation of risk-sharing arrangements with their clients.

(3) Contractors will be able to set the value of contingency in a minimum way that will beneficial for both stakeholders in a traditional contract.

(4) Improved communication about shared cost risks will potentially lead to improved project cost performance.

2.7 Research question

To achieve the overall research goal of this study, the following research question is posed:

"How do risk-sharing decisions of contractors' in the post-bid context affect building projects' cost performance when these projects are traditionally procured?"

This question is decomposed in three sub-questions, as follows:

Research sub-question 1

a. How much cost risk is transferred from contractors to clients in every building phase?
b. How likely the contractors will meet their initial estimates? What are the contingencies set in these initial conditions?

Research sub-question 2

a. How much additional or fewer cost risk can be transferred from contractors to clients in every building phase, based on their profitability-based decisions?
b. How likely the contractors will meet their revised estimates? What are the contingencies set in these new conditions?

Research sub-question 3

What are the consequences on profits and on contingencies due to the revision of the project estimates and the revision of the risk-sharing ratio?

2.8 Research objectives

Every research sub-question implies a single research objective. These objectives are outlined below:

Research sub-objective 1

a. Evaluate the degree of risk-transfer for every phase.
b. Specify the likelihood of meeting the cost estimate, the actual cost of each phase and the contingency set for each building project.

Research sub-objective 2

a. Evaluate the degree of risk-transfer for every phase for the new conditions (due to the change in margin).
b. Specify the likelihood of meeting the cost estimate, the actual cost of each phase and the contingency set for each building project.

Research sub-objective 3

a. Calculate the incentive profit element for contractors and compare the change in profit elements in the pre- and post- profit decision.
b. Compare the profit elements with the contingencies set by contractors in the two conditions.

LITERATURE REVIEW

Chapter 3

3.1 Definitions

Providing basic definitions will facilitate the reader to enter smoothly in the research context and draw own conclusions regarding the accuracy and validity of the study. The second reason to clarify in detail the terms used is their interrelating nature. For example, risks and uncertainties are often confused but they are not synonyms. Project delivery systems are not equal to payment mechanisms and overheads are not contingencies. The section below provides all the required definitions. If the readers is familiar with all these ke-terms then it is sdvised to move to the systematic review section (see in § 3.2).

◊ **Uncertainty**

In a business context, uncertainty is expressed verbally in terms such as 'it is likely' or 'it is probable'. If an action can lead to several possible outcomes then an uncertainty exists (Doctor et al. 2001, p. 80). In the economic theory, uncertainty is considered as the state in which individual actors find it impossible to assign a definite probability to the expected outcome of their choice (Keynes 1937). From a theoretical scope of view, uncertainty is defined as the lack of certainty involving variability and ambiguity (Brauers 1986; Ustinovičius et al. 2007).

Uncertainty can be alternatively defined as the variability of future outcomes where probability distributions cannot be constructed. This gap of knowledge is identified as the situation in which parameters are uncertain without information about probabilities to be known (Snyder 2006, p. 538).

The span of incomplete knowledge ranges from risk, uncertainty, ignorance and fuzziness (Pender 2001, p. 87). The main difference between the notion of uncertainty and risk is the ability of assigning prediction variables within a set of probability distributions. In uncertain situations, it is impossible to attribute probabilities to the possible outcomes of any decision (Rosenhead at al. 1972, p. 416). However in risky situations there are certain parameters controlled by probability distributions which are known by the decision maker (Migilinskas & Ustinovichius 2006).

Several definitions have been provided to distinguish the terms of uncertainty and risk. Both of them derive from three common sources which are (Ustinovičius et al. 2007):

- calculation bias
- information ambiguity
- data inaccuracy

In his fundamental book, Knight (Knight 1921) offered the first basic distinction between risk and uncertainty, based on the availability of objective probabilities. The essential fact is that "risk" means in some cases a quantity susceptible of measurement. It will appear that a measurable uncertainty is so far different from an un-measurable one that it is not in effect an uncertainty at all (Knight 1921, p. 19). Hillson (Hilson 2003), on the contrary to Knight's definition, linked uncertainty with risk by formulating the following couplet:

- Risk is measurable uncertainty.
- Uncertainty is immeasurable risk.

This implies that, when measurable, an uncertainty is to be considered a risk (KarimiAzari et al. 2011). The traditional view of risk is negative, representing loss, hazard, harm and adverse consequences. The Project Management Book of Knowledge (PMBoK) describes risk through the notion of uncertainty. These two phenomena, has to become clear that are not synonymous (Perminova et al. 2008).

Frank (Frank 1999) distinguished *aleatory* uncertainty from *epistemic* uncertainty. Aleatory uncertainty refers to variation and change, while epistemic uncertainty addresses a lack of knowledge. Other authors have based, their distinction between the two types of uncertainty, on the interpretation of probabilities outlining the role of objective and subjective probabilities or alternatively the distinction between the *frequentist* school-*epistemic* uncertainty (Abramson 1981; Paté-Cornell 1996) and the *Bayesian* approach-*aleatory* uncertainty (Aven 2010; Bedford & Cooke 2001; Doctor et al. 2001). A simplified view on the two uncertainty categories was provided by Olsson (Olsson 2006, p. 43) who posed before distinguishing between *aleatory* and *epistemic* uncertainty two core questions; the ones asking:

- With what has the uncertainty type to do with?
- Does the specific type of uncertainty have the ability to predict the expected outcome?

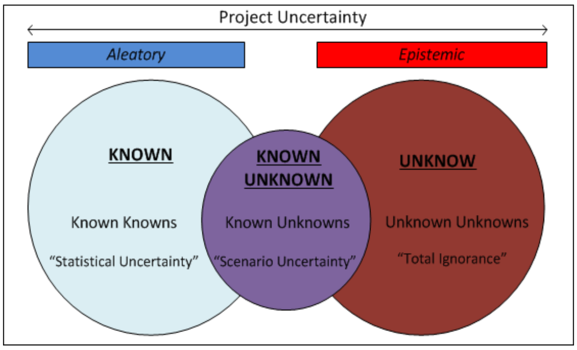


Figure 17: Project uncertainty (Joustra 2010, p.

The *aleatory* dimension of uncertainty is expressing the phenomena of changes, resulting from variability. Variability is what makes the world uncertain and unpredictable, caused by the inherent randomness of nature and human behavior (van Asselt 2000). This makes impossible to foresee what will happen in the future. *Epistemic* uncertainty is concerned with the uncertainty that rises from a lack of knowledge. The variety in the amount of knowledge "lacking" allows uncertainty to be classified into several levels (Walker et al. 2003). Uncertainty in a project ranges between statistical uncertainty and total ignorance (Figure 17).

Table 3. Differentiation between aleatory and epsitemic uncertainty

Type	Relevance	Forecasting ability
Aleatory	Having to do with chance	No ability to predict outcome
Epistemic	Having to do with knowledge	Ability to predict outcome

Uncertainty in the construction industry

What lies beneath uncertainties is the negative outcome of increased complexity into construction projects. Uncertainty is one of the major sources of indirect complexity. The criticality of meeting cost objectives or excessive quality requirements are other factors that lead to cost complexities and time escalation (Del Cano & de la Cruz 2002, p. 474).

On projects it is necessary to define one or a number of objective functions to represent the project under consideration and then measure the likelihood of achieving certain target values for them. Project uncertainty is the probability that the objective function will not reach its planned target value (Jaafari 2001, p. 89). It is significant to research the route and consequence of uncertainties in construction projects, as the path of their development shows where in the project life cycle ambiguity and variability emerges. Uncertainty when undertaking a construction project comes from many sources and often involved many participants in the project (Hendrickson & Au 1989).

Recently, research efforts are focused rather on defining uncertainty management methodologies than uncertainty as a term. Uncertainty is closely associated with uncertainty management, which is the process of integrating risk management and value management approaches of construction process (Smith 2003). Uncertainty management is not just about managing perceived threats and opportunities within their risk implications. It is about the identification and management of all the many sources of uncertainty which give rise to and shape our perceptions of threats and opportunities (Ward & Chapman 2003, p. 98).

Ward and Chapman (Ward & Chapman 2003) recognize five areas of uncertainty. The first one is related to the "variability of estimates", the other four categories are focused on uncertainty about "the basis of estimates", "design and logistics", "objectives and priorities" and "fundamental relationships between project parties". For this research, uncertainties are assumed to emerge mainly due to the "variability of estimates".

The sources and consequences of uncertainties are identified by different authors and classified in different categories. Migilinskas and Ustinovicius (Migilinskas & Ustinovicius 2008, p. 790) have aggregated and analyzed uncertainties followed with their sources and correspondent consequences in four categories, which are the following:

- Un-unified communication and undefined project language
- Low qualification and professional training of employees
- Un-estimated work amounts in project's estimates and unacceptable planning of works
- Unclear responsibility limits and no strict contractual obligations

Uncertainties are often difficult to identify and even harder to quantify. The identification and quantification of uncertainties requires a balance of project knowledge, program knowledge, risk analysis expertise, cost estimating expertise, and objectivity (Molenaar 2005, p. 346).

In the second appendix, a detailed description of uncertainty sources (events) is provided in respect to each risk factor. This study deals only with epistemic uncertainty and consequently applies the *frequentist* school approach which will give us the power to deploy probabilistic and stochastic mathematical tools to forecast cost elements.

◊ **Risk**

Generally, people associate the word risk with danger (Murray-Webster 2008) and risk's multi-layered notion makes the term been approached from different perspectives (León 1987). In the majority of activities people when dealing with risky situations are especially sensitive as they anticipate a danger or a threat to emerge. Technical studies however imply a more quantitative notion regarding the term of risk.

Risks do differ in their understanding by people. Psychometric techniques have shown that the concept "risk" means different things to different people (Slovic 1987, p. 283). Thus, different people will most probably have various scopes, viewpoints and past experiences shaping their perception on risk. For example in construction; engineers, designers and contractors view risk from the technological perspective, on the other side lenders and developers tend to view it from the economic and financial side (Baloi & Price 2003).

Renn (Renn 1998b) after reviewing the contributions and challenges of risk research observed that there is_no commonly accepted definition for the term risk – neither in the sciences nor in public understanding. However, all risk concepts have one element in common, the distinction between reality and possibility. The second fundamental trait of risk is that it is by nature a multi-attribute concept (Fischhoff et al. 1984).

The Project Management Institute (PMI) defines the risk as the cumulative effect of the chances of uncertain occurrences adversely affecting project objectives. Under the *technicist* or *modernist* approach, risk is calculable and, therefore, it is possible to think about notions of optimal risk allocation (Froud 2003, p. 569). The *technicist* approach is characterized by attempts to use quantified decision making techniques that incorporate risk into cost benefit or net present value calculations (Froud, 2003, p. 569). This distinction is indicated as the evolution from the "traditional" (*technicist*) to the "modern" (*modernist*) Operational Risk Management (SOA 2009, p. 70).

The origin of risk is the uncertainty inherent to any project, and every risk is associated with (at least) a cause, a consequence (if it occurs), and the probability or likelihood of the event occurring (del Caño & de la Cruz, 2002). The same definition is the most prevalent in the international context. Risk expresses the product of the probability of occurrence of a consequence, and considers the frequency of certain states or events (often called hazards) and the magnitude of the likely consequences associated with those to these hazardous events (Willows & Connell 2003, p. 43).

Jaafari (Jaafari 2001, p. 89) defined risk as the exposure to loss/gain, or the probability of occurrence of loss/gain multiplied by its respective magnitude. In the safety-related literature, the most widely used risk definition implies that "risk is the probability of an adverse future event multiplied by its magnitude" (Adams 1995, p. 69).

The risk concept is frequently broken down into two main components: (a) the probability which is the possibility of an undesirable occurrence, such as a cost overrun, and (b) the consequence or relative impact represents the degree of seriousness and the scale of the impact on other activities if the undesirable thing happens. Probability itself refers to "a value between zero and one, inclusive, describing the relative possibility (chance or likelihood) an event will occur" (Lind et al. 2005). Impact refers to the "extent of what would happen if the risk materialized" (Hillson & Hulett 2004). The product of the multiplicative relationship between the two risk attributes (as shown in Equation 4) has been extensively used in project risk management studies with various names; such as "expected value" (Pritchard 2000; Lukas 2002), "P-I score" (Hilson 2000), "risk exposure" (Githens 2002), "risk event status" (Wideman 1992) and "risk score" (PMI 2000).

$$Risk = Probability \times Impact \quad (4)$$

The risk "expected value" has received a lot of criticism as it hides a serious possibility for misleading risk estimations. To provide a practical example of this pitfall let's assume a minor earthquake with magnitude of 3 Richter units which has a probability to occur 5% and an impact on communities of € 10,000 and a second strong earthquake of 6 Richter units magnitude with a probability of occurrence 0.02% and an impact on communities of € 1,500,000. The first (minor) earthquake has an expected value equal to € 500 and the second (strong) earthquake has an expected value equal to € 300. Two key-points have to be kept from this simple example: (a) that a project manager cannot neglect a very catastrophic risk event (strong earthquake in example) because of the small numerical value of its probability of occurrence as the impact may be fatal, and (b) the expected value of the minor earthquake can be much higher than the one of the strong earthquake.

These observations indicate that we have to be very careful when using mathematical expressions to quantify a risk. Haimes early in 1990s recognized the insufficiecncy of the "expected value" and proposed a multi-parametric system for computing a realistic and representative risk factor (Haimes 1991) ansd later he discussed in-detail the "fallacy of expected value" especially for extreme risks (Haimes 1993). In the same line of argumentation, Williams (Williams 1996) in a brief note pointed out the danger of producing computerized risk lists suffering from misleading risk impact values if the "expcted value" logic is applied.

The risk "expected value" suffers also from its inability to incorporate other significant dimensions, which are critical in risk identification processes, such as predictability or detection. Carbone and Tippett (Carbone & Tippett 2004) respond to this weakness of the "expected value" method by adopting a Risk-tailored Failure Mode and Effects Analysis (RFMEA). They defined a risk's consequence as a Risk Priority Number (RPN) with the aid of the following formula:

$$RPN = Occurence \times Severity \times Detection \quad (5)$$

An "intersecting matrix" for the probability and severity factors was introduced by Royer (Royer 2000). Datta and Mukerjee (Datta & Mukerjee 2001) developed a nine-segment matrix for immediate project risk analysis based on weighted probability. In another study a quantitative priority ranking was developed based on a table of probability and impact (Pyra & Trask 2002). Kerzner (Kerzner 2002, p. 707) uses a mathematical function that defines the risk factor as the multiplication of a number of probability and consequence factors (Equation 6).

$$Risk\ factor = Pf + Cf - Pf \times Cf \quad (6)$$

Where:
Pf = Probability of failure due to degree of maturity and complexity
Cf = Consequnce of failure due to technical factors, cost and schedule

Providing extensive risk-related definitions would reduce the report's readability. Readers who are keen on reviewing the interconnection of risk with other terms, such as hazards, events, danger should turn to Appendix 3, wherein classical definitions on risk are tabulated in chronological sequence.

◊ **Risk perception**

> *"Managing risks is mush as psychology as much as it is mathematics. Whether on a group or individual level, perception and approach to risk influence the results of a risk management exercise. Project managers who recognize this will inevitably achieve better risk management and project performance targets (Kliem & Ludin 1997, p. 34)."*

In construction projects there are various risk drivers due to them, risks are generated and thus obligate project managers and stakeholders, such as contractors to apply systematic risk management approaches. Seeking to identify risk drivers associate with individuals at every project's life cycle stage will lead to an excessive level of analysis. Before implementing a risk management plan, the risk manager must first learn to perceive risk in every aspect of doing business and offering services (Papageorge 1988). In an effort to simplify the interpretations of teams and individuals regarding uncertainties associated with the whole lifecycle of projects the individual behavior is useful to be clarified (Chapman & Ward 1997a, p. 112).

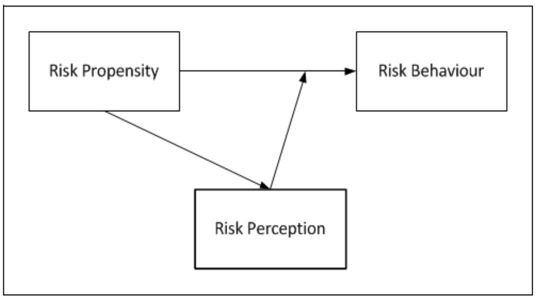


Figure 18: Determinants of risk

Sitkin and Pablo (Sitking & Pablo 1992) later concluded that the risk behavior of a person is determined by his willingness (risk propensity) to take risks within the framework (risk perception) the person creates (Figure 18).

Before attempting to define risk perception, is wise to refer to the context, on which the formulation of risk perceptions depends. Renn (Renn 1998a) conceptualized risks as factors derived from social constructions of societal actors and as technical estimates of risk representations of real hazards.

The first side encloses the *constructivis*t view on risk perception, in contrast to the second one which represents the *realist* perspective. The social *constructivist* view was founded within the cultural theory of Mary Douglas, a very influential British anthropologist who initiated the research on identifying and explaining societal conflicts on the perceptions of risks, moving away from the psychological (cognitive) and economic approaches. According to the theory perceived risk is also closely tied to cultural adherence and social learning (Douglas 1966; Douglas & Wildavsky 1983).

On the other side, several authors have raised their critique on the theory by doubting on the theory's critical points (Boholm 1996). The "personality" and "ways of life", expressed in the concept of culture are identified as the preconditions constraining the theory's explanatory capacity (Oltedal et al. 2004). This is why the second wave, the so-called *realist,* was built on the basis of integrating multi-scientific scopes and systems such as actuarial approach, probabilistic risk analysis, economics of risk, psychology of risks, etc (Renn 1998a, p. 52).

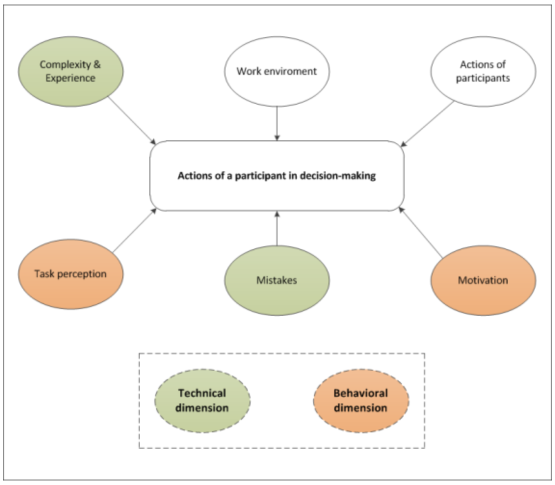


Figure 19: Factors affecting individual risk

The existing scientific base strengthens more the decision of distinguishing two dimensions in the study's problem (Figure 19). The *constructivist* approach is applied throughout the behavioral components aiming to examine the effect of risk sharing decisions to incentive profit elements. The *realist* approach is grounded on providing a more precise technical solution for minimizing cost risk estimation mistakes (deriving from variability) and empowering the link between the tender experiences and the contractual learning process (explaining risk bearing attitude).

□ *"Technical dimension"*
The two technical components are the "capability and experience" and the "mistakes". Contractors' experiences shape negotiating agreements with clients and the offer of competitive bid packages. Mistakes are the outcome of insufficient technical expertise or over/under estimated techniques in cost risk analyses. These two technical components make contractors to adopt a risk-specific profile, usually a risk seeking profile. Actions are excluded as cannot be controlled or assessed by the researcher.

□ *"Behavioral dimension"*
The "task perception" component of the individual behavior implies the need for exploring further the definition and role of perception on risks and risk management practices. Studies of risk perception examine the *judgment people make when they are asked to characterize and evaluate hazardous activities and technologies* (Slovic 1987, p. 280).

This section aims to highlight the importance of defining the perception of subjects on risks which is not the same always with the quantities derived. As will be presented in the fourth chapter ("Model Design") each study participant had to elaborate the description of each risk and quantify the probability for every single risk factor and impact values for every single risk driver. The research as was expected obtained various risk-related values, a fact confirmed in bibliography (Sjöberg 2000, p. 2). Dealing with risk perception is seen as an attempt to master uncertainty by defining social goals and applying a structure of reasoning which cannot claim a universal validity for all persons and risk objects (Renn & Swaton 1984, p. 560). The picture below will help readers of the study to obtain an understanding of the reasoning structure adopted (Figure 20). Based on this structure participants characterized and evaluated the risk factors (or risk events).

Lastly, we have to observe that "perceived risk" or "personally experienced risk" it might be defined by describing the whole complexity of measurable human reactions to a risky decision/situation (Vlek & Stallen, 1980, p. 281). This is an important aspect in order to understand that contractors have different behavioral levels and experience which affect their decision-making while they negotiate with their clients for being compensated.

The perceived risk concerns how an individual understands and experiences a phenomenon (Oltedal et al. 2004, p. 11). It is not examined usually, how their responses are shaped, since many factors can influence their perceptions on risks, such as:

- The familiarity with the risk source (Ittelson 1978).
- The control over a situation (Rachman 1990).
- The dramatic character of events (Lichtenstein et al. 1978).

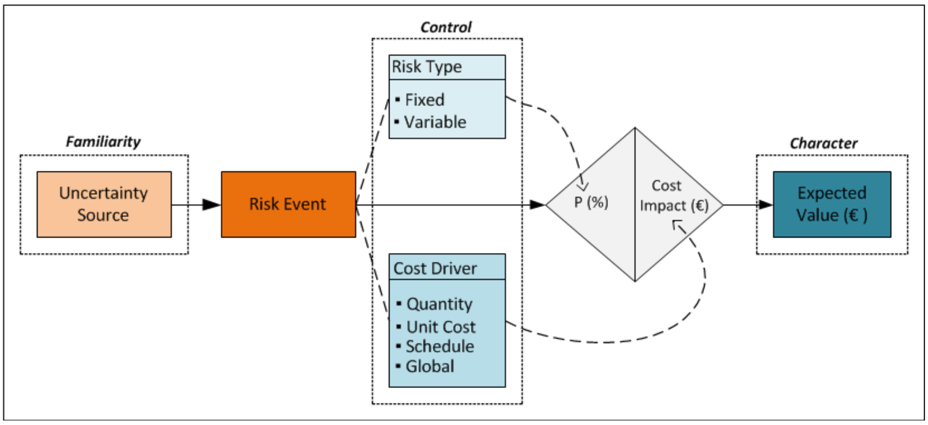


Figure 20: Reasoning approach on risk perception

In practice, the quantification of risk attitudes and risk perceptions was further explored by using psychophysical scaling methods and multivariate methods. Several researchers worked towards this direction (Fischhoff et al. 1978; Renn 1981; Rundmo, 1996). This study indicates how the trade-off between acceptable risks and perceived benefits is formulated throughout testing hypotheses based on the market structure of traditional building contracts.

Putting it all together, modeling risk perception is a complex process in which three primary concepts have to be used (Sjöberg 2000, p. 8):

- *Risk sensitivity*: is the phenomenon in which if a set of risk ratings are correlated it is almost always found that they correlate positively and rather strongly (Sjöberg 2000).
- *Attitude* or *affect*: is a function of beliefs and values (Fishbein & Ajzen 1975) or a driver of beliefs according to other authors. General attitude towards the nature is recognized as a fundamental factor concerning peoples risk perceptions (Thompson et al. 1990).
- *Specific fear*: Any hazard elicits thoughts about specific fear-arousing elements (Sjöberg 2000).

Sensitivity, attitude and fear elements although cannot easily quantified. In this study the three elements will be incorporated within the application of the Analytical Hierarchical Process (AHP) for explaining how study's participants rank the importance of each criterion and thereafter the importance of the four cost risk drivers. Sensitivity, attitude and fear will be the sub-criteria in the AHP which will be discussed and presented in the sixth chapter (see in § 6.3.3).

◊ **Risk attitude**

The attitude of individuals and organizations has a significant influence on whether uncertainty and risk management delivers what it promises. Several studies have been developed on explaining the forces pushing managers to formulate a risk-specific behavioral pattern; to name a few:

- Accounting industry (Helliar et al. 2001)
- Public risk perception's impact on several industries (Slovic 1987)
- Organizational performance (Smallman & Smith 2003)

□ *"The psychology of risk behavior"*

Risk management is impossible to be applied as a routine system, given that individual interactions, personal perceptions on risks and professional experiences on unexpected uncertain events influence the whole risk management process. The impact of human factors on the risk management process has been examined from various scopes. Recent developments in the "behavioral view" of project management induced a focus on understanding how natural, systematic biases can derail the decision-making process (Shore 2008). Thus all the potential individual attitudes should be closely observed and wisely quantified due to their serious impact on the risk process (Hillson & Murray-Webster 2004).

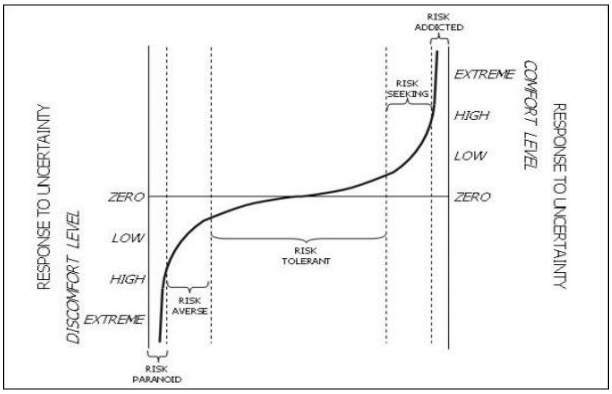


Figure 21: Risk attitude spectrum

Risk attitudes exist on a spectrum, ranging from *risk-averse* (those who are very comfortable in the presence of uncertainty) to *risk-seeking* (those who view uncertainty as a welcome change). The whole spectrum of risk-taking behavior is presented in Figure 21.

Individuals and groups are acting based on their attitude shaped by a plethora of factors as was seen above. The risk-bearing behavioral patterns are four and cited by (Hillson & Murray-Webster 2005):

- Risk averse
- Risk tolerant
- Risk neutral
- Risk seeking

Hillson and Murray-Webster (Hillson & Murray-Webster 2007) observed that risk attitude is: situational (not fixed), chosen in response to a given uncertain situation, exhibited by individuals and groups and affected by perception. Quantifying and interpreting risk attitude of contactors is a core element in this study, expressed throughout the risk-sharing percentage.

◊ **Project delivery systems**

A project may be regarded as successful if the building is delivered at the right time, at the appropriate price, and quality standards, and provides the client with a high level of satisfaction (Barclay 1994). In regard to the contractual arrangements agreed between the contractor and the client, the procurement system is the organizational system that assigns specific responsibilities and authorities to people and organizations, and defines the relationships of the various elements in the construction of the project (Love et al. 1998).

Tsai and Yang (Tsai & Yang 2010) defined a project delivery system as a method for procurement by which the clients transfer or share risks to other entities. These entities depended on the type and degree of involvement in the project phases do differ in terms of the risks they bear. Recently, procurement or project delivery systems tend to become more flexible. Clients are raising expectations for more accuracy in cost-time estimates and less cost-time variations. Thus traditional systems are being replaced by the two other dominant systems the Design & Build (no tender phase) and the Managerial ones (Figure 22**)**.

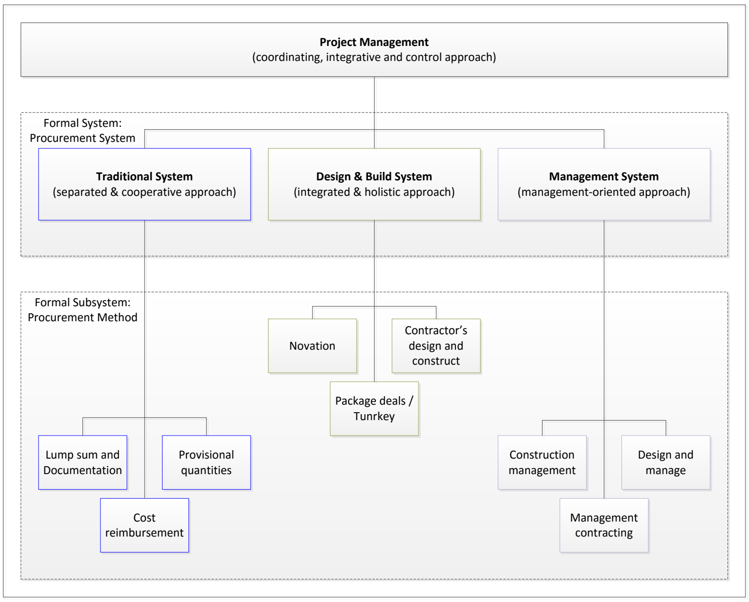


Figure 22: Categorization of building procurement systems (Perry 1985)

□ *"Traditional construction contracts (Design-Bid-Build: DBB)"*
In traditional delivery method the design is completed in-house or the agency contracts with a designer to complete 100% of the design before contracting with a general contractor. The prime contractors will thereafter build the project based on the completed drawings. The DBB procurement is the traditional U.S. project delivery method, which customarily involves three sequential project phases: design, procurement, and construction (CMMA 2012).

In this traditional situation an owner hires an architect or engineer to design the project and to prepare the plans and specifications which communicate the design to the contractor (AIA 2008) The owner then selects a contractor-by competitive bidding, negotiation, or some combination of the two-who contracts directly with the owner to construct the entire project (AIA 2007b). The contractor assumes complete responsibility for procuring and furnishing, either directly or indirectly, all labor and material necessary to complete the project within the allotted time (AIA 2007a). Usually the architect or engineer retains certain functions during the construction phase, such as processing change order and payment requests and visiting the site to see that the work is being performed in accordance with the plans and specifications.

The Design-Bid-Build (DBB) project delivery method is thought of as the traditional method by most people in the construction industry and related professions. Although various alternatives to this traditional method have come into greater use in recent years, some for as long as 40 to 50 years or more (in the case of Design-Build), the DBB method is still in use.

□ *"Design – Build (or Design & Construct) contracts"*
A project delivery method that combines architectural and engineering design services with construction performance under one contract (CMMA 2012) .The owner enters into an agreement with a single party who Designs and Builds the facility. Then the design-builder (DB) signs sub-contracts with separate designers (architects) and contractors. The owner may assign an individual consultant to assist him working closer with the main contractual party; the design-builder. The design-build team is responsible for providing the owner with all aspects required to deliver the facility, starting from design services to construction, and including equipment selection and procurement (Beard et al. 2001).

□ *"Management Contract"*
The client or owner appoints an independent professional team, and also a management contractor. Their involvement at pre-construction stages will be as adviser to the team, and during construction they will be responsible for executing the works using direct works contracts. With this type of contract it is possible to make an early start on-site and achieve early completion. Because of its flexibility, it allows the client to change the design during construction because drawings and matters of detail can be adjusted and finalized as the work proceeds.

□ *"Construction Manager At Risk (CM@R)"*
A project delivery method in which the Construction Manager acts as a consultant to the owner in the development and design phases, but assumes the risk for construction performance as the equivalent of a General Contractor (GC) holding all trade subcontracts during the construction phase. This delivery method is also known as CM/GC (CMMA 2012).

The Construction Manager (CM) as individual represents the owner and achieves the owner's interests by controlling the project and its various elements, and the effective application of the construction management delivery system is enhanced by the presence of a professional CM. The broad range of construction management services available may be pro-vided under a wide variety of contractual arrangements (Conner 1983). Construction management is often, but not always, employed on a multi-prime project. Under a multi-prime contractual regime, the owner contracts with a number of contractors, rather than with a single contractor responsible for the entire project (Bynum 1983).

The CMR holds the risk of subletting the construction work to trade contractors and typically guaranteeing completion of the project for a fixed, negotiated price following completion of the design.

□ *"Integrated Project Delivery (IPD)"*
IPD is a project delivery method that contractually requires collaboration among the primary parties (owner, designer, and builder) so that the risk, responsibility and liability for project delivery are collectively managed and appropriately shared (CMMA 2012). Owner, contractor and architect enter into one single contract, sharing risks and rewards based on a fully integrated collaborative process.

□ *"Private Public Partnerships (PPPs, DBFOM)"*
In general, the term 'PPP' is used to describe a variety of financing and delivery structures that create a long-term relationship between the public and private sectors which includes the private finance initiative (Zitron 2006).

PPP is practically a delivery method where an agency contracts with a private firm or consortium in a development agreement to design, build, finance, operate, and maintain a project over a long period of time (AASHTO 2006). PPP allows for project risks to be shared or transferred to the party best equipped to handle them (Levy 2011). At the end of the contract, the project is then turned back over to the owner.

□ *"Design Build Operate Maintain (DBOM)"*
With a DBOM contract, a private entity is responsible for design and construction as well as long-term operation and/or maintenance services. The public sector secures the project's financing and retains the operating revenue risk and any surplus operating revenue. When using a DBOM procurement system, the owner signs a contract with one party which is obligated to design and construct the project on a limited set of design requirements and selection criteria created by the client. Owner contracts with one single entity to design and construct the project based on very limited design details and selection criteria developed by the owner. The contract also entails that the entity operate and maintain the project for a set period of time. The Design-Build-Operate-Maintain (DBOM) delivery method utilizes a single contract to provide design, construction, operation and maintenance functions. Consequently, the contractor and his assigned O&M staff are involved from the beginning of the project. The early involvement of the contactor provides quick feedback for the designers about all the usability and constructability of their design.

□ *"Private Finance Initiative (PFI)"*
The PFI process involves competing private sector consortia, often joint ventures created for the purpose, with their supply chains: construction contractors, facilities management contractors, architects and design teams as well as construction, legal and financial advisors (CABE 2005, p. 2). They submit bids to design, build, and finance and manage public buildings, usually on a 25-year contract in return for an annualized or 'unitary' charge (a DBFO contract). They invest typically around 10% of the project value as equity and secure backing from funders for the remainder. PFIs however are not easily managed contractual agreements due to their financial complexity and the high transaction costs occur when entering them. High procurement and transaction costs are features of PFI projects, and the large-scale nature of PFI projects frequently acts as barrier to entry (Dixon et al. 2005). In general, risks are balanced differently among different types of procurement systems (Figure 23, Figure 24).

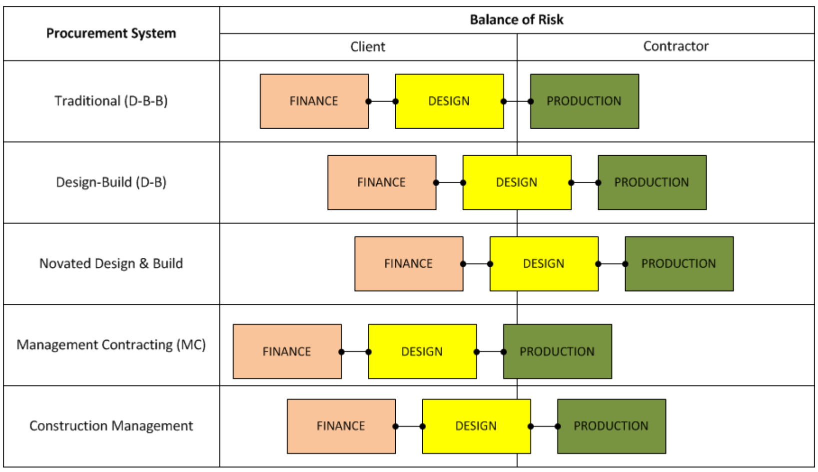


Figure 23: Simplified view of risks relative to procurement systems (Walker & Greenwood 2002)

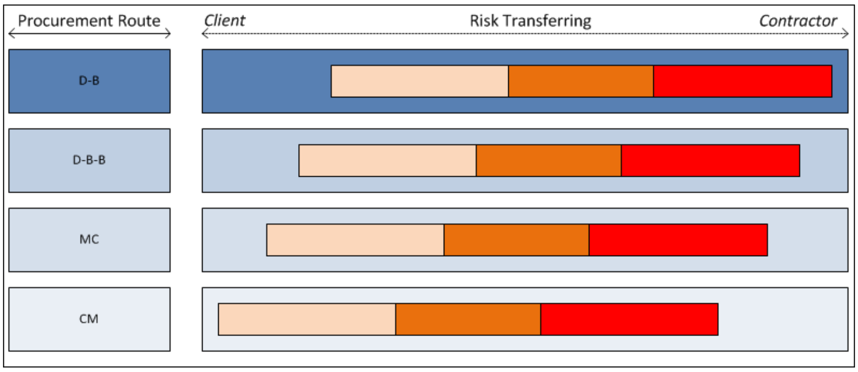


Figure 24: Schematic chart on risk transferring (Powell 1996)

◊ **Payment (compensation) methods**

Contracting and compensation methods for professional services and construction services will generally fall into one of three categories: Lump Sum/Fixed Price, Guaranteed Maximum Price (GMP), or Reimbursable.

These methods are not specific to any particular delivery method, and may be applied to contracting for professional services, such as design, engineering, and construction management, as well as contracting for construction services (CMMA 2012). In the same report, the Construction Management Association of America (CMAA), specifies that procurement of professional and construction services will generally be accomplished in one of three methods: price-based, qualifications-based, or a combination of both.

Various pricing mechanism are selected by owners. The fixed price and lump-sum are among the most known. In addition to them, the unit-price, cost plus fee, cost plus fee with a guaranteed maximum price are also used. Below the most well-known compensation methods are briefly discussed.

□ *"Fixed price"*
A common payment method where a price is set for the total cost of the project based on a set amount of work. The owner pays the set amount to the firm regardless of the actual costs that the firm incurs for the project (Schexnaydet et al. 2004).

□ *"Lump-sum"*
The lump sum contract is the most popular fixed price contract, where the total price of the project is estimated at the bidding stages (Hinze 1993).

This is the most common, where the contractor gives the owner a lump-sum price to complete the project according to the contract documents, which include the contract provisions, drawings, and technical specifications. Changes to the scope of work are accomplished through change orders, which adjust the lump-sum amount during the construction period. The contractor is paid on a monthly basis during the construction period for the work installed and for the materials furnished during the month.

Lump-sum contracts are used for projects that have a well-defined scope. For this type of contract, the contractor assumes most of the risks, which include prices of labor and material changes and weather conditions (Ibbs et al. 2003).

□ *"Cost plus fee"*
A pricing method not very often used. When the scope of the work is difficult to be defined, the contractor is reimbursed for costs on the project, plus a fee that includes indirect overhead and profit. Costs normally include all the overheads coming from price escalations in materials, labor, equipment, and subcontracts.

□ "*Cost plus, with a Guaranteed Maximum Price (GMP)*"
This compensation method is a hybrid of the lump-sum and the "cost-plus "contracts. It is a commonly used method, called as Guaranteed Maximum Price (GMP), which assumes that the contractor quotes a maximum price for the scope of work and proceeds on a cost-plus-a fee for the project, often with an arrangement to split the savings between the contractor and the owner.

□ "*Unit price contract*"
This method lists quantities for the project's components which are priced per unit by the contractor. The total of the product of the quantity and the unit price is then added to determine the lump-sum price for the bid. Payment is based on the completion of the quantities for each line item. Unit price contracts are not common in the building construction industry, but are common in civil engineering projects, such as in underground tunnels.

◊ **Price, Cost**

Price is the charge for completing an element of work; it is the cost plus allowances for general overheads, insurances, taxes, finance (i.e. interest rates) and profit (Smith 1995, p. 107). Cost refers to the cost directly attributable to an element of work, including direct overheads, e.g. supervision (Smith 1995, p. 107).

The relationship between the economic variables involved in the study is the following one, as stated by Smith (Smith 1995, p. 120):

$$Price = Cost\ estimate + Risk + Overhead + Profit + Mark - up \qquad (7)$$

◊ **Contingency, Premium, Mark-up, Overhead**

Contingencies, premiums, mark-ups, and overheads are often misinterpreted. All these terms are related to the growth of a cost estimate (or base cost) when contractors have to sell a work package.

□ "*Contingency*"
Contingency is probably the most misunderstood misinterpreted and misapplied word in project execution. Contingency can and does mean different things to different people (Patrascu 1988, p. 115)". Similarly observed by (Ferry et al. 1999, p. 131), the contingency sum is an arbitrary amount decided by the client or the design team. The contingency it is not a really part of the contractor's tender but is an amount which the contractors is instructed to add to the tender in order to enable him/her absorbing unforeseen extras.

The Project Management Institute defined contingency as "the amount of money or time needed above the estimate to reduce the risk of overruns of project objectives to a level acceptable to the organization" (PMI 2000). Contingency is generally defined as the source of funding for unexpected events (Günhan & Arditi 2007, p. 492). The Association for the Advancement of Cost Engineering (AACE) defines contingency as: "An amount added to the estimate to firstly achieve a specific confidence level, or secondly allow for changes that experience shows will likely be required" (Hollman 2008, p. 1).

There are three basic types of contingencies in projects: (1) tolerance in the specification, (2) float in the schedule, and (3) money in the budget (CIRIA 1996). For all types of contingencies cost estimates have to be drafted and included in cost documentation. Traditionally, cost estimates are point estimates. That is, single value estimates based on the most likely values of the cost elements. These point estimates may or may not accurately indicate the possible value of the estimate, and they certainly do not indicate the possible range of values an estimate may assume (Toakley 1995). When estimating, the most common method of allowing for uncertainty is to add a percentage figure to the most likely estimate of the final cost of the known works. Thus simply, the amount added is usually called a contingency (Thompson & Perry 1992).

It becomes evident that cost contingencies are very important elements in the preparation procedure of budget estimates executed by both parties in a traditional contract. Contractors are using probabilistic methods to fix contingency levels in their bids and owners are using probabilistic estimates to make "go-no-go" decisions (Diekmann 1983, p. 297).

Contractors try throughout contingency funds allocation to deal with variations, which are a major cause of disruption, delay, and disputes and generate significant cost impact. Variations issued during the construction period are time consuming and costly. Therefore, such variations that arise later in the project should be avoided by allocating suitable contingencies during the budget preparation stage to absorb the adverse consequences of such risks (Panthi et al. 2009, p. 80).

Cost contingency is included within a budget estimate so that the budget represents the total financial commitment for the project sponsor (Baccarini 2004, p. 105). Therefore the estimation of cost contingency and its ultimate adequacy is of critical importance to projects. Several attributes, according to Baccarini (Baccarini 2004), have been assigned to cost contingency while examining broadly the literature available (Table 4). Thus contingencies are the required safety-driven amounts that contractors tend to include in their estimates to be covered against mainly two categories of risks; known unknowns and unknown unknowns (Hilson 1999; PMI 2000).

Table 4. Key-terms related to contingency

Attributes	Description	Reference
Reserve	A reserve of money in order to mitigate project risk.	(PMI 2000)
Risk and uncertainty	A reflection of the amount of risk and uncertainty in projects.	(Thompson & Perry 1992)
Risk management	An antidote to risk. Setting and incorporating contingencies constitutes a financial risk treatment strategy	(Baccarini 2004)
Total commitment	Embedding contingencies in the within a budget estimate represents the total financial commitment for a project. Contingency should avoid the need to appropriate additional funds and reduces the impact of overrunning the cost objective.	(Baccarini 2004)
Project outcomes	A high-impact factor on project outcome. It should not be too low, as it will create a rigid and unrealistic economic environment and cannot be too high, as contractors may be encouraged to apply sloppy cost management techniques.	(Dey et al. 1994)

In estimating, contingency is used for two types of estimates. The first is the expected value of a possible identified event (known unknowns). For example, if there is a 20% chance a contractor may require two dozers instead of one, it may include a cost of 20% (or more) of the cost of the second dozer as a contingency (Carr 1989, p. 550). The second type of contingency (unknown unknowns) is the possible cost of unforeseen events: events that cannot be identified because the engineer does not know what can happen. This second type is a true contingency and the one that needs close attention, because it is a margin for error (Carr 1989, p. 550).

The study deals with the "known unknowns" risk events which can be quantified and consequently their cost impact transferred into a contingency amount.

Estimation of cost contingency

Several estimation techniques for calculating project cost contingencies exist. This study does not focus on analyzing the differences or similarities between the estimating methods. In the frequently cited research work of Moselhi (Moselhi 1997) the methods of contingency determination are classified between deterministic and probabilistic (Figure 25). It is out of scope of this section to explain the working process and traits of the listed methods. However, in the fourth chapter it will be argued why this study utilizes the Monte Carlo (MC) simulation method and which are the advantages of the selected method. Table 5 was adopted and updated based on the previous research articles of (Baccarini 2004, 2005, 2006) and it presents an overview of the bibliography developed towards the estimating methods of cost contingencies

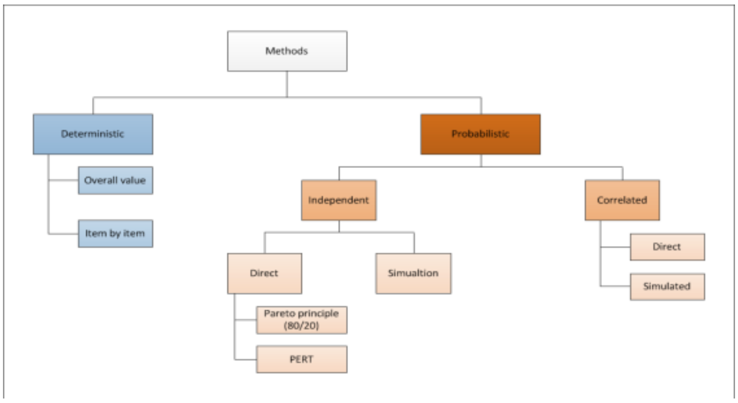


Figure 25: Classification of contingency estimation methods

Table 5. An overview of project risk assessment and cost contingency estimating methods

Contingency estimating methods	References
Traditional percentage	(Ahmad 1992; Moselhi 1997)
Methods of moments	(Diekmann 1983; Yeo 1990)
Monte Carlo simulation (MC)	(Lorance & Wendling 2001; Barraza & Bueno 2007; Ordóñez & Borinara 2011)
Factor rating	(Hackney 1985; Oberlender & Trost 2001)
Individual risks – expected value	(Yeo 1990; Mak et al. 1998)
Range estimating	(Curran 1989; Touran 2003a)
Regression analysis	(Aibinu & Jagboro 2002; Sonmez et al. 2007)
Artificial Neural Networks (ANNs)	(Moselhi et al. 1991; Williams 1994; Adeli & Wu 1998; Adeli 2001)
Fuzzy sets	(Paek et al. 1993; Choi et al. 2004; Dikmen et al. 2007; Idrus et al. 2011)
Controlled Interval Memory (CIM)	(Chapman & Cooper 1983; Cooper et al. 1985)
Influence diagrams / Belief networks	(Diekmann et al. 1998; Diekmann & Featherman 1998)
Theory of constraints	(Leach 2003)
Analytical Hierarchy Process (AHP)	(Mustafa & Al-Bahar 1991; Dey et al. 1994; Panthi et al. 2009)
Real options	(Tseng et al. 2009)

Understanding contingency allowance

In a construction project, risks are declining while project approaches its completion (Figure 26 - b). It is a simple logic implying, that the more the knowledge is increasing in a project the less the uncertainties involved embodied in project cost estimates (Figure 26 - a).

The construction procurement arrangements include two main types of contingency reserves that are allocated by the designer and the contractor in a building project (Günhan & Arditi 2007, p. 493). In the present thesis, referring to contingency is synonymous to contractor's contingency.

Probabilistic methods for contingency estimating bring the advantage of setting contingency as the difference between the expected value of a project and the desired "comfort level" of decision-makers, here of contractors. In this process of estimating the likelihood level of constructing a project within the specified budget leads to the calculation of a (probably) excessive contingency fund. The cumulative distribution curves illustrate at a specific confidence level (i.e. 95%) the contingency reserved (alternatively set or allocated) in a project phase.

The smaller the contingency allowance is, the higher the accuracy in the project cost estimates (Merrow & Schroeder 1991). In this research, the two authors showed that there is no discernible relationship between cost growth and the level of contingency provided; although one might have been expected because contingency is emend to cater for cost growth. Reasonably accurate forecasts of final costs of construction projects are needed for justification of projects on economic grounds and for efficient capital planning and financing (Baccarini 2006).

Figure 27 presents the three most widely observed interpretations of contingencies when cost estimations are performed. Based on this interpretations cost contingencies will be calculated in this study.

□ *"Premium"*
In the construction market, there many risks, such as design, logistical, environmental, political, legal and financial identified by many scholars (Perry & Hayes 1985; Mustafa & Al-Bahar 1991). All risks impose to contractors a protective thinking, leading them to apply a risk premium strategy. A risk premium strategy is a contingency allowance in construction projects (Akintoye & MacLeod 1997). The premium placed on each of the sources of risk may depend on the risk exposure faced by individual firms from each of the sources, the likelihood of occurrence, the experience of the firm in dealing with the particular type of risk, the attitude of the firm to risk, the extent of impact posed by the sources, etc. Some of the risk sources are more important to the construction industry than the others and this is recognized by the different premium put on different risks associated with construction.

This study neglects the values of premiums as they are considered as an inherent part of cost estimates if proper cost risk analysis is executed.

□ *"Mark-up"*
Estimating and bidding are two crucial areas of actions and decisions for construction contractors. According to Fayek (Fayek 1998) many of the decisions required in arriving at the final bid price are based on experience and intuition. Herein is included the decision of margin's or mark-up's level. A margin or mark-up is defined as the amount of money added to the estimated cost of the project to arrive at the contract (selling) price (Fayek 1998, p. 1). Mark-up is often seen as a synonym of profit (Ferry et al. 1999).

In his very influential bidding model, Gates (Gates 1967) had decomposed the optimum bid that a contractor submits in a tender process into two elements: (a) the estimated cost of executing the project and (b) a strategy for maximizing profit, which constitutes a constant mark-up (Runeson & Skitmore 1999, p. 286). The level of the profit margin set in the bid preparation calculations by the contractors is commonly known in the construction management literature as the "mark-up bid" (Ribeiro et al. 2012). Some authors see the mark-up bid decision making as an "all-included" process in which contractor determines the monetary value which is needed in order to level up the cost estimate by including the estimated firm overheads, project direct and indirect and contingency (Hegazy & Moselhi 1995; Hartono & Yap 2011).

It can be observed that often the notion of mark-up is synonymous to the widely known term of margin or profit. Now it can be argued the choice in this study to consider the mark-up as an equal to profit amount included into cost estimates as a percentage of the estimates.

□ *"Overhead (or Off-site costs/ "Establishment charges")"*
Overhead is by definition that portion of the cost that cannot be clearly associated with particular operations, products, projects or systems and must be prorated among all the cost units on some arbitrary basis (Ostwald 1984, p. 128). Overheads are related to both direct and indirect costs, and the key-difficulty in understanding and correctly estimating them is the way an estimator incorporates them into the individual estimates. Overall, overheads do not exist unless the product is made. Although the underestimating or overestimating of overhead rates is serious in view of the proportion of the total cost estimate, the present study does not consider overhead rates.

Overheads are approached as part of the direct costs a contractor calculates in the cost planning, a decision which is in line to the observation of (Ferry et al., 1999, p. 245).

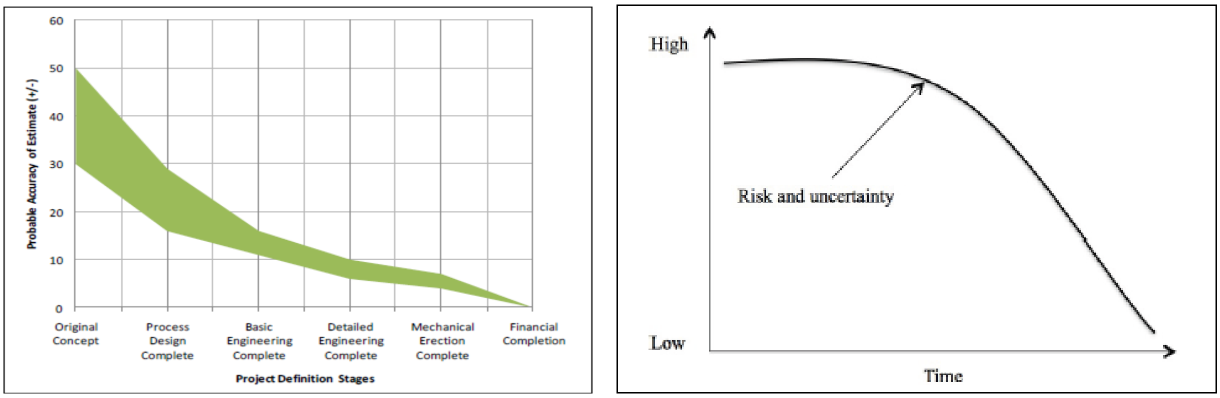


Figure 26: Left-Estimate accuracy Vs. time (Moselhi 1997),
Right-Risk & Uncertainty Vs. time (PMI2013)

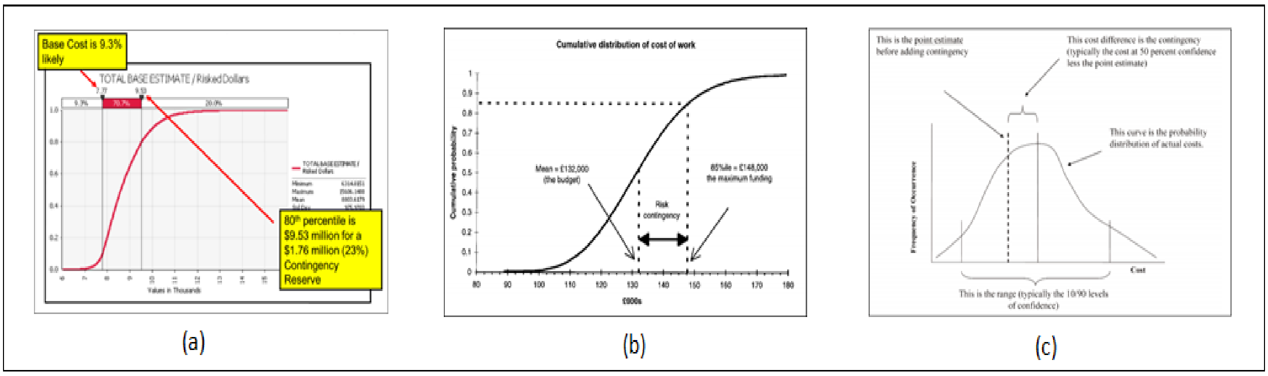


Figure 27: (a) Contingency reserve on a sample cumulative probability distribution curve (Hulett 2002), (b)Determining a bid price (Vose 1997), (c) Probability concepts used in contingency estimating (Hollman 2008)

◊ **Contractor's total costs**

Contractor's cost structure usually includes the following cost components (Ferry et al. 1999, pp. 242-245):

$$Total\ costs = \overbrace{Costs}^{Direct\ + Indirect} + Major\ plant\ costs + Overheads + Mark - ups \qquad (8)$$

Contractor's contingency is included in the construction budget to cover unexpected events that may occur during actual construction, such as weather-related delays and surprises with soils conditions or design changes. One of the typical ways to control these risks is to enter into a stipulated-price contract in which the contractor absorbs responsibility for construction risks in return for an expected price premium (Hobbs 2010, p. 15). The above cost structure shows that usually contractors have to design a financial strategy to achieve the highest mark-up and also within this strategy to diligently incorporate realistic estimations for their cost.

In respect to simplify this study's scope on the contractor's cost structure, the following assumptions are made:

1. There is not attention on distinguishing between direct and indirect costs for this research project. Although it can be important in another context such us of cost reduction of indirect costs.
2. Sub-contractors and major suppliers are embodies into the "materials"[4] cost category within the direct costs category.
3. Risks and premiums are synonyms. Risks are probabilistically quantified and after added to the base estimates.
4. Contingencies are calculated after the simulation's outcome as in Figure 27.
5. Overheads are included within direct costs category.
6. Mark-ups are taken into consideration by the contractors as a percentage of the cost estimate.

◊ **Project**

In this study, the definition for a project is aligned with the definition given by Gido and Clements (Gido & Clements 2012) who saw a (construction) project as an undertaking meant to accomplish a specific objective through unique sets of interrelated tasks and the effective utilization of available resources. Any project, whichever form or shape it takes, has well defined objectives or goals clearly stated in terms of scope, schedule and costs. A project can be defined as "a temporary endeavor undertaken to create a unique product, service or result (PMI 2000)" or as "a unique process, consisting of a set of coordinated and controlled activities with start and finish dates, undertaken to achieve an objective conforming to specific requirements, including the constraints of time, cost and resources".

3.2 Systematic review

3.2.1 Setting up the review

A literature review should contain, among other things, the following (Levin 2011):

- comparisons and contrasts among differing authors
- critique of methodology used by authors
- understanding of the areas of agreement between authors
- understanding of the areas of disagreement between authors
- suggest gaps in research
- conclusion summarizing what the literature says

However planning, preparing, practicing and presenting effectively an optimal literature review is not always a clear activity. The problem with a literature review is that it is easy to let it end in endless lists of citations and finding s without a plot (Bem 1995). Thus a routinized process to search among the basic *strings* will be utilized to end-up in a sufficient and quality-assessed amount of scientific publications. In order to obtain a set of solid publications which will produce a reliable set of input data (construction risks) three parameters must be established: (1) agreed standards, (2) high degree of focus and (3) minimized bias.

The present study will not step on the common practice *build-as-you-search.* On the contrary it is believed that due to the vast pool of information around construction contracts and risk management, more specifically on risk allocation as it is the outcome of risk-sharing schemes.

[4] It refers to the calculation method of sub-contracted (or outsourced) work packages.

To obtain the most adding-value and not repeatable citations the idea of systematic literature reviews, was used; as similarly in the research fields of information technology and software engineering (Brereton et al. 2007; Kitchenham et al. 2009), health-care (Mays & Pope 2000; Wright et al. 2007) and policy making appraisal programs (Kuper et al. 2008). The systematic review attempts to reduce reviewer's bias through the use of objective, reproducible criteria to select relevant individual publications and assess their validity. In its strengths are include the narrow focus of the question, the comprehensive search for evidence, the criterion-based selection of relevant evidence, the rigorous appraisal of validity, the objective or quantitative summary, and the evidence-based inferences (Cook et al. 1997). Executing a systematic literature review pre-assumes the creation of a research protocol; which entails the rationale of the survey, research questions, search strategy, selection criteria, synthesis and analysis of the extracted data (Asuncion & van Sinderen 2010).

A two-phased searching process was deployed to produce optimal, meaning unique and not repeated as it is seen below (Figure 28).

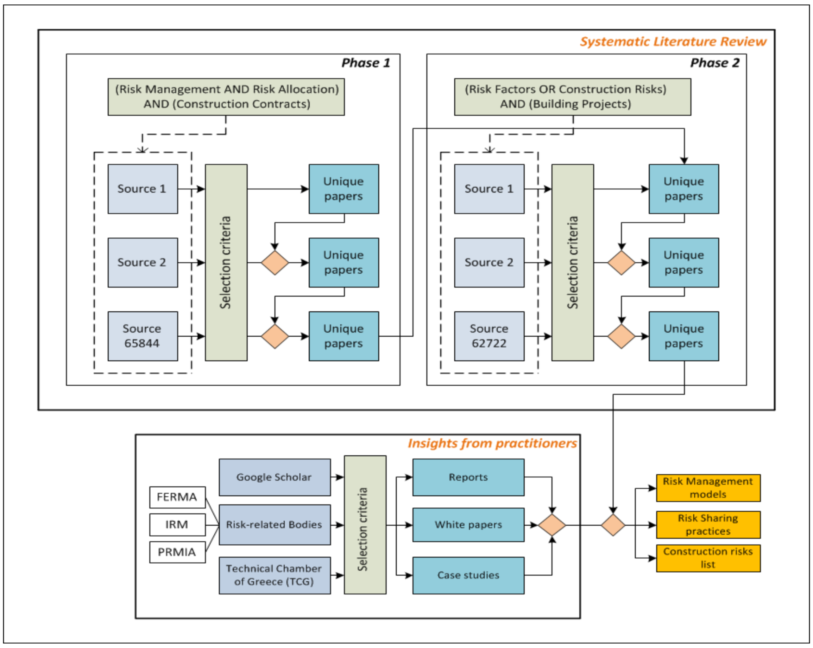


Figure 28: A summary of the systematic review process

The first step is to decompose the title of the study and try creating the most effective *search strings* in order to generate the definitions of risk management processes, more specifically focused on risk allocation and a generic list of risk factors emerging in the tender and construction phases of building projects. A note on the systematic review process is that it guarantees throughout the selection criteria set that the end-results (e.g. definitions, methods, conclusions, etc.) are not repetitive in a manner to avoid a review that is iterative and non-adding value.

The two strings used during the two phases are formulated as follows:

PHASE 1

Search string 1

< (Risk Management) AND (Risk Allocation) > AND < Construction Contracts >

Argumentation: "Risk allocation" is by definition a sub-process of risk management. Although the main component word of the thesis title is "risk-sharing", it was chosen to search initially for the problem of "risk allocation" as "risk-sharing" is considered the root of it. This philosophy of searching into the scientific bibliography is verified by Chapman and Ward (1997b) who saw risk allocation playing a fundamental role, an approach which is line with the Project Management

Institute's (PMI) definition on Risk Management. The PMI had broken down risk management as a total of nine phases where the plan response (8th phase) and the management through monitoring (9th phase) embody risk allocation practices. As risk allocation is considered an effective tool for responding to inappropriate allocation and controlling more effectively the risk-sharing relation between the owner and the contractor, there was a strong motivation for searching not only definitions regarding risk allocation but more broadly in the entire risk management area.

The focus on risk allocation does not fully cover the range of risk-sharing strategies between contractors and clients. Consequently an individual section will be developed only on examining the "risk-sharing" topic and its correspondent decisions, schemes, arrangements or agreements. This section is covered by the "Insights from practitioners" box as presented in Figure 28.

The type of the contract (traditional) was not assessed as a key-word mainly for two reasons. Firstly the use of the contract type was reducing significantly the objects (e.g. publications) produced by the search engine and this was a limiting factor against the total number of the allocation techniques. Risk allocation, to say differently was considered as more interesting factor than the contract's type. This means that the nature of the study; focused more on the allocation topic implied to take into account a broader spectrum of results.

PHASE 2

Search string 2

< (Risk Factors) OR (Construction Risks) > AND < Building Projects >

Argumentation: The construction of the questionnaire survey demanded a list of construction lists with which contractors are dealing on-site and sharing with their clients. The core aim in this stage is to generate a satisfactory amount of non-repeatable (unique) risks related to the construction phase of all civil engineering projects procured within the traditional delivery system.

Thus the first part of the string is written in a manner giving the direction of risks and but not out the construction field. The key-word '*construction* risks' - and not the usual '*project risks'* - was included to minimize an unrealistic generation of articles or chapters out of the operations of the construction industry. The second component of this string connects the risks factors within the building facilities context, although risks recorded in other types of civil engineering projects were not totally excluded.

Selection criteria

The inclusion criteria were set in a way to be repetitive and giving no space for subjective interpretation or biased selection. The selection criteria were the following:

1. Sources were limited to journals, conferences (proceedings), working papers, technical (public or private reports), dissertations/theses, books or chapters of books.
2. Written in English.
3. Publication date: not taken into consideration.
4. Within the context of construction risk management.
5. Sources must refer in their title or abstract or summary at least one of the key-words used in the search strings.
6. Similar definitions and risk-lists were compared and the most explanatory were selected.
7. The most adaptive definitions and risk-lists were selected as fitting better to the procurement (traditional) and project type (buildings) examined in the study.

The databases used in the search of results for the two strings defined in each phase were in the beginning four (Scopus, ASCE, ScienceDirect and IEEE Xplore). However after using more extensively Google-Scholar for cross-referencing and citing books or chapters of books, new sources came up, leading to the use of more databases, which in total are twelve as they are alphabetically tabulated below (Table 6). It should be highlighted at this point that the constraining options were not than same for all the databases; a fact that generated an especially big amount of results in some databases (e.g. ASCE: String 2, EMERALD, SpringerLink: String 1). The final set of sources used was the group of 109 publications (Table 7). Google Scholar and SAGE database were deployed manually. SSRN, Access Engineering and Scirus were excluded due to the low relevance of the two first ones and the high repetition of results in the second one.

Table 6. Initial results produced by the databases used

Databases	String 1	String 2
Access Engineering	4	33
ASCE	3336	9998
EMERALD	53734	40438
IEEE Xplore	34	201
JSTOR	393	940
Science Direct	343	4470
Scirus	908	2797
Scopus	145	1638
Social Science Research Network	4	1
Springer Link	6870	1426
Talyor & Francis	26	101
Wiley Online Library	47	729
Sum	**65844**	**62772**

Table 7. Final results (publications) reviewed for both search strings

Databases	Results
Science Direct	31
Google Scholar	27
ASCE	20
Scopus	10
Taylor & Francis	9
Wiley Online Library	5
IEEE Xplore	2
Springer Link	2
EMERALD	1
JSTOR	1
SAGE	1
Sum	**109**

3.2.2 Outcome of review

◊ **Search String 1**

3.2.2.1 (Project) Risk management

Risk management (RM) is not a new concept and the bibliography especially between 1960 and 1997 has been significantly augmented as can be seen in Figure 29 (Edwards & Bowen 1998). Since the 2008 financial crisis, risk management has become an important component of all facets of business (Blome & Schoenherr 2011). Several efforts have been dedicated to define the limits and steps involved in Project Risk Management (PRM) processes. Scientists across all areas have come close to produce precise definitions and working frameworks for risk management. Due to the high importance of risk management various professional bodies (e.g. the Institute of Risk Management, the Risk Management Association, the Society for Risk Analysis, the Global Association of Risk Professionals, etc.) have published numerous

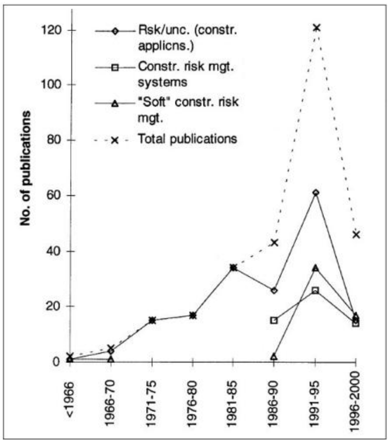


Figure 29: RM publications

application guidelines and risk management standards as cited in the book of Hilson (Hilson 2006).

The Federation of European Risk Management Associations has idetified the necessity of having some form of standards towards Risk Management (FERMA 2003, p. 3). This is needed to ensure that there is an agreed (1) *terminology* related to the words used, (2) *process* by which risk management can be carried out, (3) *organization structure* for risk management, and (4) *objective* for risk management. All the professional bodies have agreed on an - at least - three step process describing PRM and these three steps are: Risk Identification, Risk Assessment or Risk Analysis and Risk Treatment.

The most important standards for the risk management are presented in Appendix 4. For the construction of this summary previous report were used to identify the most important and widely applied standards (Avanesov 2009; Joustra 2010). Throughout the literature review process it was seen that risk management approaches are often compared without reaching a consensus regarding their applicability. Some frequently cited comparative studies, regarding risk analysis or risk assessment while adopting different industrial scopes with different research outcomes, are summarized below (Table 8). Empirical studies confirm that risk management practices often vary from prescriptions in the literature (March & Shapira 1987; Ropponen & Lyytinen 1997).

Table 8. RM comparative studies

Author	Outcome	Scope
(Kates & Kasperson 1983)	Comparative risk assessment	Risk analysis of technological hazards
(Power & McCarty 1998)	Comparative analysis of 7 National RM frameworks	Environmental science
(Raz & Hillson 2005)	Comparative review of 9 RM standards: 6 national standards and 3 professional	Drivers: Operational Vs. Project risks Steps compared: Identification, Analysis and Treatment
(Aloini et al. 2007)	Highlight key risk factors and their impact on ERP projects' life cycle	IT projects: introduction of enterprise resource planning (ERP)
(Avanesov 2009)	Outlining the ISO 9000 RM standards' requirements (ISO 9001:2008 Vs. ISO/DIS 9004:2009)	An explanatory guide of RM standards terminology (ISO/IEC Guide 73:2002)
(Tworek 2010)	Review of RM approaches for Polish companies	RM as practical knowledge and separate area of science

Joustra (Joustra 2010, p. 42) had proposed that the industry areas which apply risk management processes are four: the operational, the financial, the engineering and the business one. This section will provide an overview of the definitions on risk management conceptualized by risk practitioners and some examples of risk management applications in the four areas are discussed below.

□ *"Operational area"*

The US Environmental Protection Agency applies an integrated risk assessment process is developed for constructing a planning dialogue consisting of three main phases (EPA 1997). Nuclear energy and safety technology utilizes the Risk Assessment Methodology Property Analysis Ranking Tool (RAMPAR) which was developed by Sandia National Laboratories in order to determine the risk of extended infrastructure loss. The model was initiated after considering the development of a resilience methodology against infrastructural disruptions (Vugrin et al. 2012). In the automotive sector, many researchers have been focused on the risk assessment of the suppliers involved in the manufacturing process of vehicles (Blackhurst et al. 2008; Segismundo & Miguel 2008; Thun & Hoenig 2011).

□ *"Financial area"*

Dembo and Freeman (Dembo & Freeman 1998) had seen risk management as a method measuring the potential changes in value that will be experienced in a portfolio as a result of differences in the environment between now and some future point in time. The applications of project cost management were researched by Tummala and Burchett (Tummala & Burchett 1999) who developed a risk management model for capital budget evaluation for a transmission line project.

□ *"Business area"*

Other scholars have seen risk management as a chain of events influencing the product-creation process. In this context, Halman and Keizer (Halman & Keizer 1994) examined from a project scope, how risk diagnosis and risk management helps to identify organizational and commercial risks in product-innovation projects. Several other authors have contributed to broaden the scope of risk management in the areas of product platform development (Olsson 2006) and time-to-market situations (Hartmann & Myers 2003). Business risk capability is researched by Hillson (Hillson 1997) who developed a risk maturity model to identify areas of improvement and produce action plans for enhancing risk capability for organizations. In complex socio-technical projects, Pennock and Haimes (Pennock & Haimes 2002) saw risk management as a methodology covering risk identification, risk filtration, risk assessment, risk management, and risk tracking for large acquisition or development projects, such as an aircraft development project and governmental acquisitions.

□ *"Engineering area"*

Risk management was introduced in software engineering in two parts; risk assessment and risk control (Boehm 1991, p. 34). Kontio (Kontio 1997) introduced first, the *Riskit* method for complex software projects. Regarding the bidding processes the use of an holistic approach on estimating the project costs is proposed (Chapman et al. (2000). This approach enables the combination of the project cost components, the estimation of the probability of winning a bid and the determination of the bid price. In chemical and safety engineering, Khan and Abbasi (Khan & Abbasi 1998) designed a simplified block diagram showing the main steps of different risk and safety procedures is developed to assist process engineers in the assessment of possible risks.

Capital acquisition programs for defense personnel (DSTO 2010) are based on the *Technical Risk Assessment Handbook* (TRAH) which provides an approach for technical and technological risk assessment following the AS/NZS ISO 31000:2009 standard.

PRoject IN Controlled Environments (PRINCE2) is a world-class accepted standard and accepted as a project management tool, initially developed by the UK government in 1998. The method has been enhanced to become a generic, and be applicable as a best practice approach suitable for the management of all types of projects, and has a proven record outside both IT and government sectors. For this reason this risk management process is outlined within the construction-related ones. As the applicability of the tool is broadened to other industries, Elkington and Smallman (Elkington & Smallman 2002) researched its performance in utility projects, focused on the project success determinants. Haimes, Kaplan, and Lambert (Haimes et al. 2002) constructed a methodological framework, the Risk Filtering, Ranking and Management (RFRM) process which consists of eight core phases. The RFRM process combines a Risk Ranking and Filtering (RRF) method for risk prioritization (using scenarios and classes of scenarios) and a Hierarchical Holographic Model (HHM) which serves to develop scenarios describing the system in terms of "planned" or "success" scenarios. All the aforementioned approached towards Risk Management are summarized in Table 9.

Table 9. An overview of industry approaches to Risk Management

Industry or Projects	Research
Financial performance: Economic products	(Dembo & Freeman 1998)
Manufacturing: Production creation	(Halman & A Keizer 1994)
Product-platform development	(Olsson 2006)
Time-to-market decision making	(Hartmann & Myers 2003)
Software engineering	(Boehm 1991; Kontio 1997)
Construction: Bidding process	(Chapman et al. 2000)
Chemical engineering: Safety planning	(Khan & Abbasi 1998)
Project cost management	(Tummala & Burchett 1999)
Banking: Capital acquisition programs	(DSTO 2010)
Business risk capability: Risk maturity model	(Hillson 1997)
Socio-technical projects	(Pennock & Haimes 2002)
Utility projects with PRINCE2 tool	(Elkington & Smallman 2002)
Systems engineering	(Haimes et al. 2002)
Environmental risk assessment	(EPA 1997)
Nuclear energy sector: Safety planning	(Vugrin et al. 2012)
Automotive sector: Suppliers monitoring	(Blackhurst et al. 2008)

Risk Management in the construction industry

Regarding the role and application of risk management in the construction sector, Al-Bahar and Crandall (Al-Bahar & Crandall 1990) proposed a more technical approach, the so-called Construction Risk Management System (CRMS) model which consists of the four following processes: (1) risk identification, (2) risk analysis and evaluation, (3) response management and (4) system administration. The risk management lifecycle sets risk identification, analysis, evaluation, and control (response and monitoring) as the core steps in the whole process (Figure 30).

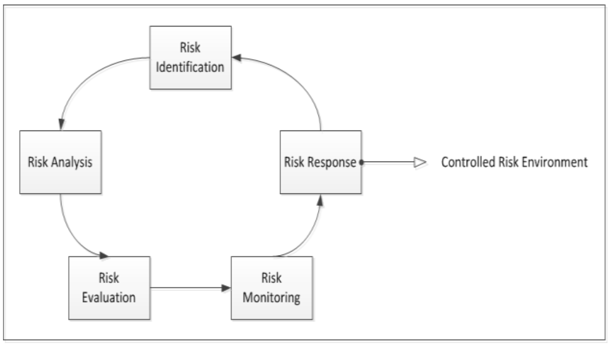


Figure 30: Risk management life-cycle (Baker et al. 1999a)

Based on the Plan-Do-Check-Act cycle (the so called Deming wheel) Kliem and Ludin (Kliem & Ludin 1997) applied the quality/control concepts in the area of construction risk management.

In the Netherlands, the Delft University of Technology, the Dutch Ministry of Transport, the NS Railinfrabeheer BV, and the Management Consultant Twijnstra Gudde BV, have together collaboratively developed a stepwise risk management method, the known RISMAN. The RISMAN method as firstly was conceptualized by Soares (Soares 1997) and thereafter analyzed (de Rijke et al. 1997; van Well-Stam et al. 2004).

The British construction industry has been based on the Risk Project Management (RPM) drafted by the Association of Project Managers (APM). In the correspondent Project Risk Analysis and Management (PRAM) Guide and the relevant book and article of (Chapman 1997; Chapman & Ward 1997a) present the structure of the PRAM generic process.

Another integrated methodology for project risk management was developed by (Del Cano & de la Cruz 2002). They developed the Project Uncertainty MAnagement (PUMA) model which is designed to serve as a generic risk management process for project owners and their consultants. The PUMA method is built on the existing risk management methods and extents them, including the PRAM process (Chapman 1997) and the one followed by the Project Management Institute (PMI 2000).

The International Technology Scanning Program study initiated in 2004 with a broad collaboration among the U.S. officials from the Federal Highway Administration (FHWA), State Departments of Transportations (DoTs) and the academia working in Canada, Finland, the Netherlands, Scotland and the UK. The outcome of this joint effort focused on identifying practices to improve construction management in highway projects and raise awareness of risk management techniques. The framework adopted to embody and describe the overall risk process flowchart is the one included in the Caltrans *Project Risk Management Handbook* (Caltrans 2003).

In the revision of the Risk Analysis and Management Process (RAMP), Chapman and Ward developed the Shape Harness and Manage Project Uncertainty (SHAPU) process which consists of nine phases: (1) project definition, (2) focusing the uncertainty management process, (3) identifying sources of uncertainty, (4) structuring issues, (5) clarifying ownership, (6) estimating variability, (7) evaluating implications of uncertainty, (8) harnessing plans, and (9) managing implementation (Chapman & Ward 2003). The SHAPU process framework addresses the six basic questions (WHYs?) as the PRAM one, in response to the roots of uncertainty.

The Multi-Party Risk Management Process (MRMP) and its application was introduced by (Pipattanapiwong & Watanabe 2000). An infrastructure construction project financed by an international lender was used a case study in the specific study.

One recently developed risk management method is the Active Threat and Opportunity Management (ATOM), initiated by (Hillson & Simon 2007). The ATOM process consists of eight core phases providing the opportunity to the assessor in the end of the cycle to continuously review through the whole project lifecycle if all appropriate actions were taken.

Seyedhoseini and Hatefi (Seyedhoseini & Hatefi 2009) produced the Two-Pillar Risk Management (TPRM) generic process. The authors in their article oppose against the traditional view of Risk Management Process (RMP) containing two main phases: (a) risk assessment (including risk identification and risk analysis) and (b) risk response. The TPRM generic methodology is introduced based on two core notions (pillars); risk and response. The equal application of the two pillars extends significantly the research on risk management as in traditional view of risk management the importance of risk assessment overrides the importance of risk response (Seyedhoseini & Hatefi 2009, p. 138). Identification of the two pillars (risk and response) includes three generic sub-steps, classification, processing and measurement.

Table 10 summarizes the aforementioned risk management processes developed for the construction operations irrespective the phase of the project's lifecycle or the phase of the risk cycle.

Table 10. Chronological sequence of Risk Management process in the construction industry

Risk Management Process/Framework	Reference
Construction Risk Management System	(Al-Bahar & Crandall 1990)
Systematic Risk Management Approach	(Godfrey 1996)
Project Risk Analysis Management	(Chapman, 1997; Chapman & Ward 1997a)
RISMAN	(de Rijke et al. 1997; Soares 1997, 2007)
Plan-Do-Check-Act	(Kliem & Ludin 1997)
Multi-Party Risk Management Process	(Pipattanapiwong & Watanabe 2000)
Project Uncertainty MAnagement	(Del Cano & de la Cruz 2002)
PRoject IN controlled Environments	(Elkington & Smallman 2002)
CALTRANS Risk Management Process	(Ashley et al. 2006; Caltrans, 2003)
Shape Harness and Manage Project Uncertainty	(Chapman & Ward 2003)
Active Threat and Opportunity Management	(Hillson & Simon 2007)
Two-Pillar Risk Management	(Seyedhoseini & Hatefi 2009)

□ *"Tools used in Risk Management"*
Before proceeding with any explanation on the steps included to a typical risk management process, it is useful to refer in total to the tools that project risk management utilizes irrespective the phase of projects. Several researches have been dedicated on gathering and presenting the tools used for project risk management.

Grimaldi, Cagliano, and Rafele (Grimaldi et al. 2012) identified three characteristic dimensions in risk management, which are: (1) the phase of the risk management process, (2) the phase of the life cycle of a project and (3) the corporate maturity towards risk. This study initially tabulates the 31 most frequently used techniques. Thereafter it classifies all these techniques according to the three risk management dimensions and finally mapped the techniques on two 2-axes diagrams. This framework construction was based on an approach of risk management in terms of knowledge, communication, and information.

Other projects summarize the risk management techniques analyzed based on the phases of execution of risk management a comparison (van der Heijden 2006, p. 31). The last part of this literature review regarding project risk management addresses the wide area of the tools used in the entire chain of the risk activities regardless the framework followed.

The use and benefits of project risk management tools are extensively discussed in the literature. Raz and Michael (Raz & Michael 2001) examined 38 tools, and classified them into five basic groupings adopted from the Software Engineering Institute Risk Management. The groupings used were: background, identification, analysis, tracking and control (Dorofee et al. 1996). The research observed that the *TOP-10* list of tools includes tools which the half of them are tied in the background stage. This indicates the tight connection between risk management and other project management practices. The mostly used tool was Monte Carlo simulations.

3.2.2.2 Risk identification
Two are the core objectives of risk identification, firstly to identify and categorize risks that could affect the project and secondly, document these risks. Risk identification is pivotal as it indicates the objectives of the project and the risk-bearing limits of contractors and owners in correlation with them. It is, in other words, the stepping stone for choosing the project delivery system, the contract strategy, and the allocation of risks (McKim 1990). The core tasks included in a typical risk identification process as described above imply two basic actions (Chapman & Ward 1997a, p. 96):

a. Search for sources of risks and responses, employing a range of techniques
b. Classify to provide a suitable structure for defining risks and responses aggregating/ disaggregating as appropriate.

The widely cited Risk Analysis and Management for Projects (RAMP) procedure includes similarly three main steps leading to an input for analysis. These basic steps include the following activities:

- Recognizing the sources and types of major risks as. If possible interconnecting the risks identified with the underlying uncertainties. The risk sources are generally identified as three groups: (1) external market conditions, (2) internal project management skills and (3) project-specific characteristics (Tah 1997, p. 300).
- Ascertaining the causes of each risk separately.
- Assessing how risks are related to other risks and how they should be classified: It also provides the capability to create risk registers and risk databases (Ashley et al. 2006, p. 11).

There is a variety of tools to execute a risk identification procedure. The most known method for risk identification is risk checklists. The use of checklists is widely accepted as they are forms easily recording and reproducing historical data. As Al-Tabtabai and Diekmann (Al-Tabtabai & Diekman 1992) had stated the primary basis for identification of risks is historical data, experience and intuition. Risk checklists have a considerable impact on project managers' risk perception, a fact also highlighted in software engineering research (Li 2013). Checklists however do have some serious shortcomings, such as:

- Important interdependencies among risks are not highlighted.
- A long list cannot clarify the relative importance of the Relative Impact of individual risk drivers.
- Some risk drivers (e.g. definition of project, scope, financing, logistics, local conditions, resources estimates, etc.) may be ignored.
- A checklist illustrates overall a simplistic view of potential effects of individual risk drivers.

An exhaustive list of risk identification tools was provided by Raz and Hillson (Raz & Hillson 2005) who focused on comparing risk management standards. It is worthy to state that most of the suggested tools and techniques are subjective and qualitative; where very few tools utilize statistical or mathematical techniques (Bu-Qammaz 2007).

Other methods, expect from the checklists are brainstorming sessions organized among experts panels, or semi-structured interviews and Delphi technique. Interviewing project personnel who have experience in similar projects ensures that corporate knowledge and personal experience are utilized in the process of identifying risks. The technique provides a wide basis of involvement and ownership of the risk lists constructed. The examination of historical data is also a useful tool which incorporates past knowledge from similar projects, however it is beneficial only if the organization has undertaken similar projects.

An easy method to classify risks is breaking down risks. A typical Risk Breakdown Structure (RBS) with five broad categories (Figure 31): (1) external unpredictable, (2) external predictable, (3) internal, (4) technical, and (5) legal was drawn by Wideman (Wideman 1992). Another classification of construction risks is the one dividing them into three categories: local, global and extreme (Smith et al. 1999, p.34). According to Charoenngam and Yeh (Charoenngam & Yeh 1999), risk identification can be executed by categorizing risks into six groups of risks, which are (1) construction-related, (2) financial and economic, (3) performance-related, (4) contractual and legal, (5) physical and (6) political and social.

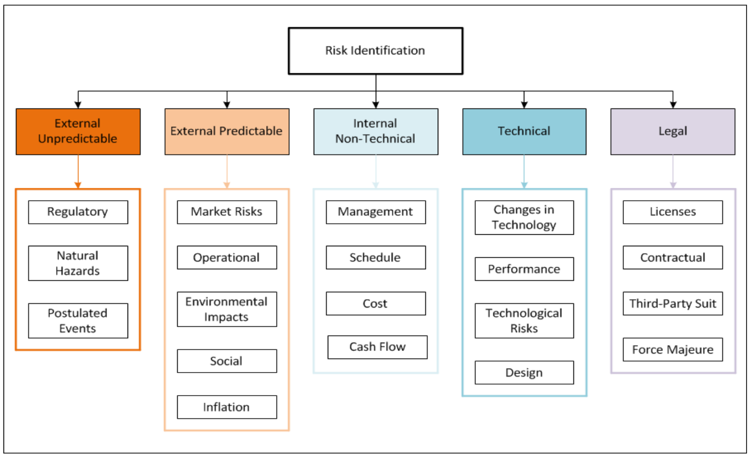


Figure 31: Risk identification classification

A prevalent classification approach or risks initiates by distinguishing risks in internal and external risks. Internal arise from the inside nature of the project. The scope and control changes of projects do create internal risks. Most internal risks can be referenced to as specific project document such as a cost estimate or a schedule. Internal risks refer to items that are inherently variable. External risks, on the other side, are generated through impositions on the project that are out of the boundaries of it. Interactions with citizens groups or regulators are typical external risks (Ashley et al. 2006, p. 16).

Other efforts on the classification of risks are focused on measuring risks with two different manners. Risks are measured then incrementally and continuously. Most internal risks are measured incrementally (e.g. cost, schedule, and durations). When a risk is measured incrementally this means that the occurrence of this risk in a series of small changes evidences itself. Many frequent, small changes are the main trait of incremental risks. On the contrary, external risks which represent incidents are discrete risks. Continuous or discrete risks are characterized by a single large change of low-frequency but high-consequence events.

In quantitative risk assessment one pivotal distinction of risks is directly tied to the underlying uncertainties. Thus, we have to refer to *aleatory* (data) and *epistemic* (model). The table below indicates the difference between these two risk categories (Table 11).

Table 11. Model and data risks classification

Risk category	**Uncertainty**	**Example**
Data / Aleatory Model / Epistemic	Data used for calculations Inability to accurately calculate a value	Materials cost Soil characteristics and correspondent technical calculations

In this study, risk identification is performed as follows:

1. The risk category chosen is <u>technical</u> risks. We are dealing with on-site (actual construction) risks.
2. The risk category lies to the <u>internal</u> one. We are dealing with cost variations incrementally measured and thus with model or epistemic uncertainty.
3. All risks are collected throughout <u>bibliographic search</u>. No specific tool, such as checklists is deployed. However on the provided list of risk factors as provided in Appendix 2.
4. Risks are classified in <u>cost categories</u> defined as <u>cost drivers</u>. These four drivers are the following: quantity (Q), unit cost (UC), schedule (S), and global (G) (Cooper et al. 1985).

3.2.2.3 Risk Assessment: Risk Analysis & Risk Evaluation

A complete risk assessment combines both qualitative and quantitative assessments. The qualitative approach assists in screening and prioritizing risks and for developing appropriate risk mitigation and allocation strategies. The quantitative assessment is best for estimating the numerical and statistical nature of the project's risk exposure (Ashley et al. 2006, p. 15).

In a construction context, risk analysis should be undertaken by the client to reduce uncertainty and risk, pursue efficiency, and check the risk expected cost balance (Singh & Goel 2006, p. 140). Risk analysis and evaluation is defined by Al-Bahar and Crandall (Al-Bahar & Crandall 1990, p. 539) as a process which incorporates uncertainty in a quantitative manner, using probability theory, to evaluate the potential impact of risk. These two intermediate steps are the connectors between identifying and actually managing risk factors.

Based on the followed analysis and evaluation strategies the upcoming decision-making will formulate an appropriate strategy, which will further affect the risk allocation decisions. Analysis and evaluation alternatively serve as the quantification process of risks. Quantification is what Williams (Williams 1995) had defined as the magnitude and frequency or time frame of each event.

Risk assessment has to deal with two aspects. These are the following, as defined in the guide addressed to the U.S. Department of Transportation (Ashley et al. 2006, p.15):

1. To determine the likelihood of a risk occurring (risk frequency)
2. To judge the impact of the risk should it occur (consequence severity)

The importance of the precise numerical assessment of risks was enlightened by Grose (Grose 1990). Several risk analysis tools are developed to enter this calculative process of analyzing risks (Guo 2004, pp. 55-56). The most frequently risk analysis techniques are shown in the table below (Table 12). Del Cano and de la Cruz (Del Cano & de la Criz 2002, p. 481) had also collected the main risk analysis techniques in their article, and they had categorized in two basic groups, qualitative and quantitative ones (Table 12). Another popular distinction regarding risk analysis methods is the one of Kangari and Riggs (Kangari & Riggs 1989) who distinguished risk analysis and risk evaluation techniques between (a) classical models (probabilistic analysis) and (b) conceptual models (i.e. fuzzy sets theory).

Table 12. Risk analysis techniques

Qualitative techniques	Quantitative techniques
Probability and impact description	Sensitivity analysis
Assumptions analysis	Probabilistic sums
Probability-impact risk rating tables	Monte Carlo and Latin Hypercube simulation
Data precision ranking	Probabilistic influence diagrams (e.g. Bayesian Belied Networks)

Table 13. Main risk analysis techniques

Qualitative	Quantitative
Probability and impact description	Sensitivity analysis
Assumption analysis	Probabilistic sums
Checklists	Monte Carlo and Latin Hyper Cube simulation
Probability/Impact tables	Probabilistic influence diagrams
Data precision ranking	Expected value tables
Flowcharts	Decision trees
Influence diagrams	Event and fault trees
Cause/Effect diagrams	Multi-criteria decision making methods
Event and fault trees	Fuzzy logic
	Processes simulation
	Systems dynamics
	Portfolio theory
	Delphi method

◊ **Quantitative methods**

Traditional risk assessment for construction has been synonymous with probabilistic analysis (Liftson & Shaifer 1982). To be reliable with their results, all these probability-based methods have to use parameters that are exclusive and independent. However, the majority of construction projects including buildings are characterized by a variety of interconnected and complex risk factors of subjective nature.
Four probabilistic methods are recognized for construction cost estimating in risk assessment: (1) direct analytical techniques, (2) the central limit theorem, (3) approximation for a general function and (4) simulation (Diekmann 1983, p. 304).

All the quantitative techniques serve one central purpose summarized in the following points:

- Assess the likelihood/probability of the risk occurring.
- Assess the possible consequence (relative impact) of the risk assessed at that moment of analysis.
- Determine the frequency of the risk occurring by classifying them.
- Assign an acceptance score to each risk category or risk factor separately.

Irrespective, the probabilistic method that a cost engineer intends to use, the following five questions are important to be answered beforehand somebody deploys a method in order to select the most suitable one. These questions are the following as written in (Diekmann 1983):

1. What data are available for each cost element (X_i)?
2. Are the individual cost elements (X_i) strongly correlated or are they relatively independent?
3. What data for the final cost (Y_i) are required? Is the mean and variance sufficient, or is the probability distribution function for Y needed?
4. Does the model contain only additive or multiplicative combinations of X_is, or are there other more complex forms?
5. How many cost elements are there in the model?

All the five questions above will be tackled in the fourth chapter entitle as "Model Design". The present study will utilize the Monte Carlo simulation quantitative method. Monte-Carlo simulation is the tool for quantifying the project cost performance under the specific risk conditions implied by the author to his survey's respondents. Historically, Monte-Carlo simulation is highly used as it is popular tool for modeling various kinds of relationships in a quantitative manner (Vose 2008). Monte-Carlo is a sort of a stochastic simulating algorithm which requires a set of random numbers to be generated. The aim of using a Monte-Carlo tool is to test several interconnected options. The algorithm is repeated as many times as the confidence level defines and in the end a probability distribution is projected. Monte Carlo technique has been in the past extensively used for:

- assessing the risk effects on the overall project cost and schedule in large transportation projects (McGoey-Smith et al. 2007).
- assisting contractors to decide on their bid price with associated certainty levels (Sammoura & Elsayed 2008).
- conducting probabilistic cost risk analysis and plotting distribution of finish dates in oilfield development projects (APM, 1992; Simon et al. 1997).
- determining total activities' costs by combining base costs and risk costs (Molenaar 2005).
- pricing insurance premiums against construction risks not beyond the control of contractors (El-Adaway & Kandil 2010).
- determining the contingency reserve amount through quantitative risk analysis while optimum budget allocation decisions have to be taken (Sato & Hirao 2013).
- choosing among different potential investments and projects (Smith 1994).

It should be pointed out that the risk quantification process is very much based on subjective judgments of project personnel. Empirical data are usually insufficient to quantify the uncertainty. Simulation, fuzzy logic and influence diagrams are generally applied to deal with the problem of ambiguous or insufficient uncertainty-related information. Making judgments of uncertainty in a quantitative manner minimizes ambiguity. In this process of assigning values to each risk factor, *we do not expect that participants in the process will have strong feelings of which probability distribution to select"* (Smith et al. 1999, p.35). Thus from a risk analyst perspective, we have to define in the risk model (as designed in chapter 4) a set of distributions representing the probability and impact values of each single risk factor.

Although, Kangari and Riggs (Kangari & Riggs 1989) noted that the majority of the classical risk assessment models are based on numerical data for some probabilistic factors there are not sufficient statistical observations to develop a pattern. This need for updated information leads to a solution based on Bayesian updating approach or more generally a linguistic-based approach. In the real construction world, there are many situations where the quantitative and detailed information to evaluate uncertainty is not available. These conceptual factors can be expressed in qualitative or linguistic terms that are the so called fuzzy information (Kangari & Riggs 1989, p. 127). Uncertainty factors such as "bad weather", "poor design," or "weak management" fall into this category (Kahneman et al. 1982).

As a third option for performing risk assessment, Influence Diagrams (IDs) and their extension Bayesian Belief Networks (BBNs) constitute a powerful solution for illustrating complex schematic representations of interrelated probabilities. In this third category, researches try to satisfy the requirements of the four main elements of decision-making problems under uncertain information (Howard & Matheson 1984). The influence diagramming method was used by (Dikmen et al. 2007) for constructing a risk model which was combined thereafter with a fuzzy risk assessment for estimating construction risk overruns. In tunneling projects, in order to cope with the problem of scarcity of risk-related information a BBN-based approach was applied to capture risk-decision making knowledge (Cárdenas et al. 2013).

The present study deploys the first category of solutions for performing risk assessment, the Monte Carlo simulation method as will be discussed in the forthcoming chapter.

◊ **Qualitative methods**

Risk /Impact matrices are with checklists the most frequently qualitative methods in risk assessment. The screening of risks is conducted throughout checklists formulated based on the experience of past projects. The prioritization of risks is conducted by using matrices. Two dimensional tables of risks which depict the frequency (likelihood of occurrence) and the severity of consequence (relative impact) of them are drawn to separate minor, moderate, and major risks. The U.S. Department of Energy (DoE) also uses the same tables to qualitatively screen the risk identified (NRC 2005, p. 25). These frequently used Probability–Impact (P-I) matrices are usually layered into five by five zones and were used in the study conducted by (Ashley et al. 2006).

3.2.2.4 Risk Response & Risk Monitoring

All construction projects are dynamic as the daily operations are full of internal risks. This reality calls for developing risk response plans throughout the entire lifecycle of projects. This constant change in all the phases of project was observed also by Tah and Carr (Tah & Carr 2000, p. 491) who raised the attention on the increasing complexity and the necessity for businesses to rethink the ways with which they treat risks. Responding to a risk or an uncertainty demands a dynamic approach depending on the magnitude of it. The greater the uncertainty associated with a project, the more deliberate the response must be (Mills 2001, p. 249). Risk response is the action plan for risk mitigation. Furthermore, risk mitigation strategies should be implemented during the entire lifecycle of a project. There are some basic actions to mitigating risks; these are (Bu-Qammaz 2007, p. 46):

- Reducing or eliminating of the risk
- Transferring the risk
- Insuring the risk
- Avoiding the risk
- Absorbing the risk
- Obtaining better information to reduce the uncertainty

Similarly, three basic types of response to risks exist (Smith et al. 1999, p. 88):

- Avoiding or reducing the risks
- Transferring the risks
- Retaining the risks

The formulation of risk responding plans entails searching for and classifying responses for each identified source of risk. Chapman and Ward (Chapman & Ward 1997a, p. 114) consider nine types of generic response types (Table 14).

Table 14. Generic risk response types

Type of response	Method of handling uncertainty
Modify objectives	Reduce or raise performance targets, change trade-offs between multiple objectives.
Avoid	Plan to avoid specified sources of uncertainties.
Prevent	Change the probability of occurrence.
Mitigate	Modify the impact of a source of uncertainty.
Develop contingency plans	Set aside resources to provide a reactive ability to cope.
Keep options open	Delay choices and commitment, choose versatile options.
Monitor	Collect and update data about probabilities of occurrence, anticipated impacts, and additional risks.
Accept	Accept risk exposure, but do nothing about it.
Remain unaware	Ignore the possibility of risk exposure, take no action to identify or manage risk.

Some mitigation methods including percentage sharing of overruns, awarding time but no money, limiting the types of costs that can be recovered, setting liquidated damages rates lower than justifiable, and using liability caps are already described in the bibliography (Norris et al. 2000). The sharing of risk gives both parties incentive to avoid and mitigate the threat of cost overrun, therefore minimizing the total cost of risk on a project (Diekmann et al. 1988).

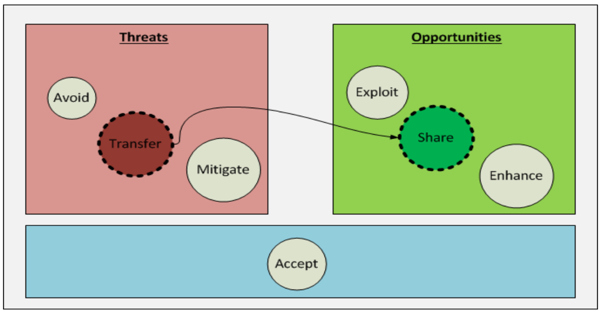


Figure 32: Risk response actions (WSDOT 2012)

A more elaborated view will be paid on the upcoming section, as risk allocation is considered to be the outcome of risk-sharing decisions. In general, risk can be manageable, transferable, acceptable or reducible, but it is not often possible to be eliminated (Lam et al. 2007). The Washington State Department of Transportation describes risk seven basic response actions as shown above (Figure 32).

3.2.2.5 Risk allocation

The curve of cost in a project's lifecycle consists of four basic stages – concept, planning, and execution, termination (operation and maintenance). The planning phase consists of the design, plan, and allocation. Ward and Chapman (Ward & Chapman 1995, p. 146) defined the following activities in the allocation stage:

- The establishment of a base plan
- The development of targets and milestones
- The allocation development
- The allocation evaluation

The objectives of risk allocation can vary depending on unique project goals, but four fundamental tenets of sound risk allocation should always be followed (Ashley et al. 2006):

- Allocate risks to the party best able manage them
- Allocate the risk in alignment with project goals
- Share risk when appropriate to accomplish project goals
- Ultimately seek to allocate risks to promote team alignment with customer-oriented performance goals

The literature review's target is to identify a unique list of construction uncertainties and construction risks arising during the execution of building projects. This mindset motivated the review's direction towards risk allocation and risk misallocation phenomena. A risk allocation problem concerns both qualitative issues (what type of risk is allocated and to whom) as well as quantitative issues (how much of the risk is allocated) (Yamaguchi et al. 2001, p. 886).

□ *"Qualitative approaches towards risk allocation"*

The most common method to evaluate risk allocation between construction parties is a questionnaire survey. In a recent study (Peckiene et al. 2013, p. 892), an overview of risk allocation evaluation tools was presented. Questionnaire surveys were classified as first with a 55% of agreement, game theory second (18% agreement) and fuzzy sets (AHP, TOPSIS) with Delphi survey ranked as the bottom three with 9% of agreement each.

Kangari (Kangari 1995) identified 23 risk factors and after conducting a questionnaire survey explored the risk allocation trends governing the U.S. construction industry. With paying more attention on the risk-clauses ambiguity, other authors (Hartman et al. 1997) tried to reduce the subjectivity in the interpretation of risk clauses in lump-sum contracts. This was the first serious effort in reducing diffusion and differences in contract's clauses, having as result to improve the overall quality of the contract and enhance a common understanding of clauses between contractors, consultants and contractors. Bing, Akintoye, Edwards, and Hardcastle (Bing et al. 2005) conducted a questionnaire survey to explore preferences in risk allocation for PPP and PFI contracts in the UK. The previous qualitative efforts were extended by researching how risk allocation was organized among construction stakeholders under a systematic risk management scope (Uher & Davenport 2009).

Qualitative approaches are limited in addressing such issues as: to what extent the parties share the various risks; and how to rank possible strategies of risk allocation according to their impact on, for example cost, efficiency and satisfaction (Levitt et al. 1979). For this reason it is highly interested to investigate the advantages of the quantitative techniques of risk allocation.

□ *"Quantitative approaches towards risk allocation"*
Cooperative risk allocation assumes that the stakeholders jointly search for an agreement that is mutually acceptable. This is the fundamental principle of reaching a risk-sharing agreement between contractors and clients.

Most quantitative studies of risk allocation have defined the optimum solution as the allocation where the <u>total contingency costs of the project are minimized</u>, a target that in itself assumes cooperation between the stakeholders (Yamaguchi et al. 2001, p. 887). Project entities in order to cooperatively find the optimal point of risk allocation; they need to combine their competitive attitude with the necessity for achieving a best value contract. In this sense decision-making must be modeled by using decision sciences tools and algorithmic programming.

Arndt (Arndt 1998) looked from an investment scope how risk allocation in a public megaproject, the Melbourne City Link project, can affect the project performance. The quantification and optimization of the risk allocated in Private-Financed-Incentive (PFI) contracts was investigated by (Arioka 1997; Arndt 1998).

Decision-support models for optimal risk allocation as was stated above require the use of dynamic modeling systems and computer engineering. In this light of research several efforts have enlighten the optimization process throughout the use of fuzzy logic theory, adaptive systems and game theoretic models. Although the examination of the "optimality problem of risk allocation" is out of this study's scope, in Appendix 5 it is provided a complete overview of risk allocation related research in the three aforementioned scientific areas. This bibliographic search assisted the author to collect and discuss which construction risks should be included in the present thesis.

Risk misallocation: A construction literature consensus

Inappropriate risk allocation is most commonly accomplished through direct contract language since such provisions are required to formalize agreements (Hanna & Swanson 2007). The literature study does not focus only on the contractual side of misallocated risks but on the poor risk sharing practices which inevitably will lead to losses and increased claims. A reality already showcased in the American construction industry (Hanna 2007).

It is not uncommon to find projects in the construction industry with poor project performance that result from cost overrun, schedule delay, and poor quality – resulting from suboptimal risk allocation (Shen 1997). The same conclusion was drawn by AlSalman and Sillars (AlSalman & Sillars 2013) who had summed up that:

- Poor project performance – deterioration of the goals of cost, schedule, or quality – is quite common.
- Naive pricing of risk is a common factor of the current practice of risk allocation.
- Misallocation of risk which is defined as allocation to parties that cannot manage the risk or withstand the consequences (or both), leads to poor project performance. One major sub-factor of misallocation is allocation by aversion, a fact already exposed in Figure 3.

Therefore appears to be a consensus in the reviewed literature that poor risk management and sub-optimal risk allocation can lead to disputes, tension, delays, and cost overrun in construction industry projects. Risk misallocation in tunneling projects as a phenomenon leading to cost-overruns and delays is observed (Baker et al. 1999). Past research results are supported by the modern trend of using disclaimer clauses to allocate risks adds a premium amount of between 8% - 20% to the final bidding price (Zaghloul & Hartman 2003). This shows the need for making aware owners that being too much risk aversive may work against them, as the contractors if unrealistic risks are transferred to them, they will react by transferring the risk back (Ng & Loosemore 2007).

If contractors are treated unfairly they have two decision-options: firstly they will simply include in the bidding price an additional covering amount (contingency) or secondly they will fail to accomplish their tasks due to financial losses. The cost of improper risk allocation could be seen from the response from contractors such as adding a high contingency to the bid price or delivering low quality work (Lam et al. 2007, p. 485).

Risk-sharing behavior is a multi-level process determining the appropriateness of consequent risk allocation. Thus the appropriateness of risk allocation is of pivotal significance. If inappropriate allocation of risks, imposed by project owners, exceeds a given amount then it can be assumed that:

1. Contractors will transfer directly possible contingencies to be covered.
2. Additional costs for executing risk management processes will be transferred to owner.
3. Project's quality will be reduced due to lack of contractor's motivation to retain project cost-estimates on track.
4. Contractors will embody an extra amount in the bidding price to cover legal claims costs.

The above four points are what was stated as "Defensive Strategies" in Figure 3. In this study, the previous four assumptions will be explored. The study will measure:

1. The size of the transferred contingencies from contractors to project owners.
2. Additional costs for executing risk management processes cannot be quantified.
3. Change in project quality cannot be quantified.
4. The extra amount set by contractors in the bidding prices cannot be quantified as the study does not focus on the bidding process, but on the execution stage of building projects. Consequently the focus is located on the contingency embedded in the target total cost by contractors into their initial cost estimations.

Overall, the study's approach regarding Risk Management is outlined below.

Risk Management in this study

Risk Identification

✓ A generic risk checklist will be prepared. The list includes 27 construction risks.

✓ No interviews are conducted. However participants can fill in their opinion for future improvements.

✓ Risks are classified based on 4 cost drivers: Quantity, Unit Cost, Schedule, and Global.

✓ Only construction-related risks will be assessed.

Risk Assessment

✓ Project's risk level and cost risk quantification are computed in an excel sheet by using @RISK, an excel add-in performing Monte Carlo simulation.

Risk Response – Contingency allocation

✓ The generated cumulative distributions provide the needed information for determining the level of contingencies set in every building phase and for the total project.

RM Model

✓ The study's model is adopted from Hobbs (Hobbs 2010).

3.2.3 Risk sharing: From theory to motivation

3.2.3.1 Factors shaping risk allocation decision-making

From the moment that the decision to draft the design of a building until the new facility is in use, the client is uncertain about the outcome of the project. "Will it be finished on time?", "What will it finally cost?", "Will it perform as it was intended to?" These questions posed three decades ago by Barnes (Barnes 1983) still remain the main drivers for both parties; owners and contractors, to decide the risk-sharing formula fitting to both.

Different approaches exist when analyzing who, between owners and contractors is more risk aversive. Erikson (Erikson 1979) for example sees contractors risk aversive and clients more risk neutral. On the contrary, in public traditional procurement, many public owners, for example, are allowed to bear very little risk of the final cost of the project (Gordon 1994). Thus there is no a rule about the general attitude on risk bearing as it is the amount of financial risk the owner is willing or allowed to bear is important in determining the contract type. In general, appropriate risk allocation might be based on the willingness (risk sharing behavior) of project parties to take on a risk (Ward et al. 1991). However, willingness to bear risk will only result in conscientious management of project risks if it is purely based on (Chapman & Ward 1997a, p. 274):

1. an adequate perception of project risks,
2. a reasoned assessment of risk / reward trade-offs,
3. a real ability to bear the consequences of a risk eventuating,
4. a real ability to manage the associated uncertainty and thereby mitigate risks.

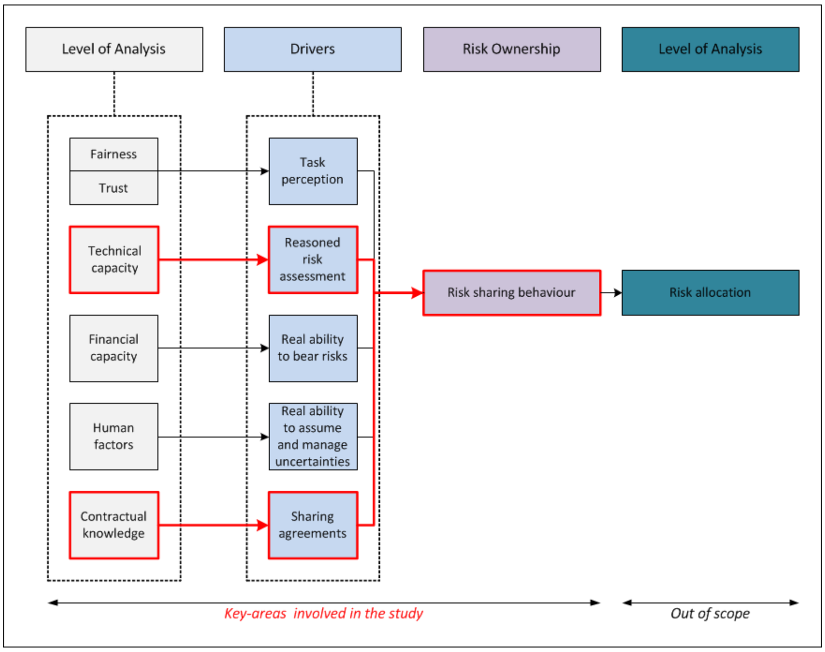


Figure 33: Factors leading to appropriate risk allocation

Figure 33 depicts above the layers involved into an appropriate risk allocation decision. The driving forces in the 'red boxes' which are the <u>technical capacity of performing a reasoned risk assessment</u> and the <u>contractual knowledge of sharing agreements</u> will be evaluated as the two sub-criteria of "risk propensity".

3.2.3.2 Risk sharing principles

Singh and Goel (Singh & Goel 2006) presented a conceptual model of risk sharing in geotechnical projects, dividing equitable and inequitable sharing of risks. The International Tunneling Association (ITA) has drafted many articles and guidebooks on the types of contracts and risk management strategies for underground projects (ITA 1996). Some practical preliminary guidelines have been developed to indicate when a party is appropriate to bear the risks (Baker et al 1999b). This study suggested the following five conditions clarifying when a contracting party is appropriate to be transferred risks, if:

1. the risk is of loss due to his/her own willful misconduct or lack of reasonable efficiency or care.
2. he can cover a risk by insurance and allow for the premium in settling his charges, and it is most convenient and practicable for the risk to be dealt with in this way.
3. the preponderant economic benefit of running the risk accrues to him.
4. it is in the interests of efficiency to place the risk on him.
5. when the risk eventuates, the loss happens to fall on him in the first instance, and there is no reason under any of the above headings to transfer the loss to another, or it is impracticable to do so.

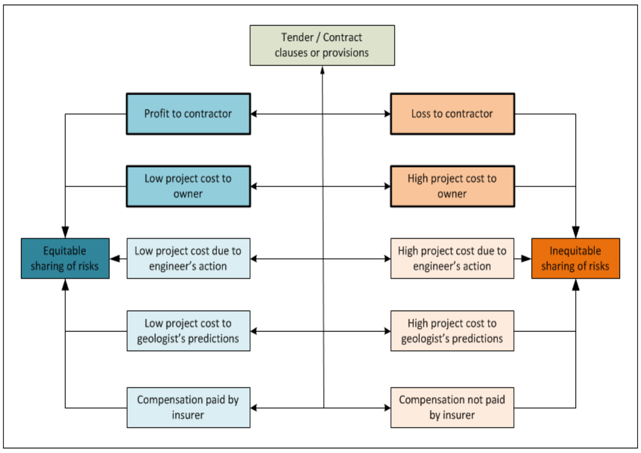


Figure 34: Conceptual model of risk sharing

The above principles are implemented with a distinct way depending on the procurement path selected by the project promoter. A summary of all past research work on contractual risk allocation is presented in Table 15. It is interesting to notice that no specific allocation rules are published in traditional procurement; a fact providing more incentives for the present study.

Table 15. Classified bibliography on risk-allocation mechanisms

Procurement system	**Research focus**	**Reference**
CM@R	Prequalification of contractors	(Kwak & Bushey 2000)
D-B-B Vs. D-B Vs. CM@R	Cost, Schedule, Quality indicators	(Konchar 1997)
D-B D-B	Risk allocation efficiency Allocation through RFPs	(Adnan et al.2008) (Molenaar et al. 2000)
PPP Vs. BOT	Responsibilities transfer from public to private sector	(Chee & Yeo 1995, p. 275)
PPP & PFI	UK-Public sector risks	(Li et al. 2001; Bing et al. 2005; Nisar 2007)
PPP	China-Public sector risks Greece- Public sector risks	(Ke et al. 2010) (Jin & Doloi 2008) (Roumboutsos & Anagnostopoulos 2008)
TCCs	Incentives for contractors Cost savings	(Chan et al. 2007) (Lahdenperä 2010)

3.2.3.3 Risk sharing: Implications & Motivation

The fundamental principle of cooperative risk allocation between contractors and clients remains valid. The observation that *"the total contingency costs of the project should be minimized to achieve an optimum risk allocation"* is the driver of exploring the formation of risk-sharing agreements.

The concept of risk sharing has often been discussed and sometimes seen as a new form of contractual agreement between a client (buyer) and a contractor (seller) who is assigned a project and legally obligated to deliver a product. Risk sharing agreements have gained more space in the negotiation process in all industries. The upcoming section discusses briefly the bibliographic search results in "risk sharing" tailored to the construction industry.

Risk sharing in the construction industry

Risk sharing is usually set as a platform of designing and integrating sharing rules in contractual project forms following the GCW (Government Contract Work) and FIDIC (Fédération Internationale Des Ingénieurs-Conseils) standards. The construction-related research is focused on comparing how much efficiently these sharing risks rules perform for endogenous and exogenous risks (Onishi et al. 2002).

Several studies have contributed towards the development of risk sharing models. Some models raised the focus on the design of optimal contracts or optimal sharing ratios. Other scholars paid attention on the explanation of the advantages of specific sharing principles. In Appendix 6, various risk sharing approaches are summarized and interested readers are strongly adviced to pay some attention into it.

Wieland and Meinholz (Wieland & Meinholz 1983) while researching how equitable risk sharing and dispute & claims resolution could be achieved for a complex project, achieved to prove that:

"If risks are shared, the contractor can reduce the amount for contingency costs which he includes in his bid."

This rationale observed and clarified by this past American study sets a strong incentive for investigating to which extent risk sharing in traditional building procurement enhance transfer efficiency and what is the impact of sharing decisions on the project cost performance.

Design of contractual incentives

Scherer (Scherer 1964) discussed the theory of contractual incentives for cost reduction. He assumed a constant value of the sharing proportion and tried to maximize contractor and government (owner) profit. As was previously noticed the design and integration of incentives into a project contract depends also on the risk-bearing behavior of parties. Scherer pointed out the special attention that should be paid on the risk-aversion theory regarding contract incentives formation.

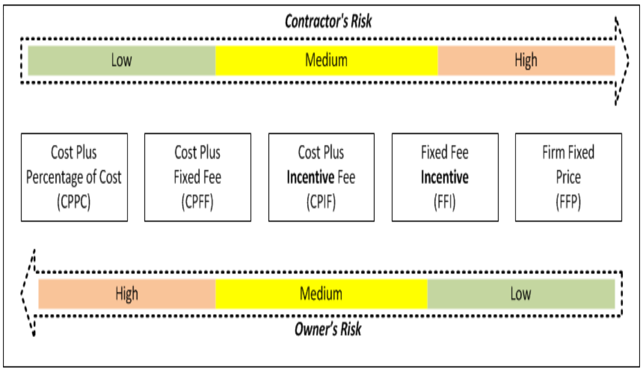


Figure 35: Contract type Vs. Risk level

Incentives however are not independent from the risk encapsulated into the various contract types. Contractors and owners have opposite risk-taking attitudes while entering into a contract negotiation. Cavendish and Martin (Cavendish & Matin 1987) presented for various types of contracts how the two parties will tend to bear risks (Figure 35). Fixed Fee Incentive contracts are in detail discussed in the article of (McCall, 1970). In this research, risk-sharing is investigated under the regime of government (owner) and private sector (contractor) contracts in a non-competitive bidding environment.

Baron (Baron 1972) based on the economic procurement model of McCall (McCall, 1970) focused on the effect of the terms of the contract and the firm's (contractor's) attitude toward risk on the bid price. Baron examined how risk attitude has an impact on the bidding behavior of a firm in a competitive bidding context.

Risk sharing in firm fixed price construction contracts was discussed by Erikson (Erikson 1979) who used the utility theory to develop a model showing the cost effects of varying risk shares. Gandhi (Gandhi 1979) explored alternatives to the current practice of making single-stage choices of incentive sharing rates in government contracts.

Overall, the study's approach regarding Risk Sharing is outlined below:

Risk sharing in the study

Motivation

- ✓ No past study was dedicated regarding risk sharing agreements in the post-bid context of the traditional building procurement.
- ✓ Risk sharing is mainly approached as a mathematical vehicle for designing an optimal contract. Contractual incompleteness was seen as the main driver behind each research. Consequently the financial choices of contractors regarding their target profits and their perception on quantifying the cost impact of uncontrollable risks were often ignored.
- ✓ In the reviewed bibliography project delivery (in)-efficiency was not examined leading clients to trasnfer unfair cost risks to their contractors.

Variable level

Risk sharing is considered as the variable providing incentives for the contractors involved into a traditional contract. A simple intuition of the risk sharing variable is that the higher the value of the sharing ratio, the more risk taker (or risk seeking) is a contractor, and vice versa.

Measurement level

Risk sharing is measured as a percentage depicting the risk-taking behavior of contractors. Risk sharing in this study has a similar role as the *cost share parameter* as was used in the financial research of Reichelstein (Reichelstein 1992), as the *sharing rate* in past seminal economical papers (McCall 1970; Canes, 1975) and as the *incentive profit rate* expressing risk-sharing decisions (Baron 1972).

Mathematical expression

$$P = F + \overbrace{b \times (E - C)}^{Incentive\ \ profit} \tag{9}$$

Where:
P = price of contract
F = fixed fee
b = cost sharing ratio
E= (base) estimate
C = (expected) cost or budget

The above formula is the simplified expression of the widely used in the "economics of incentive contracting". Equation (10) is written by Canes (Canes 1975) and Equation (11) is written by Reichelstein (Reichelstein 1992).

$$\pi = \overbrace{\alpha \times \rho}^{Target\ \ profit} + \overbrace{\beta \times (p - C)}^{Incentive\ \ profit} \tag{10}$$

$$H(x) = \overbrace{\alpha}^{Target\ \ profit} + \overbrace{b \times (T - x)}^{Incentive\ \ fee} \tag{11}$$

MODEL DESIGN

Chapter **4**

4.1 Introduction

4.1.1 Project risk analysis

Project management techniques are tightly connected to risk analysis methodologies drafted by leading research bodies such as the Project Management Institute (PMI), the Association for Project Management (APM) and the Office of Government Commerce (OGC). Their studies focus on determining the likelihood/probability of occurrence of risk-events and their degree of impact on project objectives: time (schedule) and cost components. Risk events as identified throughout the literature review impose either negative outcomes (e.g. financial losses, schedule delays) or positive outcomes (e.g. benefits from reduced claims).

The beginning of each project's risk analysis initiates with the "Risk Identification". A three steps approach was followed as shown below in Figure 36 which achieves to:

1. Gather in a generic list all the construction risk mapped during the literature review.
2. Characterize the probabilistic profile of each individual risk. Fixed (F) or Variable (V) are the options in this decision.
3. Describe the driver and the event behind each individual risk.

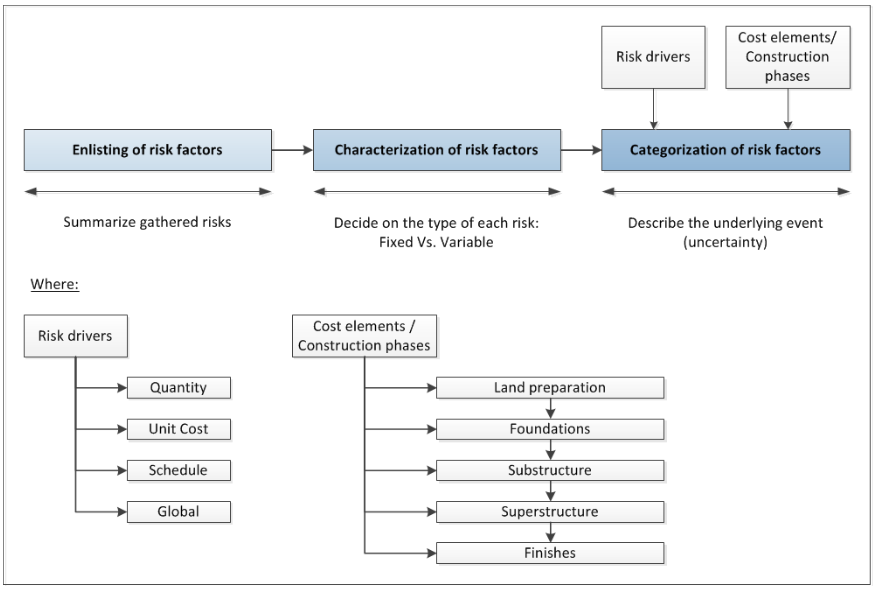


Figure 36: Risk identification logic approach

Utilizing the results from the second searching phase of the systematic literature review a generic list of construction risks was extracted. This list is the outcome of the bibliographic review as presented in Appendix 2. After enlisting the risks identified we characterized the risk factors as Fixed (F) or Variable (V).

Fixed risks are risks that either occur or don't (with probability each). When these risks occur, they have a range of effect which can be described with a probability density function. An example of a fixed risk is the additional costs due to delayed planning of legal permissions, in case that a client or his/her contractor wants to transfer sensitive equipment through a traffic circle at an intersection, this might have a 40% probability to happen and consequently a 60% probability of not happening.

Variable risks are risks that will certainly occur but their impact is quantified over a range of values. For variable risks thus, the assignment of probability of occurrence is 100%. The impact of variable risks in the cost elements/activities of a project is introduced with a value of 1. Errors or omissions in design specifications are risks that certainly will emerge due to the human factor.

In total 27 "unique" (not repeatable) risk factors were identified. These risks were classified based on 4 cost risk drivers which are: quantity, unit cost, and schedule and global. These drivers were firstly introduced by Cooper, Mac Donald and Chapman (Cooper et al. 1985) and later adopted by Baccarini and Panthi (Baccarini 2004; Panthi 2007). This classification lead to the following project risk taxonomy as presented below.

Table 16. Project risk taxonomy

Cost drivers	**Construction (on-site) risks**
Quantity	R1: Removal of obstructions and existed structures R2: Additional costs for inspection and removal of buried contaminants R3: Costs of stabilizing sloped or landslide ground parts R4: Costs of damages due to ground subsidence in existing projects R10: Underestimated stiffness of support systems R11: Settlements in the surrounding due to vibration during pit-wall construction or due to deformation of the pit-wall R12: Additional costs due to finding of cultural buried heritages R18: Costs of reinforcing under-designed diaphragm walls
Unit Cost	R5: Rework costs due to incomplete dewatering R6: Deflection of earth retaining walls in deep excavations R13: Rework costs due to wrongly connected formwork and inappropriate scaffolding R14: Fixing costs of deflected earth retaining walls R15: Additional costs of waterproofing box type basements R26: Incomplete surface treatment (e.g. flooring, plastering, painting) R27: Inefficient tightness test (e.g. gas, air leakage, acoustics, heating system, drainage water)
Schedule	R16: Liability costs of damages after the excavation to existing third party structures R17: Leaking substructure due to insufficient inspection R19: Costs of installation delays of prefabricated or in-situ elements R20: Costs of transportation delays of prefabricated or in-situ elements R21: Additional transportation costs due to unavailability of "purpose-built" plant R24: Rework costs due to inaccurate installation of insulations R25: Rework costs due to faulty adjustments of electrical components
Global	R7: Protection costs due to unsafe access to excavation site R8: Additional costs of permits related to safety and health issues R9: Rework costs of permits due to water inrush R22: Costs of re-planning waste management practices and determining proper locations R23: Accident costs due to incorrect lifting practices or lack of handling equipment

The detailed view of the Risk Breakdown Structure (RBS) can be found in the second appendix. The significance of executing continuous risk analysis lies in the power provided to contractors and project managers to plan their financial, mechanical, material and labor resources in a cost-effective way. On-going risk analysis provides project managers with the opportunity to organize the development of contingency plans and funding (Wallace 2010, p. 5). The risk assessment can be performed both qualitatively and quantitatively. The present study utilizes primarily a quantitative approach. The quantitative part of the assessment completes two actions:

a) Assigning numeric values to the probability of occurrence of all risks involved within each construction phase or cost element. The discrete probability density function was chosen for "fixed" risks and a value equal to 1 (100%) was set for "variable" risks.

b) Estimating the potential impact of each construction risk category by using a 3-point estimates (best case, most likely, worse case). The Trigen probability density function (PDF) will be utilized in our model for determining the monetary impact range of each individual risk. The Triang_probability density function was used to specify the most likely value of the base estimates, given that a standard error was often admitted by the contractors.

The two actions assist to quantify the total effect of each individual risk in the project for every of the five construction phases approached as cost elemental categories.

4.1.2 Monte Carlo simulation for probabilistic analysis

The most fundamental question to answer is: *"Why to use Monte Carlo (MC) simulation in this study?"* Two reasons are covering this issue: (1) The final outcome of the calculations performed is depended on an unknown relationship between all the risks involved in the five construction phases of a typical building project. All the construction phases in the execution of a building are interconnected in terms of schedule and budget decisions without having although a clear mathematical connection. (2) All the risks involved in each cost element/construction phase are unknown variables. Consequently it is needed a set of random distributions to model them.

The MC method, as it is understood today, encompasses any technique of statistical sampling employed to approximate solutions to quantitative problems[5]. A system or a real-life situation is developed and described by correlated or uncorrelated system-specific variables. These variables have different possible values which are represented by probability distribution functions of the values for each variable identified in the system. The MC method simulates the system many times (hundreds or thousands), each time randomly choosing a value for each variable from its probability distribution (Kwak & Ingall 2009, p. 45). The outcome is a probability distribution of the overall value of the system calculated through the iterations of the model (Kwak & Ingall 2009, p. 45).

The Project Management Institute (PMI) had defined the MC method as:

"A technique that computes or iterates the project cost or schedule many times using input values selected at random from probability distributions of possible costs or durations, to calculate a distribution of possible total project cost or completion dates (PMI, 2004a)".

In Monte Carlo simulation, risk and uncertainty is represented by probability distributions which recognize that each value in a range of potential outcomes has its own probability of occurring. Probability distributions are therefore a much more realistic way of describing uncertainty in risk analysis (Wallace, 2010, p. 6). Monte Carlo becomes important in project managerial decisions as it enables the project manager to justify schedule reserves, budget reserves or both with the issues that could adversely affect the project completion. The output accuracy of the MC results, regardless the scope adopted (budgeting, scheduling or both) depends on the iterations number and on the subjective input required before the simulation.

Monte Carlo method, although constitutes a powerful tool in the hands of project or cost engineers, is effective only if it is provided with the appropriate information to simulate. Among its limitations, MC requires accurate input values derived from experts or professionals judgments. The selection of probability distributions is a tricky decision step affecting the final outcome. Kwak and Ingall (2009, p. 50) had noted this, rising the focus on the prior experience and the detailed data from previous projects that project managers should use in reviewing estimates and choosing probability distributions. Two other drawbacks of MC method were reported by Williams (Williams 2003): firstly the requirement for high computing_power plus the resources and time demanded to complete a simulation activity and secondly the very wide project duration distributions that lead to executing unintelligent iterations while assuming no management action."

In respect to the three limitations of MC method as identified above, this study takes the following measures:

[5] http://value-at-risk.net/the-monte-carlo-method/

1. The choice of probability distributions is driven based on the most recent trends on probabilistic cost estimating and it will be discussed below.
2. The high computational power was not an inhibiting factor as the software used (@RISK) is an excel add-in performing smoothly.
3. Project duration distributions were not examined in this study as the focus of the risk analysis is based only on cost.

Previously (in § 3.2.2.3), while analyzing the tools used for conducting risk assessment, we saw that in every stochastic-probabilistic process five questions have to be answered:

1. What data are available for each cost element (X_i)?
2. Are the individual cost elements (X_i) strongly correlated or are they relatively independent?
3. What data for the final cost (Y_i) are required? Is the mean and variance sufficient, or is the probability distribution function for Y needed?
4. Does the model contain only additive or multiplicative combinations of X_is, or are there other more complex forms?
5. How many cost elements are there in the model?

The study addresses these questions, as follows:

1. For every risk of the 27 collected, the available data are: the probability of occurrence and the impact range of each risk. Both data are modeled throughout appropriate distributions and their combination provides an individual level of risk effect. This effect of each risk is then transformed to a cost impact value for the cost line (or cost element) assessed.
2. Whether or not correlations exist among the 27 individual risk factors (X_is) is a very difficult and arbitrary task. From the preliminary talks with the participants, it was seen that they were not enable of providing correlation values. Thus we have to assume no correlations among the 27 individual risk factors.
3. The final cost (Y_i) of each of the 5 elements assessed requires two monetary values. Firstly, the base estimate (E_j) of each cost element. Secondly, the cost risks (C_R) quantification. Both values are obtained throughout the values participants provided in the survey form. Simply the cost element (Y_i) is the sum of the base estimate (E_j) plus the summation of cost risks as shown in the formula below:

$$Y_j = E_j + \overbrace{n * C_{R_i}}^{X_i} \tag{12}$$

   Where:
   Y = cost element (or construction phase)
   j = number of cost elements (range: 1 – 5)
   E = estimate
   n = number of risks assessed in the specific cost element
   C_R = cost risk
   i = number of individual risk factors (range: 1 – 27)
4. The cost risk estimates derived by the application of the model are considered additive. The summation of cost risks (Xis) leads to the total project cost.
5. The execution of building projects was decomposed into five cost elements. The model is constructed based on the sequence of the construction phases as follows: (1) land preparation, (2) foundations, (3) substructure, (4) superstructure, and (5) finishes.

4.1.3 Statistics, Tests & Probability distributions

Statistics is the wide area of mathematics undertaking the summary and analysis of data collected. The field of statistics is divided into two basic groups: descriptive and inferential statistics. Descriptive statistics is a branch of statistics in which data are only used for descriptive purposes and are not employed to make predictions (Sheskin 2003, p. 1). So the use of descriptive statistics aims to present and summarize data. Inferential statistics employs data in order to draw inferences or make predictions

(Sheskin 2003). Typically, sample data are derived to draw inferences about one or more populations from which the samples have been derived.

The statistical tests deployed are divided into: parametric and non-parametric. Parametric is a statistical test when the information about the populations (sample) is completely known by means of its parameters. Frequently used parametric tests are: *f*-test, *z*-test, *t*-test and ANOVA. Non-parametric is called the test when there is no information about the populations and its parameters. A non-parametric test is often useful to test hypotheses regarding the population examined. Frequently used non-parametric tests are: mann-Whitney, rank sum test, Wilcoxon rank/sum test and Kruskal-Wallis test. Below some basic tests are summarized (Table 17).

Various types of probability distributions play a role in modeling expert opinion (Table 18). Probability Distribution Functions (PDFs) can be categorized into: parametric and non-parametric. Vose (Vose 1997) defined as parametric a distribution based on a mathematical function which, combined with one or more distribution parameters which determine its shape and range. These parameters will often have limited obvious or intuitive relationship to the distribution's shape. Vose defined non-parametric distributions as the ones whose shape and range are directly determined by their parameters in an obvious or intuitive way.

Table 17. Parametric and analogous non-parametric tests (Hoskin 2012)

Analysis type	**Parametric tests**	**Non-parametric tests**
Compare means between two distinct/independent groups	Two-sample t-test	Wilcoxon rank-sum test
Compare two quantitative measurements taken from the same individual	Paired t-test	Wilcoxon signed-rank test
Compare means between three or more distinct/independent groups	Analysis of variance (ANOVA)	Kruskal-Wallis test
Estimate the degree of association between two quantitative variables	Pearson coefficient of correlation	Spearman's rank correlation

Table 18. Frequently used Probability Density Functions

Parametric	**Non-parametric (or Distribution free)**
Normal Log-normal Beta Weibull Pareto Log-logistic Hyper-geometric Gamma & Exponential Beta PERT	Uniform General Triangle Double Triangle Cumulative Discrete (e.g. Binomial, Poisson) Beta PERT*

* The beta PERT distribution is frequently used to model an expert's opinion. Although it is, strictly speaking, a parametric distribution, it has been adapted so that the expert need only to provide estimates of the minimum, most likely, maximum values for the variable and then the Beta PERT distribution finds a shape that fits (Vose 1997).

□ *"(Three) Points estimating"*

Traditionally construction cost estimates have been "point-in-time" estimates that represent a single value for the cost of a project and its elements, which can lead to miscommunication among designers, project managers, funders and decision-makers (Hobbs 2010, p. 21). Point estimates are one methodology designed to fit the probability distributions describing the cost of each cost element (i.e. metals, finishes, earthworks) in building projects.

The three-point estimation technique is used in project management for the construction of an approximate probability distribution representing the outcome of future events. When information about risk sources is significantly limited making a judgment from experience is required. Three-point estimates are often made for the cost or schedule effects of project risk. However they may also be used in connection with other important variables. Three-point estimates originated with the Program Evaluation and Review Technique (PERT). This method uses three estimates to define an approximate range for an activities cost: Most Likely (M), Optimistic (O) (or best case), and Pessimistic (P) (or worst case). The cost estimate is calculated using a weighted average, as the next formula shows:

$$Cost\ (Base) Estimate = \frac{O + 4M + P}{6} \tag{13}$$

When using a range-estimating methodology, the cost items are assumed to be random variables rather than known parameters. As a result, a probable distribution of total cost is obtained as compared to a single-point estimate that would be generated in a deterministic cost approach. The resulting probability distribution enables the cost estimator to define cost estimate values that can be associated with prescribed levels of confidence, thus permitting a quantification of the exposure to financial risk (Back et al. 2000). In respect to applying "point-estimates" the most frequently used PDFs associated with 3-point estimates are the Triangular and Beta PERT distributions. Below it is presented the shape of these distributions (Figure 37) and their basic parameters: mean and standard deviation (Table 19).

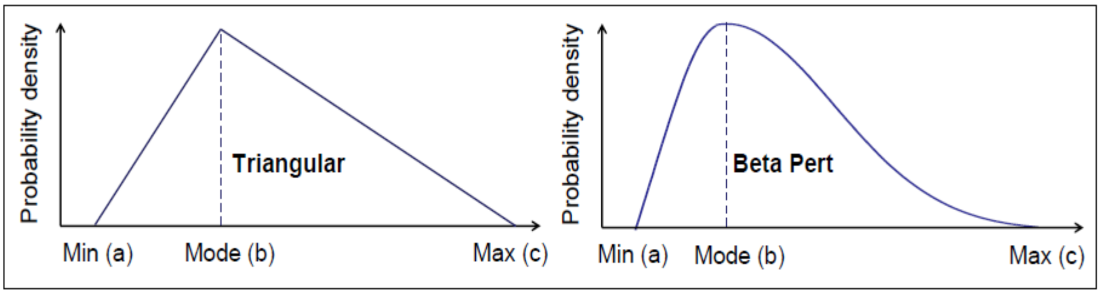


Figure 37: Triangular and BetaPERT PDF shapes

Table 19. Mean & St. Deviation parameters of Triangular and Beta PERT distributions

PDF	Mean	Standard Deviation
Triangular	$\mu = \frac{a+b+c}{3}$	$\sigma = \sqrt{\frac{a^2+b^2+c^2-ab-ac-bc}{18}}$
Beta PERT	$\mu = \frac{a+4b+c}{6}$	$\sigma \cong \frac{c-a}{6}$

Several other PDFs are often investigated and used by scholars. However, triangular distribution has be the dominant in the choice of cost engineering studies. Nemuth (2008, p. 8) recognizes also that for regular and practical cases the triangular distribution with the threshold values (minimum, most likely, maximum) are useful. Other continuous distributions, such as rectangular, beta, normal or uniform distributions could be used. Humphreys (Humphreys 2008, p. 6) points out the use of double triangular distribution in cases where the single triangular implies a probability of overrunning different from the probability assessed by the project team. Touran and Wiser (Touran & Wiser 1992) used a multivariate lognormal distribution for generating correlated random numbers for various construction cost components.

Some researchers have posed their objection against the assumption of using triangular PDFs for modeling cost estimations in construction projects (Chau 1993, 1995b). In the study of Piccardi (Picardi 1972) the lognormal distribution is preferred against the triangular one. Hulett, Hornbacher, and Whitehead (Hulett et al. 2008, p. 14) recommended a switch from the triang to the trigen distribution.

4.1.4 Monte Carlo assumptions

4.1.4.1 Types of probabilities

"Subjective" and "objective" probabilities are the two different types in which the term probability is categorised. The differentiation of these probabilities is based on how they are estimated and the relation to some real world phenomena. A straightforward way for dealing with the two types of probabilities is what Anscombe and Aumann interpreted: objective probabilities are seen as "physical probabilities" or "chances" and subjective probabilities are seen as "logical probabilities" (Anscombe & Aumann 1963). Subjective probabilities are based on expert experience or knowledge of the process at hand.

The measurement of the likelihood as perceived and expected by individuals is dependent on the past experiences and knowledge. The observed preferences of decision-makers defines their subjectivity in the probability measurement as in past studies was widely examined (Ramsey 1931; Savage 1954; Kahneman & Tversky 1974).

Objective probabilities are based on historical data. Observed data on various outcomes (i.e. failures rates, accidents rates, cost overruns) can be recorded and elaborated to produce a range of probability distributions representing them. Objective probabilities represent the *frequentist* school and mathematically are expressed by the "relative frequency" as was seen previously (see in § 3.1).

Due to the uniqueness and fragmented nature of the construction industry, subjective probabilities seem to be used more used than objective probabilities in construction risk management. The lack of historic data or availability of limited suitable data hinders the process of predicting variability in future outcomes (i.e. returns, cost outcomes, contingencies).

The present study deals with subjective probabilities assigned by the contractors onto the risk factors assessed.

Taking the value (estimate) of each cost element as a random variable, X_i, the probability that the cost element takes the certain value can be described by a probability distribution function, $P(X_i=x)$, where x is the possible value of the cost item (practically the risk-adjusted estimate) and $P(X_i=x)$ is a function that assigns a probability to every possible cost element value, x.

This allows us to place or identify:

1. a value of how much the cost estimate is likely to vary within a degree of (statistical) confidence
2. a value of how much is the contingency level on the desired confidence level
3. contribution values of each risk factor on the cost estimate for each cost element

4.1.4.2 Choice of probability distributions

Choosing the most appropriate probability distribution is one of the most elegant issues as a researcher I had to consider and implement. Although the criticism existing around the use and properties of the triangular distribution, such that underestimates the uncertainty in cost component variables (Chau 1995a p. 376) or that it negatively predisposes experts to underestimate their best and worst case scenarios (Smith et al. 2006, p. 90), there are still valuable properties of the Triangular distribution that should be seriously taken into consideration before proceeding to the simulation stage. An example of risk distributions is provided in Table 20 (Smith et al. 1999, p. 86).

Considerable arguments in favor of using triangular distributions have been provided when dealing with construction costs (Back et al. 2000, p. 30). Other studies respect this pattern and apply the same the triangular distribution (Salling & Leleur 2011). Four conditions have been proposed, regarding probability distributions, when dealing with construction cost estimating activities:

1. On any estimate, upper and lower limits should exist. Beyond these limits an estimator is relatively certain that no values will occur. Consequently, a *closed-ended* distribution is desirable.
2. The distribution should be *continuous*. It is illogical to assume that the probability distribution for project costs is discrete. The construction cost may have any value within reasonably defined limits.
3. The distribution of construction cost will be *unimodal*. This is particularly relevant to construction cost, as it is expected that cost will have one most-probable value.
4. The distribution must be able to have a greater freedom to be higher than lower with respect to the estimation - *skewness* must be expected.

Table 21 below summarizes the four properties required for applying a probability density function in construction activities cost estimations, as presented in (Back et al., 2000, p. 30). The triangular distribution as can be seen is the only distribution satisfying the four pre-set conditions (Table 20). Based on the table's options and the next figure's decomposition of distributions options we conclude to the choice of the triangular distribution (Figure 38).

Table 20. Examples of probability density functions for building activities

Activity	**Distribution**
Construction	Long-normal
Equipment	Triangular
Market size	Triangular
Market share	Triangular
Unit price	Triangular
Operational cost	Triangular

Table 21. Properties of possible probability distributions

Distribution	**Bounded**	**Continuous**	**Unimodal**	**Skewness**
Normal	No	Yes	Yes	No
Log-normal	At one end	Yes	Yes	Yes
Uniform	Yes	Yes	No	No
Gamma	At one end	Yes	Yes	Yes
Triangular	Yes	Yes	Yes	Yes
Beta	Yes	Yes	Sometimes	Yes

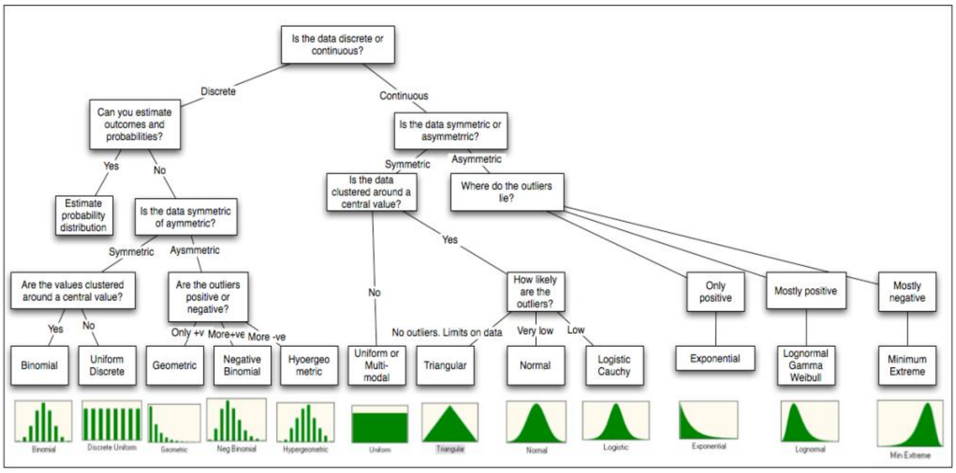


Figure 38: Distributional choices[6]

[6] http://people.stern.nyu.edu/adamodar/pdfiles/papers/probabilistic.pdf

4.1.4.3 Interdependency of system variables

The correlation represents the co-movement of two cost elements; when one is more expensive, the other tends to cost more as well or cost less for a negative correlation (Yang 2005, p. 275). Correlation is an indicator ranging from -1.0 to +1.0 representing the strength of the interdependence between two or more variables and it simply shows if the cost elements are expected to "move together".

One of the more common sources of error in Monte Carlo simulation is that cost components are assumed to be independent, so changes in one cost component do not affect any other component. This is clearly inaccurate in typical construction projects (Touran & Wiser 1992, p. 260). There is a huge problem with reflecting interdependencies among various risks in risk analysis (Kaczmarzyk 2013). Wall (Wall 1997, p. 241) had argued that "the effect of correlations is more significant than the effect of the choice of distributions", the same observation was shared by (Chau 1995a; Le Isidore et al. 2001, p. 419).

This frequent cited concern with Monte Carlo simulation lies on the assumption that "all of the cost components or system variables are independent (Hobbs 2010, p. 25). In reality however, there is usually significant correlation between risks in projects since if one thing goes well or badly other things tend to follow (Wallace 2010, p. 19). Therefore project managers have to seriously consider the effect of correlation into their results interpretation as correlation can increase the total project uncertainty.

Hulett (Hulett 2002) has identified two basic reasons for explaining why correlation occurs: Firstly and most important is the influence of a common "cost driver" that can influence the total project actual cost if correlation is strongly positive. If a new ground freezing technique is used several other cost elements, such as labor productivity, workers' familiarity with the new technology have to be successful, too. Secondly, one element may depend on other. For example the cost of providing an incomplete Ground Baseline Report (GBR) to a contractor and demanding from an inexperienced contractor to deliver a high-quality and on-time earthwork project. The incompleteness of the GBR in combination to the contractor's inexperience can lead to an important cost overrun and schedule escalation.

Arguments and evidences for the existence of correlations and their profound impact on simulation results have been presented in the literature. Diekmann (Diekman 1983, p. 304) provides a strong argument for not ignoring either positive or negative correlations, as "to ignore positive correlations would understate the final variance, and to ignore negative correlations would overstate the final variance." Correlations have been further analyzed (Wall 1997; Raftery 2003). Although correlations were not possible to be obtained due to the unawareness of the majority of the study's participants, a comparison for one project with correlated and uncorrelated cost elements will be performed (in chapter 6) to visualize the theoretical differences.

To treat the correlations, various approaches have been proposed. Wall (Wall 1997) developed a correlation matrix that related the cost components variables together so that values chosen by the Monte Carlo algorithm to be appropriately correlated. Touran and Suphot (Touran & Suphot 1997) showed that, rank correlations can equally effectively as Pearson correlations, model data dependency. Wang (Wang 2002) focused among other research goals to examine how the number of initial input distributions (child distributions) affects the Coefficient Correlation. Further theoretical requirements for structuring positive correlation matrices were discussed by Ranasinghe (Ranasinghe 2000) with exploring simultaneously the concept of induced correlation in between derived variables. A more detailed presentation of the correlation effect will be analyzed in an upcoming paragraph (§ 6.2).

□ *"Methods for quantifying interdependencies"*

The relevant method of reflecting the interdependencies should work with most common correlation measure such as the Pearson's coefficient (Kaczmarzyk, 2013, p. 29). Usually scholars deploy two correlation measures: the Correlation Coefficient (CC) and the non-parametric rank correlation (Spearman Correlation). Chau (Chau 1995a, p. 370) has proposed that the rank correlation (Spearman) is a better measure to quantity construction cost data dependencies as they are unlikely to be normally distributed. The present study initially assumes no dependencies of the risks assessed and the subsequent cost categories including them. However, due to many objections raised against the non-interdependence of construction cost elements, the functioning of the cost risk model will be demonstrated in the case of having a project with fictitious inter-correlations among the cost elements, obtained by using the SPSS statistical package. This action will show off the contribution of inter-correlated cost elements towards the project cost performance and the level of contingencies set.

4.1.4.4 Determining number of iterations

Consider an iterative MC simulation that has no upper bound to the number of iterations to be performed. As the iterations proceed, the cost estimates accumulate into a sample of increasing size (Driels & Shin 2004). The more the iterations take place the more the sample approaches the population. In their study, regarding weapon effectiveness, Driels and Shin (Driels & Shin 2004, p. 6) concluded that "as we take more iteration the half interval decreases and the sample's mean value approaches the population's mean value and the sample's variance approaches the population's variance.

In simulation, one major question is the one asking how many iterations are needed to reach a chosen level of precision in the results? Simulation as a tool provides an approximation of the actual relationship between the input and output variables. The precision of the approximation is based on the number of iterations of the simulation done. More iterations in the sample lead to greater precision. But the relationship between iterations and precision depends on the relationship between the variables in the precision. In addition, the analyst must decide which output variable is the variable of interest, and what degree of precision is required. The next step is to determine a sufficiently large number of iterations R which has to satisfy the following condition:

$$P\left(\left|\hat{\Theta} - \Theta\right| \leq \varepsilon\right) \geq 1 - \alpha \tag{14}$$

Where:
$\hat{\Theta}$ = the estimate of the mean
Θ = the actual mean
ε = the specified error
$(1 - \alpha)$ = the probability that the estimate is within ε of the actual value, called "confidence interval"

Simply now the minumum number of iterations for simulations is provided by the formula below (Banks et al. 2001):

$$R \geq \left(\frac{z_{\frac{a}{2}} \times s_0}{\varepsilon}\right)^2 \tag{15}$$

For example: if we had a case with a selected confidence level $\alpha = 95\%$ and a set percentage error $\varepsilon = 5$, we take $z_{a/2} = 1.96$. The actual variance is assumed to be equal to $Var = 2046.37$. Thus we compute the required number of iterations as follows:

$$\mathrm{R} \geq \left(\frac{1.96 \times \sqrt{2046.37}}{5}\right)^2 = 314.42 \text{ iterations} \tag{16}$$

Given that the simulation process is run on every single output cell, we have in each excel-sheet 6 output cells (cell 1: "land preparation", cell 2: "foundations", cell 3: "substructure", cell 4: "superstructure", cell 5: "finishes", cell 6: final project"). In total, the study sampled 22 different cases/projects which imply the examination of the 6 cost elements 22 times, as shown below.

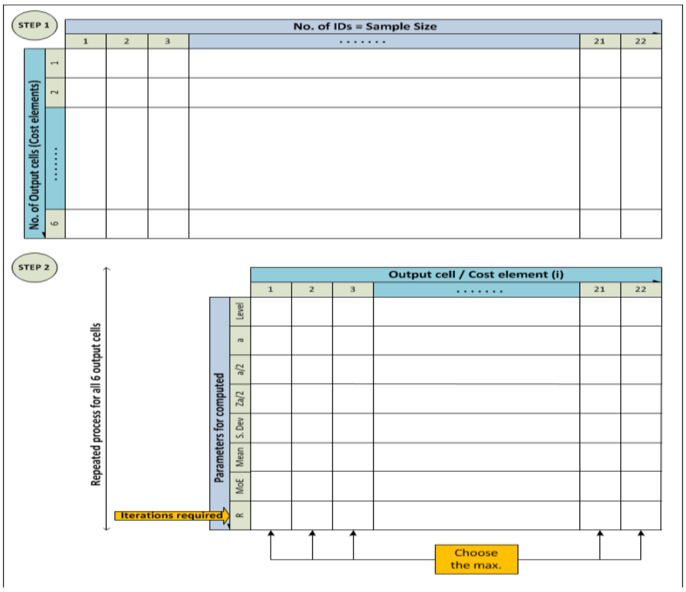


Figure 39: Computing the iterations number required for each output cell

In this study the main problem for specifying the minimum required number of iterations is the setting of the Margin of Error (MoE) as it is the only arbitrary value. To determine the MoE (in units) the following parameters had to be defined and computed:

<u>Confidence (desired) level</u>

$$Confidence\ (desired) level = 50\% + \overbrace{Risk\ package\ effect\ (\%)}^{as\ specified\ \ in\ the\ risk\ analysis\ \ model} \quad (17)$$

<u>Confidence coefficient</u> (1-α)

$$Conf.\,level = 100 \times (1-a) \rightarrow a = 1 - \frac{Conf\ .level}{100} \rightarrow \frac{a}{2} = \cdots \quad (18)$$

<u>Critical value</u>

$$Z_c = Z_{\frac{a}{2}} \rightarrow specified\ with\ z - table\ or\ in\ excel{:}\ NORMSINV\ (1 - \frac{a}{2}, 0, 1) \quad (19)$$

<u>Standard deviation & Mean</u>

For each output cell, the following commands were typed in @RISK model:

For Standard deviation: $RiskStdDev\ (\ \overbrace{\cdots}^{output\ \ cell}\ )$

For Mean: $RiskMean\ (\ \overbrace{\cdots}^{output\ \ cell}\ )$

<u>Margin of Error</u> (ME or MoE)

$$MoE = Z_c \times \frac{s}{\sqrt{R}} \quad (20)$$

Percentage MoE of mean (E)

$$E = \frac{100}{\bar{x}} \times \frac{z_c \times s_x}{\sqrt{R}} \tag{21}$$

To determine the percentage of error (E), I provide the following example taken for the 1st respondent of the "land preparation" cost category with a confidence level of 68.74%.

Table 22. Single run of a cost estimate MC simulation

R	$\bar{x}$	s_x	$1-\alpha$	$z_{\frac{a}{2}}$	E
100	53567.67	9434.87	0.180	1.010	176.13
1000	60872.35	5860.17	0.169	0.958	0.291
10000	62755.00	5979.77	0.156	1.011	0.096

From Table 22 it is seen that the more the number of iterations increases, the more the percentage error of mean decreases which indicates a safe pattern for selecting the highest number for iterations required. Generally in bibliograpgy, researchers very rarely dedicate a section for proving mathematically how many iterations were required for performing a MC simulation. For those interested in understanding how the number of iterations was determined in this study, the report written for the US Defense Threat Reduction Agency has to be consulted (Driels and Shin 2004).

For the calculation of the minimum required number of iterations, the following formula is applied:

$$R = \left(\frac{100 \times z_c \times s_x}{E \times \bar{x}}\right)^2 \tag{22}$$

Using the Equation 23 we conclude that the minimum required number of iterations for the example used, at a confidence level of 68.74%, is 0.003 iterations. This number seems to be unrealistically small, a fact can be explained based on two reasons: (a) the confidence level may be very small and thus affecting negatively the iterations number, which means that if the confidence level was set at 95% the minimum number of iterations would be 0.011 iterations; an increase of 274% and (b) the maximum size of percentage error (E) used in equation 23 (E=176.13) is unrealistically large. The calculations below were performed for the minimum and maximum values of the E so to compare the number of required iterations and accept the higher as the safest pattern.

$$\text{R} = \left(\frac{100 \times 1.010 \times 5979.77}{176.13 \times 62755}\right)^2 = 0.003 \text{ iterations}$$

$$\text{R} = \left(\frac{100 \times 1.010 \times 5979.77}{0.096 \times 62755}\right)^2 = 10050.15 \text{ iterations}$$

Consequently, the minimum required number of iterations is set equal to 10000. In general, two rules of thumb are followed; the first rule implies that the more the iterations number the higher the precision level achieved and secondly 300 iterations is the minimum threshold above which "*we start getting a reasonably well defined cumulative distribution, so you can approximately read off the 50th and 85th percentiles.*[7]"

[7] http://www.epixanalytics.com/modelassist/AtRisk/Model_Assist.htm#Montecarlo/The_minimum_number_of_iterations_one_can_run_in_a_Monte_Carlo_simulation.htm

In Appendix 7, the whole spectrum of calculations for determining the required number of iterations is presented for each output cell/cost element. To keep iterations consistent for all respondents and in all cost elements 10000 iterations were chosen for running the MC simulation.

4.1.4.5 Determining sampling method
@RISK offers two methods of generating samples from probability distributions: Monte Carlo sampling, and Latin Hypercube sampling. In this study the MC sampling was deployed as it is the oldest and best known. MC sampling is useful if one is trying to get a model to imitate a random sampling from a population or for doing statistical experiments. However, the randomness of its sampling means that it will over- and under - sample from various parts of the distribution and cannot be relied upon to replicate the input distribution's shape unless a very large number of iterations are performed[8]. Latin Hypercube sampling addresses this issue by providing a sampling method that *appears* random but that also guarantees to reproduce the input distribution with much greater efficiency than Monte Carlo sampling.

4.1.5 How @RISK works?
The @Risk Monte Carlo simulation software that comprises part of Palisade Corp's Decision Tools suite contains no fewer than 31 continuous and 8 discrete probability distributions that an analyst can choose from (Chau 1995a, p. 370) and yet it is commonly acknowledged that due to its simplicity, it is often the simple triangular distribution that is most commonly employed, to the detriment of the end estimate. The process of setting up appropriately a model is grounded on three steps, as is described below:

1. *Set Up Your Model:*

a) Select probability distributions
b) Define uncertainty: correlation between distributions may be individual or on time-series depended. Correlations are quickly defined in matrices that pop up over Excel, and a Correlated Time Series can be added in a single click[9].
c) Select outputs from the "bottom line".
d) Define number of iterations.

2. *Run the simulation:*

@RISK recalculates your spreadsheet model thousands of times. Each time, @RISK samples random values from the @RISK functions you entered, places them in your model, and records the resulting outcome.

3. *Interpret the results*:

The result of a simulation is a look at a whole range of possible outcomes, including the probabilities they will occur. The results will be plotted with:

a) Histograms: to show how likely is to meet the initial base cost estimate and whether the new estimate is closer to the initial one based on the margin-related decision.
b) Cumulative graphs: to measure the contingency levels at the specified confidence levels obtained by participants' answers.
c) Tornado graphs: to visualize the contribution of each risk factor to the outcomes set, before and after taking the margin-driven decision.
d) Scatter plots: to indicate the effect of hypothesized correlations among the cost elements to the project cost performance.

4.1.6 Quantification of cost risk and contingency

The risks identified should be quantified by using two basic categories of data for each risk factor or each cost component:

[8] http://www.epixanalytics.com/modelassist/AtRisk/Model_Assist.htm#Montecarlo/Monte_Carlo_sampling.htm
[9] http://www.palisade.com/risk/

a. Values expressing the subjective judgments of the experts asked: These are three simple numerical prices: a planned value (usually stated as baseline cost), an optimistic value (upper limit) and a pessimistic one (lower limit).
b. Probability distributions representing the "gut feeling" of project members used as input to a risk model.

In the process of quantifying the risk probability of each, risk historical data or subjective data from managerial experience, are required to assign a probability of occurrence for each risk factor. Hobbs (Hobbs 2010) classified risks as *fixed* and *variable*. *Fixed* are the ones which are represented by a static probability, meaning that either they occur or they don't, thus fixed risks are described by discrete PDFs. *Variable* risks occur with a 100 % probability of occurrence. In Figure 40 the cost risk model used to quantify the contingency amount set by contractors is determined. The excel-based model of Figure 41 presents supports line by line the model of Figure 40. The model of Figure 41 is structured with 14 columns and 27 rows. The 14 columns are examined one by one in Table 21. The 27 rows represent the different risk factors assessed by this model.

4.1.7 Monte Carlo software package selection

Simister (Simister 1994) identified 22 different computer-based packages for performing Monet Carlo risk analysis. It was observed that although a wide range of programs are used, a single program (@ RISK) is used by nearly three-quarters of the respondents. @RISK is a very cost-benefit add-in compatible with Excel spreadsheets simplifying the cost engineering calculations. Several other software packages (e.g. Crystal-Ball, ModelRisk, winBUGS) with their limitations and advantages are discussed in the book of Vose (Vose, 2008, pp. 37-38). Three main reasons implied the choice of @RISK package:

a. The model's simplicity
b. The widely-acceptance of it in the academia
c. The relatively low price of the student version

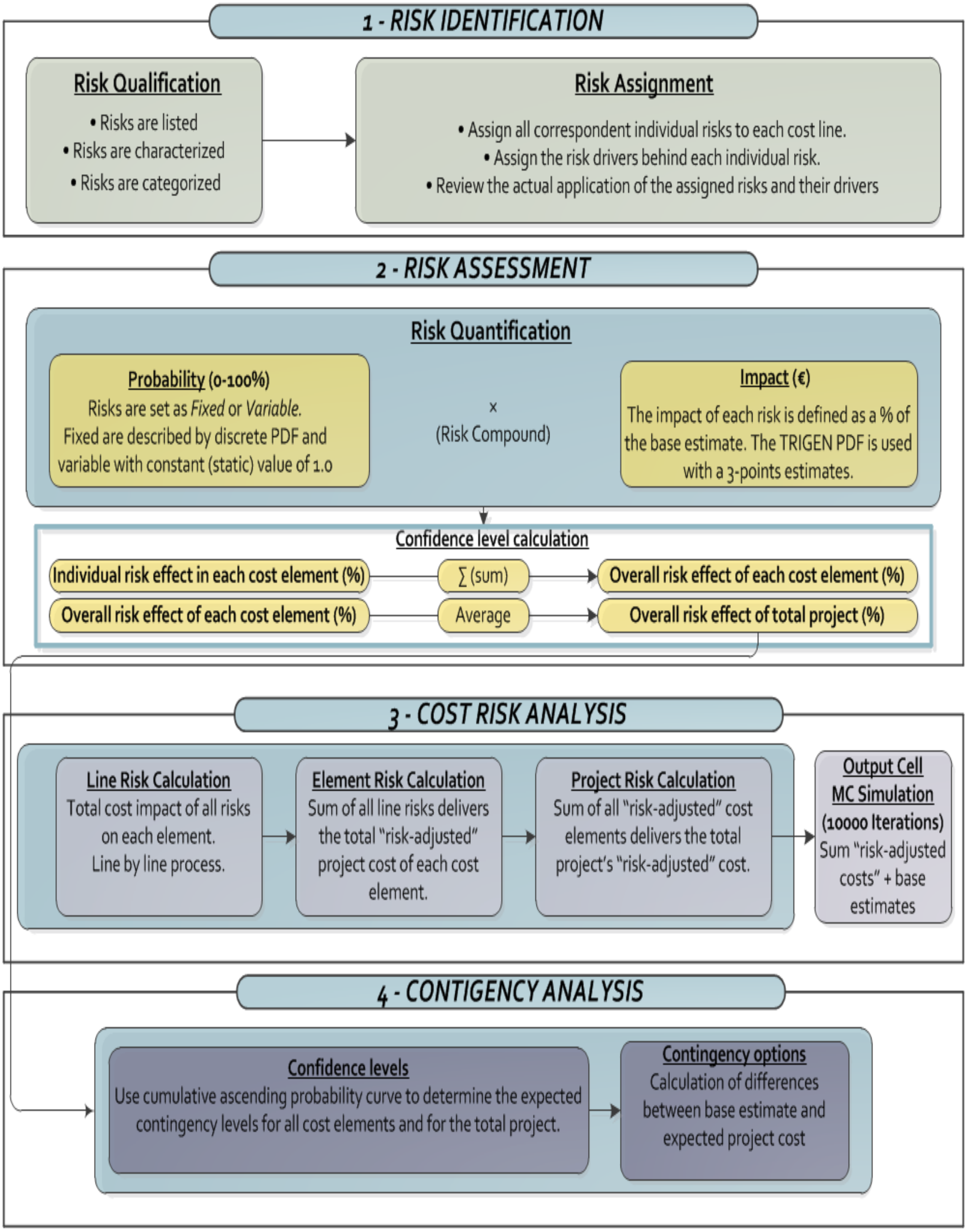
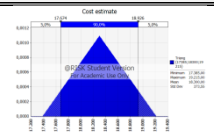
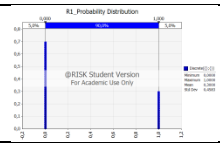
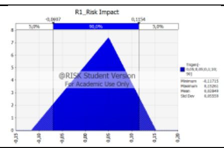


Figure 40: Applied methodology for determining construction contingency

Table 23. Explanation of @RISK-based risk analysis model

	Columns in the model	**Description**	**Tools used**	**Excel or @RISK expression**
No.	Input values			
(1)	Construction phase (Cost element)	Cost Estimates ($E_{i=1-5}$)	"RiskTriang" Incorporating the error range limits	
(2)	Risk factors	27 rows ($R_{i=1-27}$)	List from literature review	-
(3)	Cost risk drivers	4 drivers	Q – UC – S – G	-
(4)	Type of risk	2 types	Fixed (F) Variable (V)	Fixed risks / Variable risks
(5)	Risk probability	Occurring / Not occurring	p %, (1-p) %	i.e. 30%, 70% (0,30;0,70)
(6)	Input distribution	Probability distribution	Discrete for F, 100%=1 for V	
(7)	Risk impact	3-point estimate for the 4 drivers	Low, Most likely, Max	The % change on cost estimate
(8)	Input distribution	Impact distribution	RiskTrigen	
	Output values			
(9)	Overall risk effect	Riskiness of each work phase	Combining "Probability" and "Impact"	= RiskCompound ((6);(8)) For each risk
(10)	Amount of individual line cost impacted by risk	How much would the cost impacted by each risk	Risk Probability (of occurrence) × Cost line	= (5) × (1) (in €)
(11)	Estimated cost effect of each risk on line item (Cost risks)	How much would be the cost effect of each risk	Overall risk effect × Amount impacted	= (9) × (10) (in €)
(12)	Percentage impacted	How large is the cost risks proportion against the estimate	Cost risks : Estimate	= (11) / (1) (%)
(13)	Total (risk-adjusted) costs	Estimates + Cost risks	Simulation output cells	= (1) + (11) For each cost element (€)
(14)	Final project cost	Total cost	Sum of cost elements	$=\sum_{1}^{5}(13)$

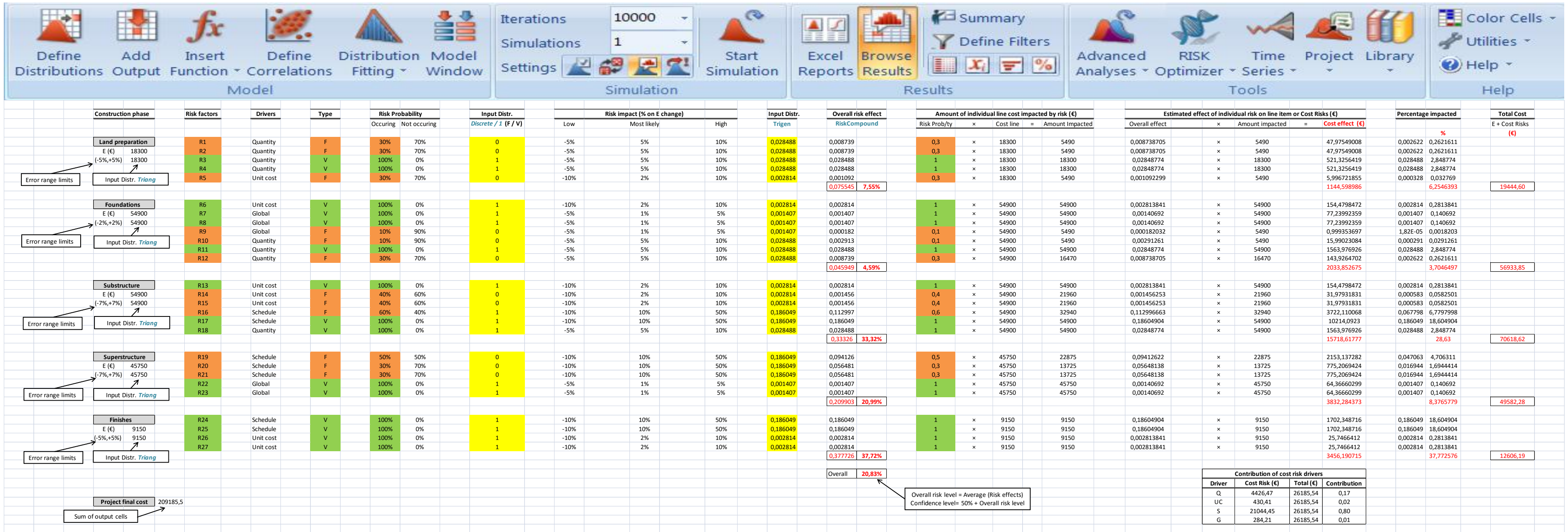


Figure 41: Excel-based Cost Risk Analysis (with use of @RISK add-in)

SURVEY DESIGN

Chapter **5**

5.1 Survey use for data collection in construction PRM

Several questionnaire surveys have been conducted in order to investigate construction Project Risk Management (PRM) practices and perceptions of academics or industrial professionals regarding risk importance, risk allocation principles and risk response. Below, the author discusses extensively in chronological order the most frequently published and the most recent studies in construction project risk management. All the referred studies have deployed a questionnaire tool for gathering the required data. Some studies draw conclusions similar to the ones of the author's study, where this applies a brief comment will be made.

Kangari (Kangari 1995) constructed a questionnaire survey to investigate the current attitude of large U.S. construction firms toward risk, and determines how these contractors conduct construction risk management. The top-100 largest contractors participated in this study which showed that contractors have been more willing to assume risks that accompany contractual and legal problems in the form of risk sharing with the owner. It was also found that contractors tend to assume the risk associated with actual quantities of work and finally, the attitude of contractors toward the practice of defensive engineering was determined.

In the UK, a survey of 43 practitioners was conducted trying to explore the use of risk management techniques (Akintoye & MacLeod 1997). A similar survey among 200 Australian construction practitioners was conducted by Uher and Toakley (Uher & Toakley 1999); they particularly focused on the use of risk management in early project phases. Another survey methodology was designed to concentrate data on the choice and use of the most successful risk response techniques within the oil and gas industry and statistically compare them (Baker et al. 1999).

For the Chinese construction industry, a three-phases questionnaire survey was conducted within the Joint Risk Management (JRM) initiative (Rahman & Kumaraswamy 2002). The survey compared perceptions on both present and preferred risk allocation, including JRM, in construction contracts. The study revealed quite wide divergencies with many individual cases of diametrically opposing views on allocating particular risks within specific groups. All respodents however accepted enthousiastically the JRM initiative. Study's participants were found to be prone to assign reduced risks from either one or both contracting parties to JRM, rather than shifting more risks to the other party. This finding indicated a direction for developing more collaborative and risk sharing work environment.

In Australia, Lyons and Skitmore (Lyons & Skitmore 2004) conducted a survey with 44 construction practitioners. Their survey covered the whole risk management process, i.e. risk identification, assessment and response throughout all project phases. Andi (Andi 2006) constructed a questionnaire survey for evaluating the perception of contractors on the risk types identified and it was argued that to effectively manage risks in construction projects, it is crucial to correctly identify important risks and properly allocate them to the contractual parties. The article demonstrated significant differences in perceptions of construction contractors and owners on the importance and allocation of risks to a specific party.

In the Korean construction sector, a survey was conducted to identify and explore pertinent conflicting factors in construction projects (Acharya et al. 2006). A 43-item questionnaire survey in a five-point Likert scale was carried out to collect professionals' experience on conflicting activities in Korean construction projects. Differing site condition were found as the top inhibiting factor with public interruption, differences in change order evaluation and design error following. The study also revealed that owners (counting for 35.6%) and consultants (counting for 34.18%) are mostly responsible parties for conflicts in construction projects.

In 2006 another significant study was published which developed and tested a partnering model that reveals the relationships between the critical success factors (CSFs) of partnering and demonstrated their importance to construction (Tang et al. 2006). The authors delivered a questionnaire form on fieldwork and the 116 respondents had the opportunity of face to face interaction with the researchers. Respondents were given answers in a 5-Likert scale format to specify to which degree they agree with the statements provided. On the evaluation of the partnering CSFs, the average rating of the 10 factors was found equal to 3.56 with "timely responsiveness" scoring the lowest value. This indicates that when problems and issues arise, they cannot be solved quickly as schedule risks were perceived as mostly important. This finding is line with the finding of the author's study which will be proved in chapter 6.

Wiguna and Scott (Wiguna & Scott 2006) a path model was developed and path analysis was used to determine the relationships between risk and performance. The authors in order to analyse the impacts of perceived project risk on project performance conducted a survey study via both inteviews and questionnaire form. The questionnaire was delivered to 80 potential respodents and 26 returned it back so the authors were enabled to produce a list of 4 critical risk factors in each category, or 16 risk factors in all.

Hammed and Woo (Hameed & Woo 2007) developed a questionnaire-based survey to investigate the perception of Pakistani contractors regarding risk importance and risk allocation. For risk importance, the respondents had to judge the relative importance of 31 risks types and for risk allocation, the respondents had to select the party actually taking the risk while being given three options: owner, contractor or shared by both the owner and the contractor. Another survey was focused on investigating the status perception among construction practitioners, operating in China, regarding risk management approaches (Tang et al. 2007). A triangulated survey approach was used to gather all the required data.

In the UK's industrial context, a survey study was developed to identify and assess the extent of occurrence and impact of risk factors responsible for the variation between the forecast and actual construction cash flow (Odeyinka et al. 2008). This UK-based study detected 11 significant risk factors out of the 26 research risk variables being very significant. These significant risk variables were grouped under three generic factors namely: "changes in the design or specification", "project complexity" and "natural inhibition". The article showed that there is no statistically significant difference in the opinions of different categories of contractors regarding the extent of risk occurrence and impacts on cash flow forecast.

The Pakistani construction industry was investigated regarding identification and assessment of risk factors rank wise (both internal and external risks) and an evaluation was from national and international perspective was conducted (Masood & Choudhry 2010). The authors constructed a questionnaire-based survey using the 5-Likert scale for investigating the current practices for considering risk factors by firms. The study assessed 22 risk factors: 8 internal factors and 14 external factors and ranked them according to the computed Relative Importance Index (RII) values.

Osipova and Eriksson (Osipova & Eriksson 2011) used a five-sectioned questionnaire to cover general questions about the respondent, the aspects of the risk management process through the different phases, and relationships and collaboration in risk management between the actors.

For the Lithuanian construction industry, Banaitiene and Bonaitis (Banaitiene & Bonaitis 2012) conducted a survey to firstly identify contractors' opinion on the significance of the construction projects risks; and secondly to explore the risk analysis and risk management practices. The first section of their questionnaire includes the respondents' opinion on the risk factor in terms of its probability and impact to overall construction project success. The second section includes the respondents' opinion on the risk consequences for construction project performance measures as well as the risk assessment and response practices. The third section aims to collect the background information of the respondents, e.g. their age, gender, position, education, work experience and professional background. The structure of the survey of Banaitiene and Bonaitis is close to the author's questionnaire structure with some differences determined by the research goal.

In a global survey examining the construction industry's shift trends it was observed via a survey of 161 construction and engineering executives that only 36% feel their project review processes to be very efficient and the majority of 54% of respodents admited that they failed at bidding stage to identify the risk that ultimately materialized and caused margin erosion. As the authors of the KPMG report state: *"This is a surprisingly high response, suggesting a clear need to employ more rigorous upfront assessment of potential project risks."* (KPMG 2012, p.31).

In Pakistan, an empirical survey was recently conducted aiming to explore how risks are ranked by key-stakeholders, which is the role of current management techniques, which is the existing status of risk management systems, and what are the barriers to effective risk management (Choudhry and Iqbal 2012). Among other results, it was found that the risk management system and practices of most of the organizations are reactive, semipermanent, informal, and unstructured with nonexistent and limited committed resources to deal with risks; a finding which will be proved to be similar in the Greek construction industry.

Barlish, De Marco and Thaheem (Barlish et al. 2013) identified the necessity of comparing and converging industrial and academic perceptions on risk management practices. The authors performed via a content analysis literature review and conducted a survey study to map industrial views. According to the authors the bibliographic knowledge base tends to focus on political; acts of God classified risks, whereas the industry places emphasis on regulatory risks. The end-product of the study was an improvement of the existing the literature-based risk taxonomy by combining the industry's perspectives as mapped via the survey.

The US research team of Construction Industry Institute (CII) – 210 in response to the increasing discussion around risk allocation and problematic contracting produced a cooperative approach by constructing three excel sheets for enabling practitioners to identify, assess and allocate risks (Hanna et al. 2013). A three-phased survey methodology for data collection was followed by the authors. The three worksheets were developed to identify construction risks with high potential for conflict and to aid in assessing and allocating these risks to the appropriate parties.

Aiming to find out the global picture of PRM practices and approaches Thaheem and De Marco (Thaheem & De Marco 2013) deployed the use of survey. The purpose of this study was to look into the usage of PRM techniques and the relevant diffusion of software tools, their level of maturity, and their usefulness in the construction sector. The authors divided their questionnaire into 3 sections; namely (a) background information, (b) Risk Management processes, and (c) software tools. A total of 271 respodents across 56 countries participated in the on-line survey as LinkedIn assisted the authors to approach a high number of potential target groups.

Other scholars chose to focus on investigating the resource allocation, effectiveness, impact and understanding of construction Project Risk Management (PRM) in Singapore (Zhao et al. 2014). A questionnaire survey was conducted with 43 participants. The study revealed that a higher proportion of cost was invested in PRM than in time and labor resources, and that more resources invested would not have necessarily led to a higher level of PRM effectiveness and greater assurance with the achievement of project objectives. A low-level understanding of PRM by the participating firms was uncovered, the overall impact of PRM on project outcomes differed according to levels of understanding but interestingly all the nine PRM principles and guidelines were significantly agreed among participants.

In India, a survey study was executed to identify in bridge projects the risk factors that affect the performance of bridges as a whole and analyze by using appropriate tools and technique and to develop a risk management framework (Vidivelli & Surjith 2014). The authors constructed a questionnaire divided into two factors area namely time and finance management. In the study 25 bridge projects were examined and a 5-Likert scale was used for enabling risk rating. In total 54 risks were examined; 36 related to financial management and 18 related to financial management.

The most recent questionnaire-based survey investigates the attitude of construction practitioners toward different types of risk and respective responsibility and in addition explores the most effective techniques in preventing/mitigating different types of risk (Iqbal et al. 2015). The survey used a 5-Likert scale to obtain rankings of the importance perception of 37 individual risks from the 86 study's participants and provided relative answers on the risk responsibility; following 4 categories: client-responsibility, contractor-responsibility, shared responsibility and undecided to obtain appropriate replies. Risk management techniques, distringuished between preventive and remedial, were evaluated by participants throughout the use of a 5-Likert scale. From this study the author highlights the finding on the effectiveness of risk management techniques where the preventive technique "the production of accurate schedule by getting updated projected information and referring to similar projects" gained respondents attention. This finding will be indirectly validated in this report.

To sum up this introductory section regarding questionnaire-based survey in the broad context of construction Project Risk Management (PRM) 24 published studies were extensively reviewed. This section was not included in the "Literature Review" chapter as the author considers very important to showcase that all past survey works are primarily occupied with investigating perceptions of practitioners on risk importance, risk management tools and risk allocation decisions. Not surprisingly the majority of the questionnaires constructed deploy the well-known 5-Likert scale for enabling risk ratings and Relative Importance Index calculations.

This study will not follow the known pattern as was shown above. Although the necessity of a questionnaire tool became evident for enabling data collection, the specific questionnaire will be quite differently structured. The questionnaire encloses three separate sections. The first section gathers the organizational and personal characteristics of the respondents. The second section is focused on the project-related characteristics where cost, profit and risk sharing values are asked by the respondents. And the third one is focused on the direct rating the cost risk drivers and the risk factors, where respondents have to fill in "risk importance" and "risk impact" tables. The questionnaire concludes with a section providing space to the respondent so to fill in his/her personal contact details. The questionnaire form was delivered to the participants both as a printed booklet and via e-mail; it can be seen in Appendix 8.

◊ **Construction of risk factors list**

The first step was to identify risks in construction projects and especially related to the traditional procurement system. This process was conducted in the literature review study which gave an output of 57 risk factors. The initial list of risks was constructed as to classify risk factors in the pre-construction, construction, and post-construction stages. This list was generated after reviewing several studies on risk identification, developed from previous checklists such as the ones referred in the following studies (Perry & Hayes 1985; Al-Bahar & Crandall 1990; Edwards 1995; Zhi 1995; Laokhongthavorn 1998; Fisk 2000; Molenaar 2005; McGoey-Smith et al. 2007). However, all these factors (such as "risk of defective design", "risk of changes in scope of work", "third party delays", "risk of labor disputes and strikes", "delay of material supply", "inadequacy of insurance", "Acts of God", etc.) were not directly related to the contractor's on-site technical operations and seem to the author as repeatable among scholars and too generic.

Thus this list is narrowed to a new one in which more technical risks are embodied. For this reason some additional studies (Love & Li 2000; Yi & Langford 2006; Love et al. 2009; Castillo et al. 2010; Lin et al. 2011; Fok et al. 2012) were reviewed to transform the wide risk list into a more 'on-site' focused list. The final result was the formation of a list including 27 construction (technical) risk factors as provided in Table 16.

5.2 Planning the survey research

5.2.1 Survey design

Two goals may be achieved while using a survey (Kitchenham & Pfleeger 2002a) and these are:

- To describe a phenomenon of interest: *descriptive* design.
- To assess the impact of some intervention: *experimental* design to support some tested hypotheses.

To decide which survey design – descriptive or experimental – is appropriate for the present study it was required to select the most "effective" means of obtaining the information needed to address the thesis objectives.

Effectiveness in a survey study is defined by three factors:

a) Resiliency to bias: The design should not be prone to a particular aspect or opinion.
b) Appropriateness: Make sense and represent realistically the context of population examined.
c) Cost-effectiveness: Budget and time resource allocation should be useful for both the researcher and the study's participants.

◊ Selection of survey design

Section A: "Descriptive design – Cross sectional type of study"
In this type of study, participants are asked for information at one fixed point in time. Given that our participants will be asked for personal and corporate level information at a specific time moment, the first section lies to this type of descriptive survey.

Section B: "Experimental design – Self-control study"
In this type of study, participants are asked for information before and after some intervention. When pre- and post- treatment measures are proposed to be considered by survey participants, then self-control survey is appropriate. Given that our participants will be asked based on pre- and post- margin change decision to answer some numerical questions, the second section lies to this type of experimental survey.

Below we will analyze the two core influencers of a survey. The sample size and the response rate are explained. Both are important factors affecting the final study's outcome and its power to express the phenomenon studied. Precision and validity are the two driving powers of sample size and validity is the driver of response rate (Figure 42).

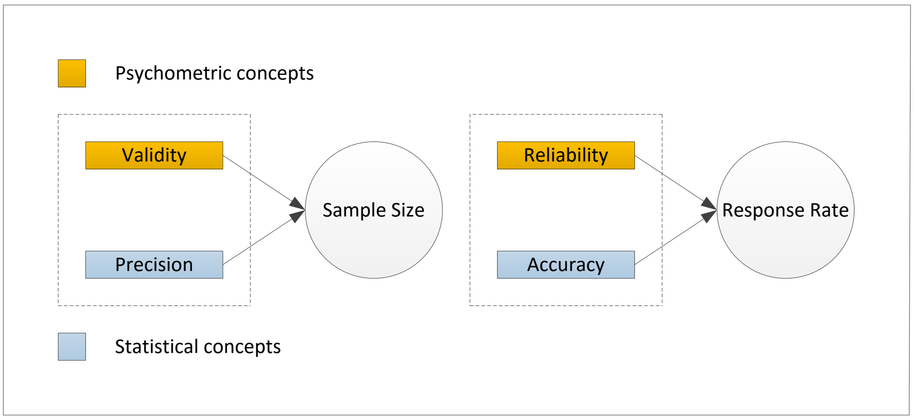


Figure 42: The drivers of sample size and response rate in a questionnaire survey.

◊ Sample size

It is not usually cost-effective and not realistic or possible to survey the entire population examined. Instead of the whole population we choose to limit the population to a smaller proportion, called sample. Regarding the sample size, two main conditions have to be met: (1) precision and (2) validity. To assure these two conditions, we must have previous information about the phenomena we are hoping to study. Below the number of contractors examined in past studies is summarized (Table 24).

◊ **Sampling design**

The choice of the sampling design used in every survey depends on the scope and research goal of the study. Leedy and Ormrod (2010) have identified eight different sampling designs which all fall into two basic categories: probability and non-probability sampling. The specific study deploys a non-probability sampling design and more specifically a systematic sampling design. The rationale behind this choice is the following:

"The non-probability sampling is chosen because there is no way to guarantee that each unit (contractor) of the population (construction practitioners operating in Greece) examined can be equally represented in the sample. Systematic sampling technique was selected as the population is generally homogeneous in terms of professional experience and business relationships with private or public clients." This rationale was adopted and supported in past studies (Sambasivan & Soon 2007). Regarding the primary area of selection for our sample this was the entire state of Greece. The majority of the sample received was located in the province/prefecture of Achaia, in Greece.

The last aspect that needs further clarification is the choice of this geographical area. Two reasons implied the focus to Greek construction industry. Firstly, the flexibility of the author to contact directly potential study's participants and enhance trust for receiving a higher response rate implied the focus on Greek contractors. Secondly, the experience of construction practitioners, operating inside the Greek territory, within traditional building procurement implied the specific target group choice.

◊ **Response rate**

In general there is a common criticism developed in respect to mail surveys which lies on the side of having often suffer from low response rates (Phillips 1941; Benson 1946). Leedy and Ormrod (Leedy & Ormrod 2010, p. 189) had noticed that the majority of people who receive questionnaires don't return them and the people who do return them are not necessarily representative of the originally selected sample. The table below summarizes some past studies by illustrating the sample size used. Based on past experience the study's response rate will be further judged. It must be highlighted although, that mail-addressed surveys have usually low response rate, approximately equal to 30% (Moser & Kalton 1971). The aforementioned assertion implying a close to 30% response rate for mail-addressed surveys was accepted by (Uher & Toakley 1999; Zou et al. 2006).

Table 24. Number of contractors (sample size) used in previous studies

Study	**No. of contractors**	**Response ratio from contractors**	**Total No. of respondents**	**Total response ratio**
Akintoye and MacLeod (1997)	70	42.8%	100	86.1%
Bajaj et al. (1997)	19	100%	19	100%
Uher & Toakley (1999)	24	12%	200	32%
Baker et al. (1999)	80	50%	107	48.6%
Andi & Minato (2003)	100	91%	250	80.5%
Lyons & Skitmore (2004)	95	17.9%	200	44%
Andi (2006)	28	80%	70	75.7%
Zou et al. (2006)	n/a*	n/a*	60	36.7%

Tang et al. (2007)	30	100%	115	100%
Thomas et al. (2003)	15	24%	124	50%
Osipova and Eriksson (2011)	30	60%	54	66.7%

n/a*: Not available

□ *"Maximizing the response rate"*
The chosen respondents were initially identified and contacted via personal relationships and reputation. Direct contact confirmed their willingness to assist in this study. Following this line of contact two advantages were acquired during the delivery and collection process:

- Contractors (respondents) got quickly familiar with the research goal as all of them they had the opportunity to contact the researcher personally.
- Contractors (respondents) trusted the researcher's commitment for confidentially or anonymity.

In order to improve our response rate, firstly three conditions have to be ensured, as stated by (Kitchenham & Pfleeger 2002a):

- Respondents should be *able* to answer the questions.
- Respondents should be *willing* to answer the questions.
- Respondents should be *motivated* to answer the questions.

The table below shows the actions taken towards each of these three conditions (Table 25).

Table 25. Actions taken to improve response rate

Conditions to ensure	Actions taken
Ability	Minimum professional experience: 3 years. Contractors: all of them members of the TCG[10].
Willingness	Phone call and face-to-face meeting before the questionnaire delivery.
Motivation	A whole survey booklet was delivered via e-mail before the initial meetings. Confidentiality and if required anonymity were guaranteed.

Regarding the respondents' willingness the method of mailing and delivering them the questionnaire form in a printed booklet proved to be a first good increasing willingness-driver to survey's participants. This method was adopted based on the second guideline, called "*Make a good first impression*" (Leedy & Ormrod 2010, p. 198). Regarding the respondents' motivation the guidelines provided by (Kitchenham & Pfleeger, 2002b) were followed and the introductory part of the booklet delivered aimed to answer all the questions that prospect respondents would have. The information provided in the booklet's introduction addressed the next questions:

- What is the purpose of the study?
- Why is the study relevant to the respondents?
- Why each individual's participation is important?
- How and why each participant was chosen?
- How confidentiality will be preserved?

5.2.2 Survey construction
Constructing a survey instrument, in this case a questionnaire requires the use of the following classic steps (Kitchenham & Pfleeger 2002c):

[10] TCG: Technical Chamber of Greece

(1) "Search for relevant literature": what previous studies have been done and how data were collected. This step was undertaken in the literature review section.

(2) "Construct the questionnaire":
a. Define the question type – open or closed: Section A is developed based on closed questions and section B with both open and closed questions.

b. Select a questionnaire format: A self-administrated format was selected while complying with the needed requirements:

- Provide space for the respondents to comment.
- Use space between questions.
- Use vertical format, spaces, boxes and arrows to maximize the clarity of questions.
- Consider the use of simple grids: Our questionnaire uses tables.
- Consider the use of booklet format: The questionnaire was structured in this format.

c. Minimize the researcher's bias: All the questions were structured with the highest neutrality degree without taking the side of contractors (respondents) or clients. The number of questions asked was judged satisfactory to cover the topic examined. The order of questions was grounded on the use of the two sections. The instructions used were completely based on academic or empirical definitions and not on personal judgments.

d. Decide on the administration type: The present questionnaire was administrated with a *semi supervised* way and in some cases with *one-to-one* way. Mainly the semi-supervised method was chosen as it was the most time effective, inexpensive and providing the power to monitor the communication between the respondents and other parties, as was observed also by (Bourque, Fink, & Fielder, 2003). The one-to-one (or face to face) administration was chosen in the cases where contractors were initially partially willing to complete the questionnaire. Thus in this case, the direct contact increased the trust between the respondents and the author, and enabled the author to provide in-depth answerability to respondents' questions.

(3) "Evaluate the questionnaire": The *pre-testing* stage assisted the researcher in checking whether the questions are understandable, assessing the validity and the reliability of the questionnaire and extracting comments on incomplete or ambiguous parts of the instruments from external observers. The two common ways for evaluating a survey instrument are: focus groups and pilot studies. The present study used a small focus group of five individuals. Five industry practitioners took place in the evaluation of the questionnaire.

(4) "Document the questionnaire": As was previously discussed, in the introduction of our survey instrument a questionnaire specification section was dedicated which included:

- The objective of the study.
- A description of each question or section.
- The rationale behind each question or section with appropriate citations.
- A description of the evaluation process.

Once the questionnaire is administrated the documentation should be updated to record information about (Kitchenham & Pfleeger 2002b, p. 23):

- Who the respondents were.
- How it was administrated.
- How the follow-up procedure was conducted.

All the three administration-related requirements were guaranteed by the specific questionnaire format.

5.2.3 Psychometric concepts

A researcher should provide evidence that the instrument used in a survey study has a reasonable degree of validity and reliability for the research purposes (Leedy & Ormrod 2010, pp. 92-93). Thus, the focus below is paid on these two core concepts expressing the psychology of respondents in our survey.

◊ Determining the validity

Validity is the extent to which test scores mean what you say they mean. "Are we interpreting the scores appropriately?" This is the question we have to address. Focusing on validity guarantees us that the survey instrument measures what exactly we want to measure. Five types of validity are identified (Table 24).

Table 26. Types of validity and their use

Validity type	Definition	Purpose	Measurement indicator
Face	Cursory review of items by untrained judges.	Ensuring the cooperation or relevance of participants in a research study.	Expert's feeling if a test is measuring what should measure. Indicators: (1) Implicit Association Test (Wittenbrink et al. 1997) (2) Likert scale (3) Emotional intelligence competences (Goleman et al. 2013).
Content (Logical)	Subjective assessment of how appropriate seems to a focus group the instrument in relation to the research subject.	Reflecting if the items or questions represent the content domain and require the correct skills and behaviors to that domain (Anastasi & Urbina 1997).	Content Validity Ratio (Lawshe 1975).
Criterion (Concrete)	The extent to which the measures are demonstrably related to concrete criteria in the "real" world.	Assessing of how well one instrument compares with another instrument or predictor.	(1)"Predictive criterion": A personality test to predict future performance or behavior (2)"Concurrent criterion": Comparison of a new instrument against a gold standard one. Use of correlation tests.
Construct	The extent to which an instrument measures a characteristic	Quantifying how an instrument behaves.	(1)"Convergent construct": The extent to which different data collection methods produce similar results.

	(construct) that cannot be directly observed but is assumed following human behavior patterns.		(2)"Divergent construct": The extent to which results do not correlate with similar but distinct concepts.
Incremental	The degree of one meta-analytic estimate having a relationship with two or more predictors (Sackett & Lievens 2008).	Forecasting whether a "a measure add to the prediction of a criterion above what can be predicted (Hunsley & Meyer 2003)."	A predictor-criterion based inter-correlation matrix with each element in the matrix estimated by meta-analysis (Bobko et al. 1999).

◊ **Determining the reliability**

Reliability is the extent to which test results are consistent over time. It is formally defined as the extent to which measurements are repeatable and that any random influence which tends to make measurements different from occasion to occasion is a source of measurement error (Nunnally et al. 1967, p. 206) Reliability. The specification of a reliability level depends on the error-producing factors that should be identified (Cronbach et al. 1971). There are different kinds of consistency, so there are different kinds of reliability. Reliability requires statistical, not logical analysis and calculating reliability requires test scores. Reliability can be reported in three ways, which serve different purposes:

- Correlations
- Standard error of measurement (SEM)
- Percentage agreement

Baumgarter (Baumgater 1989) has identified two types of reliability: relative and absolute. Relative reliability is the degree to which individuals maintain their position in a sample over repeated measurements. Absolute reliability is the degree to which repeated measurements vary for individuals; this implies for example that the less the measurements vary, the higher the reliability. The reason for estimating reliability in surveys is based on three motives and summarized below (Table 27). This study will be focused on measuring the first type of reliability, the instrumental. Table 26 presents all the possible reliability types applicable to survey research.

Table 27. General types of reliability and their purpose

Type	Purpose
Instrumental reliability	The reliability of the measurement instrument.
Rater reliability	The reliability of the researcher administering the measurement device.
Response reliability	The reliability/stability of the variable being measured.

Table 28. Types of reliability and their use

Reliability type	Definition	Purpose	Measurement indicator
Inter-ratter (Inter-observer)	The extent to which two or more individuals evaluating the	To check whether or not different observers give similar answers	Kappa statistics are often used (Landis & Koch 1977).

	same product or performance give identical judgments.	when they assess the same question.	
Internal consistency	The extent to which all of the items (questions) within a single instrument yield similar results.	To quantify the interrelatedness among the items of the instrument (Green et al. 1977).	Organize a pilot study and measure as indicator the Cronbach's alpha statistic (Cronbach 1951).
Equivalent form (alternative)	The extent to which two different versions of the same instrument yield similar results.	To minimize the large "practice-effect", by re-wording or re-ordering questions in each instrument's version.	(1) Reforming the writing style from "positive statements" to "negative ones" (Schuman & Presser 1996). (2) Asking questions in different orders and recording YES/NO or 0-5 scales (Lethbridge 1998).
Test-Retest (Intra-observer)	The extent to which a single instrument yields the same results for the same people on two different occasions.	To compare the correlation of the same respondents' answers at different times.	Correlation Coefficient (CC): If correlation between first and second answers is greater than 0.7 we can assume the reliability is good (Kitchenham & Pfleeger, 2002c, p. 21). Common CCs: (1) Pearson product-moment, Spearman rank, Intra-class coefficient, Kendall's coefficient of concordance.

5.2.4 Statistical concepts

◊ **Determining the precision of the sample's size**

The total sample size in this study was 36 potential respondents. To evaluate it precision we will use validity measures.

◊ **Determining the accuracy of the response rate**

The accuracy of the response rate will be evaluated by using reliability measures. Out of the 35 study participants, 22 respondents returned completed valid questionnaire forms resulting to a <u>62.86% response rate</u> which is judged significantly high. The specific response rate is much higher than an expected one of 30% based on the assertion of Moser and Kalton (Moser & Kalton 1971) regarding self-administrated surveys. The high response rate is not explained due to the reluctance of Greek construction professionals, it is rather explained due to the trust enhanced and motivation that respondents acquired after the contact with the researcher. In Appendix 9 and Appendix 10, the participants' profiles are presented and their feedback status is presented, respectively.

5.3 Descriptive statistics – Questionnaire: Section A

The items assessed in the first section of the questionnaire delivered to respondents belong in the descriptive part of our survey study. It should be noted at this point that first question of "Section B" of the questionnaire belongs also to the descriptive part. This question was not integrated in "Section A" as it belongs to the project-specific characteristics. In total the descriptive analysis performed using the SPSS software (Statistical Package for Social Sciences, v.20) included 9 variables derived from the first 8 questions of "Section A" and the first question of "Section B".

To derive our results: "frequencies, means, range limits, percentiles, variances, bar charts" for each single variable and for the entire set of the variables, the next three steps were followed.

Step 1 Define each variable in the "Variable View" tab. For every single variable 9 characteristics were defined. In Appendix 11 the variables set as input are presented.

Step 2 Insert all the information obtained in the "Data View" tab. An excel sheet was constructed to record all the responses for every participant and then they data recorded were inserted to the data-sheet of SPSS.

Step 3 Analyze your model's input. Following the path "Analyze" → "Descriptive Statistics" → "Frequencies" & "Descriptives" we extract all the results needed for statistically explaining the data gathered from the descriptive survey design.

◊ **General information of respondents**

In general, the majority of the respondents were either company directors (40.9%) or in-house/site engineers (36.4%). Approximately the half of respondents (45.5%) has been operating in construction companies with high experience (more than 20 years) in the field of buildings procurement and construction. The average construction volume during the last 3 years is considered relative low (36.4%: ranging between € 0.5-1.0 million) and in cumulative terms 59.1% of average volume ranged between low and relative low returns (€ 0-1.0 million). Table 29 summarizes the aforementioned data.

Table 29. General information of participants

Company role	Contracting/Subcontracting		Other
No. of respondents*	15		7
	Variable choice	***Replies***	***%***
Position of participants	Director	9	40.91
	Project manager	4	18.18
	Engineers	8	36.36
	Risk manager	0	0.00
	Procurement officer	1	4.55
Company experience (in years)	< 5	3	13.64
	5 – 9	1	4.55
	10 – 14	6	27.27
	15 – 19	2	9.09
	≥ 20	10	45.45
Av. Volume (past 3 years)	< € 0.5 mil.	5	22.73
	€ 0.5 – 1 mil.	8	36.36
	€ 1 – 5 mil.	6	27.27
	€ 5 – 10 mil.	3	13.64
	≥ € 10 mil.	0	0.00

*Total (valid) sample size: 22 respondents

To better visualize the proportion of the choices the participants made in section A of the survey, the following pie charts were constructed. When examining the position each participant holding in the company it was shown that the majority of them were directors, which is explained due to the nature of the sampled industry. The Greek construction industry consists mostly of Small Medium Enterprises (SMEs) founded, established and operated by the same person. Quite more than the one third (36.36%) of participants were employed in the company as either in-house or on-site engineers. Project managers counted for just 18.18% of the total sample followed with only one person within the category of procurement officer. Not surprisingly, given that the Greek construction industry is in a decreasing path and unfamiliar with risk management models, no risk managers were observed (Figure 43).

Corporate experience was above twenty years for almost the half of the companies participated in the study. Between fifteen and nineteen years a proportion of 27.27% was within this range of experience and followed by a 13.64% of companies with having experience in traditional procurement below five years (Figure 44).

The companies participated in the survey were found scoring a relatively low volume of building projects traditionally procured. The last three years with a majority of eight companies out of the twenty two participated had an average volume of between € 0.5 – 1 mil. Almost equally, the range of € 1 – 5 mil and below € 0.5 mil represented the 27.27% and the 22.73% of the sample population. Only three companies had an average volume ranging from € 5 mil to € 10 mil. Not surprisingly, no company has a high volume over 10 mil; a fact explained due to the declining profitability period of the industry, which is considered a core limitation of the study (see in § 8.1.1).

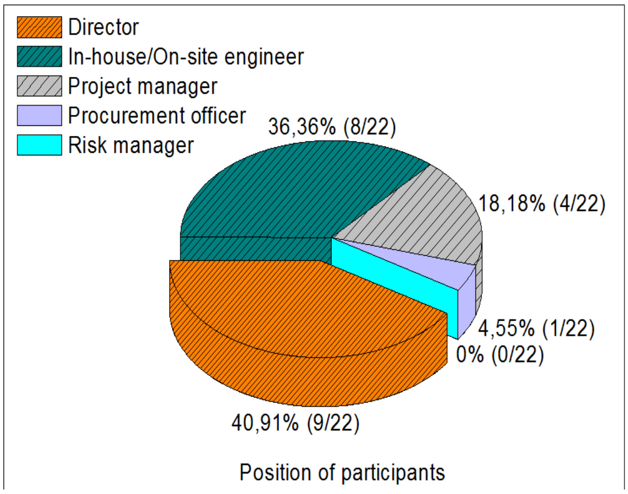


Figure 43: Sample population of study's participants

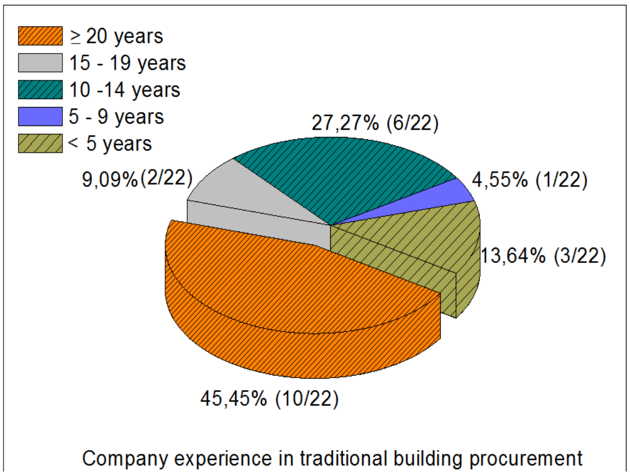


Figure 44: Sample population of study's companies

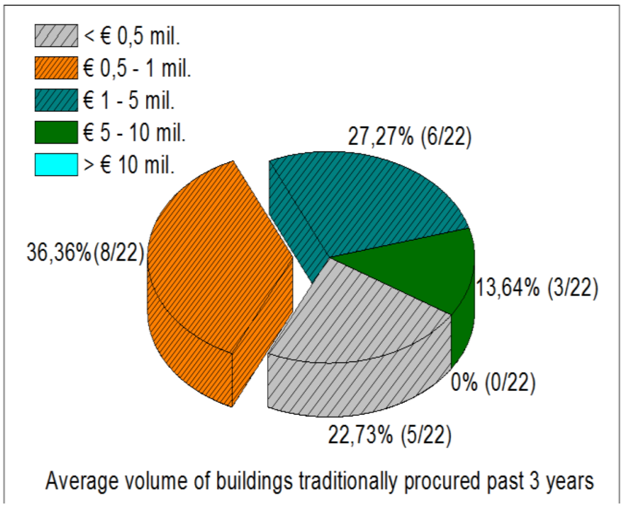


Figure 45: Average volume (€) procured the last 3 years

All variables expressing the organizational characteristics of the survey's participants are visualized with pie charts in Appendix 12. It was chosen not to discuss and present in-text all of them as it would have reduced the readability of the report. The analysis executed of the descriptive design produced the following results for each variable/question assessed. Table 30 summarizes only the numeric variables. The string variables cannot be expressed by numerical values. In Appendix 11 frequency tables are provided for all the 9 variables.

Table 30. Mean values observed for numeric variables

Variables	Type	Mean values (SPSS scale)	Mean values (Interpolated)
Position	String	-	-
Company role	String	-	-
Av. Volume	Numeric	2.32	€ 2.27 million
No. of projects completed	Numeric	1.73	16.55 projects
Company experience	Numeric	3.68	16.13 years
No. of traditional bids	Numeric	1.50	36.5 packages
RM personnel	String	-	-
Client type	String	-	-
Payment mechanism	String	-	-

Table 31 summarizes below all the descriptive results for the variables assessed. While using descriptive statistics to determine the mean (arithmetic) and standard deviation of each of the factors, it can be observed that the sampled population of firms had:

- a average corporate volume of 2.27 millions.
- constructed the last 3 years 16.55 building projects.
- 16.13 years average experience in the constructing and procuring building.
- bidded for 36.5 projects during one year period.

Table 31. Descriptive statistics summary for all variables assessed

		Position	Role	Av. Vol.	Buildings	Experience	Traditional bids	RM personnel	Client type	Payment mechanism
N	Valid	22	22	22	22	22	22	22	22	22
	Missing	0	0	0	0	0	0	0	0	0
Mean		-	-	**2.31818**	**1.7273**	**3.6818**	**1.5000**	-	-	-
Median		-	-	2.00000	1.5000	4.0000	1.0000	-	-	-
Mode		-	-	2.000	1.00	5.00	1.00	-	-	-
Std. Deviation		-	-	**.994574**	**.88273**	**1.46015**	**.67259**	-	-	-
Variance				.989	.779	2.132	.452			
Range				3.000	3.00	4.00	2.00			
Minimum				1.000	1.00	1.00	1.00			
Maximum				4.000	4.00	5.00	3.00			
Percentiles	25			1.75000	1.0000	3.0000	1.0000			
	50			2.00000	1.5000	4.0000	1.0000			
	75			3.00000	2.0000	5.0000	2.0000			

5.4 Validity tests – Content Validity

Content validity is defined as the extent to which an instrument adequately samples the research domain of interest when attempting to measure phenomena (Carmines & Zeller 1979; Waltz et al. 2010). A measure has content validity if there is general agreement among subjects and researchers that the instrument has measurement items that cover all aspects of the variable being measured (Love & Irani 2004).

Content validity, as was referred in Table 24, is practically the extent to which members of a Content Evaluation Panel perceive overlapping between the test and the job-related domain (in our case construction industry). Such analyses are essentially restricted to (1) simple proficiency tests, (2) job knowledge tests, and (3) work sample tests (Lawshe 1975, p. 566). By examining the content validity of this study (survey instrument) it was achieved to detect potential weakness in the questionnaire delivered to the potential respondents and then make improvements.

The particular Content Evaluation Panel was selected after the author contacted personally five experienced construction professionals with more than 15 years of professional experience in the traditional procurement and construction of building projects in Greece. All of them had performed survey researches in their past. Two main criteria were applied for choosing the panel members: (a) their expertise in the construction industry at a national level and (b) their knowledge and familiarity with the construction of survey instruments. These two criteria were strictly followed as they were formulated as selection rules.

In Appendix 13 the profiles of the experts forming the evaluation panel are presented. Five evaluators were addressed to be sufficient based on the bibliographical requirements as Lynn (Lynn 1986) had advised a minimum panel of 3 experts.

The Content Validity Index (CVI) will be deployed as a measuring indicator allowing the five raters to review and evaluate the relevance of the questions (items/variables) involved in the questionnaire form. The use of CVI measurement enables the raters to independently express their agreement in respect to the items used in the questionnaire. Lynn (Lynn 1986) has identified that scholars have been using two types of CVI. The first type of CVI is related to content validity of individual items (I-CVI) and the second type involves the content validity of the overall scale (S-CVI). In the present thesis study we focus primarily on the item-related content validity to examine whether the questions designed satisfy the research purpose and are compatible with the skills and knowledge of potential respondents.

The use of CVI generally provides a researcher the quantitative power to tally the proportion of cases in which the raters agree and determines the stability of their agreement (Lynn 1986). A Likert-type, ordinal scale with four possible responses is used. The responses include a rating of 1 = "*not relevant*", 2 = "*somewhat relevant*", 3 = "*quite relevant*", and 4 = "*very relevant*" which is the most widely used scale as designed by (Davis 1992). For every single question involved in both sections of the questionnaire the five raters were asked to rank the relevance of every construct/item.

Constructs are higher level concepts which are not directly observable or measurable (Agarwal 2011). The following constructs were subjectively conceptualized for the present survey instrument (Table 32). In Appendix 13 the validation-related questions asked to each expert are presented.

Table 33 provides with a satisfactory level of Item-CVI equal to 0.80 which is higher than the proposed threshold of 0.78 according to Lynn (Lynn 1986). Researchers use I-CVI information to guide them in revising, deleting, or substituting items (Polit & Beck 2006). Based on the results derived, from

Table 33 the five raters were thereafter to propose improvements on the lowest scored constructs, namely the *self-efficacy* (CVI=0.60) and *ambiguity* (CVI=0.60).

Then computed a modified kappa statistic is computed which is denoted as k^*. This parameter adjusts each I-CVI in the table for chance agreement. The index is called a modified kappa because it is an index of agreement of a certain type, namely agreement among the judges that the item is relevant. Agreement about non-relevance is not counted, because such agreement does not inform judgments about the content validity of an item. The idea of computing the modified kappa statistic is based on the methodology followed by Polit, Beck, and Owen (Polit et al. 2007).

The 4th and 5th columns of Table 35 were computed as follows:

The probability of a chance occurrence (p_c) is calculated as a binomial variable. With N and A representing the total number of experts and the number of agreeing experts (giving rankings 3 or 4), respectively. The probability of a chance occurrence is given by the formula below:

$$p_c = \frac{N!}{A!(N-A)!} \times 0.5^N \quad (23)$$

k* is defined as the modified kappa statistic and given by the formula below:

$$k^* = \frac{(I-CVI) - p_c}{1 - p_c} \quad (24)$$

The evaluation of the modified kappa was performed based on the range limits designed by (Cicchetti & Sparrow 1981; Fleiss et al. 2013) and presented in Table 32.

Table 32. Conceptualization of constructs

Attribute of	**Construct/Item**	**Definition**
Researcher (Information source)	Communication	The difficulty in interacting with, conversing with, and understanding the information source.
	Self-efficacy	The degree to which the information seeker considers himself an expert in doing the task at hand.
Problem/Task	Complexity	The time-effort relationship required.
	Importance	Importance of the outcome of the task.
Participant (Information seeker)	Comprehension	The extent to which the cognitive skills have to be used.
Questionnaire design	Ambiguity	The sufficiency of stating non-over looped or illogically connected variables.
	Clarity	The sufficiency of activities to define, explain, and simplify confusing or multi-dimensional terms.

Table 33. Item-Content Validity Index

Items	1	2	3	4	5	No. of raters in agreement	I-CVI
Communication	3	4	3	4	4	5	1.00
Self-efficacy	3	2	3	2	3	3	0.60
Complexity	2	3	3	3	3	4	0.80
Importance	3	4	4	4	4	5	1.00
Comprehension	2	4	4	4	3	4	0.80
Ambiguity	3	2	3	3	2	3	0.60
Clarity	2	3	3	3	3	4	0.80
Mean value							0.80

Table 34. Kappa values range limits

Evaluation criteria	Range limits
Fair	0.40 – 0.59
Good	0.60 – 0.74
Excellent	≥ 0.75

Table 35. Evaluation of I-CVI with different levels of agreement

Items	No. of total experts	No. of experts in agreement	I-CVI	p_c	k^*	Evaluation
Communication	5	5	1.00	0.03125	1.00	Excellent
Self-efficacy	5	3	0.60	0.3125	0.42	Fair
Complexity	5	4	0.80	0.15625	0.76	Excellent
Importance	5	5	1.00	0.03125	1.00	Excellent
Comprehension	5	4	0.80	0.15625	0.76	Excellent
Ambiguity	5	3	0.60	0.3125	0.42	Fair
Clarity	5	4	0.80	0.15625	0.76	Excellent

As can be judged from Table 35 the present survey tool scores low ($k^* = 0.42$) for the *self-efficacy* and the *ambiguity* individual items. The *self-efficacy* examines how strong is the researcher to present with practical and theoretical examples the context of the study. The fair judgment of the panel on the researcher's attitude (self-efficacy) to explain quantitatively and qualitatively his research indicates the space for improvement he has to consider in communicating better the study's context. *Ambiguity* score was judged fair showing that either the writing structure was not efficient in communicating the thesis's key-terms or that the panel was partially familiar with the specific type of survey. In both cases, some improvements suggested on the format were taken into consideration, such proposals were focused on:

- Clarifying with an example all the key-terms during the discussion meetings.
- Explanations on the relation among all tables used in the survey booklet.

Complexity, *comprehension* and *clarity* follow, with a relatively high score of the k^* equal to 0.76 which showcases that some improvements could be incorporated. The specific proposals were focused on:

- The expected time/effort ratio was realistic but perhaps demotivating. An e-survey was proposed with which however participants were not familiar with.
- The raters proposed a less tabulated format as it was to a point difficult to fill in all the required values.
- Regarding the use of language, the core suggestion was a distinction between the term "budget" and "estimate". The second one was followed as in estimation activities are linked to the side of contractor and budgeting to the side of client.

Communication and *importance* items were both validated as excellently expressed. No actual proposals were provided in these two fields as the raters were fully satisfied.

5.5 Reliability tests – Correlation results

The purpose of correlation is to help address the question: "What is (1) the relationship, (2) the degree of association and (3) the amount of shared variance between two variables (bivariate correlation)?" For examining the existence and importance of possible correlation between two variables, it is required while using the SPSS software to follow two basic steps, which are:

(1) Building a scatter plot with the two variables examined

(2) Computing the appropriate CCs. In general, the scatter plots will help to examine:

- If there is a linear relationship between the two variables.
- The type – positive or negative – of relationship observed.
- If the relationship has a given form.
- If there are outliers.
- Finally, if the relationship is linear or curvilinear.

The computation of the CCs will lead us to conclude about the reliability of the response rate received. The choice of the appropriate CC will be discussed below (see in §5.5.2). All the derived results from the tests performed are presented in detailed tables in Appendix 14.

5.5.1 Scatter plots observations

The numeric variables only will be examined whether or not are correlated. The string variables cannot be plotted as they represent categorical variables type.
Table 36 summarizes the observations obtained regarding the four numeric variables following all of the scale measurement.

The variables examined and plotted are the following:

Var. 3:	Average construction volume the last 3 years	(Section A – Question 3)
Var. 4:	Number of building projects executed the last 3 years	(Section A – Question 4)
Var. 5:	Company experience in procuring and constructing building projects	(Section A – Question 5)
Var. 6:	Traditional bid packages prepared every year	(Section A – Question 6)

Table 36. Scatter observations

	Topics examined					
Pairs of variables	Linear relationship	Type of relationship	Given form of relationship	Outliers	Shape of relationship	CC: R^2
Var.4 – Var.3	Yes	Positive	No	11	Linear	0.397
Var.5 – Var.3	Yes	Positive	No	9	Linear	0.417
Var.6 – Var.3	Yes	Positive	No	7	Linear	0.285
Var.3 – Var.4	Yes	Positive	No	9	Linear	0.417
Var.5 – Var.4	Yes	Positive	No	11	Linear	0.089
Var.6 – Var.4	Yes	Positive	No	8	Linear	0.412
Var.3 – Var.5	Yes	Positive	No	10	Linear	0.397
Var.4 – Var.5	Yes	Positive	No	10	Linear	0.089
Var.6 – Var.5	Yes	Positive	No	8	Linear	0.071
Var.3 – Var.6	Yes	Positive	No	8	Linear	0.285
Var.4 – Var.6	Yes	Positive	No	7	Linear	0.412
Var.5 – Var.6	Yes	Positive	No	8	Linear	0.071

5.5.2 Correlation coefficients

A usually debatable topic in measuring correlation is the selection of the most appropriate correlation coefficient (CC). To solve this issue we have to consider two main influencers: the types of CCs available and the Level of Measurement (LoM) used in the variables defined (Table 37). Reliability in the present thesis project is narrowed to the relative type. Given that the author does not want to examine if the survey participants would have changed their replies in repeated measurements but his focus is on whether the instrument used (questionnaire) is effective to guide them in keeping their replies consistent. Baumgarter (Baumgarter 1989) pointed out that correlation methods actually indicate the degree of relative reliability. This rationale leads to the exclusion of the following CC measurements which are expressing absolute reliability: Standard Error of Measurement (SEM), Coefficient of Variation (CV) and limits of agreements.

Consequently, we remain with the relative reliability CC measures, which are:

- Pearson's product-moment coefficient (r)
- Spearman's rank correlation coefficient (rho)
- Intra-class coefficient correlation (ICC)
- Coefficient of Determination (R^2) – Linear regression
- Kendall coefficient of concordance (W)
- Contingency coefficient (C)
- Kendall tau correlation (τ)

Table 37. Types of CCs and LoMs

LoM	Nominal	Ordinal	Interval/Ratio
Nominal	Clustered bar-graph Chi-squared Phi (φ) or Cramer's V	← *Recode* Clustered bar-graph Chi-squared Phi (φ) or Cramer's V	Scatter plot, bar chart or error-bar chart Point bi-serial correlation (rpb)
Ordinal		Scatter plot or clustered bar chart Spearman's Rho or Kendall's Tau (b)	↑*Recode* Scatter plot Point bi-serial or Spearman/Kendall
Interval/Ratio			Scatter plot Product-moment correlation (r)

◊ **Pearson's product-moment coefficient**

One of the most frequently used Correlation Coefficient (CC) is the Pearson's product-moment. Pearson Correlation allows one to measure the strength of an association that is assumed to be linear between two quantitative variables. The calculation of Pearson's CC and subsequent significance testing of it requires the following data assumptions to hold: (1) interval or ratio level, (2) linearly related and (3) bivariate normally distributed. The last assumption is the strongest for applying bivariate normality and thus using the Pearson correlation coefficient.

In practice the last assumption is checked by requiring both variables to be individually normally distributed (which is a by-product consequence of bivariate normality). However the data normality assumption cannot be easily verified. Pragmatically Pearson's correlation coefficient is sensitive to skewed distributions and outliers. Observing the scatter plots values (no scatter plots are drawn) and reading the number of outliers from Table 36 we cannot only rely on the Pearson's CC. Thus the Spearman's CC will be also computed. The strength range limits of Pearson's CC are given below (Table 38, Table 39).

Table 38. 5-classes range of Pearson's CC strength

Correlation strength	Zady (2000)	Evans (1996)
Very weak	0.00 – 0.29	0.00 – 0.19
Weak	0.30 – 0.49	0.20 – 0.39
Moderate	0.50 – 0.69	0.40 – 0.59
Strong	0.70 – 0.89	0.60 – 0.79
Very strong	0.90 – 1.00	0.80 – 1.00

Table 39. 3-classes range of Pearson's CC strength

Correlation strength	Taylor (1990)
Weak	0.00 – 0.35
Moderate	0.36 – 0.67
Strong	0.68 – 1.00

◊ **Spearman's correlation (rho)**

Spearman's rank correlation is a non-parametric test. Non-parametric tests are also referred to as distribution-free tests. The underlying population examined in this study cannot be assumed that has a pre-defined distribution. This is the first advantage of the Spearman measure. Moreover, Spearman statistic as a non-parametric is not affected by the type of mathematical relationship between the variables (Vose 2000, p. 53). The distribution-free tests have the obvious advantage of not requiring the assumption of normality or the assumption of homogeneity of variance. They compare medians rather than means and, as a result, if the data have one or two outliers, their influence is negated. In this research the Spearman's Correlation is used.

A non-parametric association in the form of Spearman's (rho) allows one to determine an association between variables if the straight enough condition is not met or when extreme outliers are present (Ophof 2013). While using Spearman's Rho, the original data values get replaced with their ranks.

Rho is used to measure the test-retest reliability for the first variable (var.1) which is the only ordinal variable, but also for measuring the test-retest reliability for the numeric variables (var.3, var.4, var.5 and var.6). Below it is explained why this measure is used for the making pair correlation computations (see in § 5.5.3).

◊ **Intra-class coefficient (ICC) correlation**

When the reliability of repeated studies or measurements has to be assessed for continuous data of scale, ratio, and interval levels of measurement the test-retest reliability is examined. A repeatability study required to help establish and quantify reproducibility, and thus provide an indication of the 'test-retest' reliability of the measurement instrument used (questionnaire questions/variables). ICC is applicable only for the numeric – scale variables of this study which are variables 3, 4, 5, 6.

◊ **Kendall coefficient of concordance (W)**

When two variables involve ranking and hence are ordinal data and the researcher wants to determine to which degree the rankings are similar the Kendall's CC is the most appropriate (Leedy & Ormrod 2010, p. 274). Given that the present study does not compare any different rankings made by independent judges this coefficient is not applicable for our research.

◊ **Contingency coefficient (C)**

Contingency coefficient is appropriate only when both variables involve nominal data. Thus, variables 2, 7, 8, 9 will be tested with this correlation measure.

◊ **Kendall tau correlation (τ)**

As in the Kendall's coefficient of concordance, Kendall's tau correlation is applicable only for ordinal data derived from small sample sizes (e.g. N<10). Given that the valid size of our sample is N=22, we cannot compute this CC for our study.

A complete picture of the reliability tests that will be performed is shown in the following table.

Table 40. Reliability tests

	Internal Consistency	Test-Retest/Intra-observer reliability			
CCs / Variables	Cronbach (α)	Spearman (rho)	Pearson (R)	Intra-class (ICC)	Contingency (C)
Var.1 (Ordinal)		√			
Var.2 (Nominal)					√
Var.3 (Scale)	√	√	√	√	
Var.4 (Scale)	√	√	√	√	
Var.5 (Scale)	√	√	√	√	
Var.6 (Scale)	√	√	√	√	
Var.7 (Nominal)					√
Var.8 (Nominal)					√

For all the variables involved in the Section A of the questionnaire the following reliability tests are performed:

(1) Pearson correlation (parametric) test: For the variables 3, 4, 5, 6.

(2) Spearman correlation (non-parametric) test: For the variables 3, 4, 5, 6. The reason for using a non-parametric test is to examine if the data normality assumption (as assumed in Pearson test) provides more realistic results. From the histograms derived for each variable we observed a relative normal data distribution only for the data of the third variable ("average construction volume"). The use of Spearman correlation relaxes the normality assumption and converts all the data to rankings.

(3) Cronbach internal consistency test: Cronbach's alpha is a measure of internal consistency, that is, how closely related a set of items are as a group. It is considered to be a measure of scale reliability. Thus this test will be applied only for the scale variables, meaning the variables 3, 4, 5, 6.

(4) Intra-class consistency correlation test: Intra-class correlation coefficient was firstly introduced by (Fisher 1958) and it is a measure of the relative similarity of quantities which share the same observational units of a sampling and/or measurement process (Koch 2004). Cronbach's alpha is said to be equal to the intra-class correlation coefficient, which is commonly used in observational studies. If and only if the value of the item/variable's variance component equals zero only then the Cronbach's alpha will be equal to the Intra-Class Coefficient. In our case, this is verified in Appendix 14.

5.5.3 Interpretation of reliability results

Quantitative variables

□ *"Pearson correlation test & Spearman correlation test"*

Pearson Correlation allows one to measure the strength of an association that is assumed to be linear between two quantitative variables (bivariate correlation). In order to allow for such a measurement, conditions have to be met. The variables have to be quantitative, the straight enough condition (linearity) has to be met and no extreme outliers should be present. However these three assumptions cannot be easily verified having obtained subjective data from respondents with different experiences and professional viewpoints. Thus we used also the Spearman correlation measure as a more realistic measurement. Table 41 cross compares the results of the two CCs used. The reason for basing out judgment on the Spearman coefficient is based on the fact that Spearman incorporates also the size effect by taking into account the influence of the outliers.

A Pearson's correlation was run to determine the relationship between the four numeric variables: var.3 ("average construction volume"), var.4 ("buildings completed the last 3 years"), var.5 ("company experience"), and var.6 ("traditional bid packages prepared every year"). The following results were derived the tables provided in Appendix 14.

- Strong, positive correlation between var.3 – var.4 ($r = .646$, $N=22$, $p < .01$).
- Strong, positive correlation between var.3 – var.5 ($r = .630$, $N=22$, $p < .01$).
- Strong, positive correlation between var.4 – var.6 ($r = .642$, $N=22$, $p < .01$).
- Moderate, positive correlation between var.3 – var.6 ($r = .534$, $N=22$, $p < .05$).
- Weak, positive correlation between var.4 – var.5.
- Weak, positive correlation between var.5 – var.6.

Overall, it is observed that the majority of the variable pairs examined are moderately or strongly correlated with only two exceptions, the relationships between var.4 – 5 (rho=0.277) and var.5 – var.6 (rho=0.219). The low correlation found can be explained also from the very low Coefficient of Determination (R^2) as was observed in Appendix 14. Practically, it was expected that these two pairs of variables would have a low degree of correlation as their interrelation cannot be considered linear.

A Spearman's correlation test was run to determine the relationship between the four numeric variables: var.3 ("average construction volume"), var.4 ("buildings completed the last 3 years"), var.5 ("company experience"), and var.6 ("traditional bid packages prepared every year"). The following results were derived from Appendix 14.

- Strong, positive correlation between var.3 – var.4 ($r = .603$, $N=22$, $p < .01$).
- Strong, positive correlation between var.3 – var.5 ($r = .648$, $N=22$, $p < .01$).
- Moderate, positive correlation between var.4 – var.6 ($r = .550$, $N=22$, $p < .01$).
- Moderate, positive correlation between var.3 – var.6 ($r = .439$, $N=22$, $p < .05$).
- Weak, positive correlation between var.4 – var.5.
- Weak, positive correlation between var.5 – var.6.

Table 41. Comparison of parametric and non-parametric CCs

CCs / Variables	Pearson (r)	Spearman (rho)	Strength - (Evans, 1996)
Var.4 – Var.3	.646	.603	Strong
Var.5 – Var.3	.630	.648	Strong
Var.6 – Var.3	.534	.439	Moderate
Var.5 – Var.4	.299	.277	Weak
Var.6 – Var.4	.642	.550	Strong (r)/Moderate(rho)
Var.6 – Var. 5	.267	.219	Weak

□ *"Cronbach internal consistency test"*

In social science research, a Cronbach Alpha of 0.7 or higher is commonly believed to be acceptable for the reliability of the measurement (Fornell & Larcker 1981). Since the total Cronbach Alpha's value is equal to 0.758 it can be supported that the consistency among the measured items is relatively high. In Appendix 14 the last column provides an interesting observation implying that if we had excluded the fifth variable of "company experience" from our questionnaire then the internal consistency of the study would have increased from 0.758 to 0.810 which approximately equals to 7% improvement.

Here we recall that the fifth variable was also the one of provoking low levels of correlation with the other numeric variables. Despite of the negative effect of the fifth variable "company experience", the variable was considered as a pivotal characteristic for describing respondents' profile.

□ *"Intraclass coefficient (ICC)"*
The single value of ICC was computed at a moderate value of 0.439 showing a medium internal consistency in the case of rating every element separately. The average ICC was computed at a higher value of 0.758 which equals to the Cronbach's alpha verifying the total degree of internal consistency which was judged as satisfactory. We accept the average ICC value as satisfactory and strong, with a probability of 95% the average ICC value to range between 0.537 – 0.889 (Appendix 14).

Qualitative variables

□ *"Correlation among nominal and ordinal variables"*
The appropriate measure of correlation, when working with nominal data, is based on the characteristics of the data and can be determined by the structure of the data matrix used to calculate the chi-square statistic. When the data matrix is 2×2, the Phi (φ) statistic is used. When the number of rows and columns in the data matrix is the same (3x3, 4x4, 22x22), the Contingency Coefficient (C) is employed. Cramer's V is used when the number of rows and columns is unequal (2x3, 3x5, 5x7). Siegel (Siegel 1956) had reported a widely accepted scale of classifying the association range for Contingency and Cramer's coefficients. Based on this, as follows below, we will judge the strength of the association among the variables examined (var.1, var.2, var.7, var.7, var.8 and var.9). Table 42 presents the range limits of Phi and C correlation coefficients for assessing the strength of the association observed between the variable pairs. The variables examined have a specific number of reply-options which are the dimensions of each variable. These dimensions are important to determine which coefficient is appropriate (Table 43) and below the choice of each coefficient is tabulated for each variables pair (Table 44). In Table 45 all the values derived from the correlation tests performed are summarized. The variable pairs were found to be mostly moderately correlated, with three pairs (var.9 – var.1, var.8 – var.7, var.8 – var. 9) to be strongly correlated and only one pair (var.8 – var.2) to be weakly correlated.

Table 42. Association strength limits (Phi & C)

Association strength	Range limits
Little/any	0.00 – 0.1
Low	0.1 – 0.3
Moderate	0.3 – 0.5
Strong	>0.5

Table 43. Dimension and type criteria for variables examined

Variables	Type	Dimensions (Response options)
1	Ordinal	5
2	Nominal	6
7	Nominal	4
8	Nominal	2
9	Nominal	5

Table 44. Selection of CC for the variables examined

Variables pairs	Choice of CC
Var.2 – Var.1	V
Var.7 – Var.1	V
Var.8 – Var.1	V
Var.9 – Var.1	C
Var.7 – Var.2	V
Var.8 – Var.2	V
Var.9 – Var.2	V
Var.8 – Var.7	V
Var.9 – Var.7	V
Var.8 – Var.9	V

Table 45. Correlation between nominal/nominal and nominal/ordinal variables

CCs / Variables	Phi (φ)	Cramer's (V)	Contingency (C)	χ^2	Association
Var.2 – Var.1	0.724	0.362	0.586	11.535	Moderate
Var.7 – Var.1	0.627	0.362	0.531	8.64	Moderate
Var.8 – Var.1	0.441	0.441	0.404	4.284	Moderate
Var.9 – Var.1	0.652	0.376	0.546	9.345	Strong
Var.7 – Var.2	0.862	0.492	0.653	16.361	Moderate
Var.8 – Var.2	0.289	0.289	0.277	1.833	Low
Var.9 – Var.2	0.780	0.390	0.615	13.368	Moderate
Var.8 – Var.7	0.514	0.514	0.457	5.806	Strong
Var.9 – Var.7	0.785	0.453	0.617	13.556	Moderate
Var.8 – Var.9	0.786	0.786	0.618	13.597	Strong

□ *"Tests of data normality"*

There are approximately 40 normality tests in the statistical literature (Dufour et al. 1998). This study agrees with the majority of scholars who have been using the Shapiro-Wilk test due to its good power properties (Mendes & Pala 2003). A data normality test was performed to determine in addition if the numeric variables follow a normal distribution pattern. The results of Table 46 lead to the following observations:

- Var.3: W=0.882 (N=22, p>0.05) → Null hypothesis rejected: No data normality.
- Var.4: W=0.784 (N=22, p<0.05) → Null hypothesis accepted: Data normality.
- Var.5: W=0.806 (N=22, p<0.05) → Null hypothesis accepted: Data normality.
- Var.6: W=0.714 (N=22, p<0.05) → Null hypothesis accepted: Data normality.

Table 46. Normality tests

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Var.3: Average volume	,216	22	,009	,882	22	,013
Var.4: Buildings completed	,295	22	,000	,784	22	,000
Var.5: Company related experience	,271	22	,000	,806	22	,001
Var.6 Traditional bids	,362	22	,000	,714	22	,000

Table 47 concentrates below all the above results derived from the validity and reliability tests performed. Overall, a satisfactory level of both validity and reliability measures is gained.

Table 47. Summary of validity and reliability observations

	Type	Tests/Coefficients	Values	Evaluation
Validity	Content	I-CVI	0.80 > 0.78	Satisfactory
Reliability	Instrumental	Pearson (r) Spearman (rho)	Only two pairs: (var.5 – var.4) & (var. 6 – var.5) were found weakly correlated.	Satisfactory with strong effect of the 5th variable on the correlation strength.
		Contingency (C)	0.546	Satisfactory
	Response	Intraclass (ICC)	0.758 Average 0.439 Single	Satisfactory Weak
		Cronbach (α)	0.758 > 0.70	Satisfactory with strong effect of the 5th variable on the overall internal consistency.

DATA ANALYSIS

Chapter **6**

Descriptive statistics will be used to assess the characteristics and properties of the resulting distributions. The study uses descriptive statistics because they summarise data into single figure statistics and allow inference which can be applied to analyse the estimates of the costs of future projects. This power of descriptive statistics is well known and applied in building economics (Skitmore & Marston 1999). The input for the descriptive statistical analyses is obtained throughout the execution of Monte Carlo simulation for the proposed cost risk analysis model (Figure 41). The specific chapter uses and analyses only the data obtained in SECTION B (*Project profile*) and in SECTION C (*Direct rating of risks drivers and risk factors*) of the questionnaire booklet.

6.1 Marginal distributions – Case Project 10

Below the summary statistics for the fitted marginal distributions of the elemental cost data is presented, with 5 cost elemental categories (Table 48). The reason for calling the fitted distributions marginal is because they express marginal variables. Marginal variables are used to be found by summing values in a table along rows or columns, and writing the sum in the margins of the table (Trumpler & Weaver 1962, pp. 32-33). In the context of this study, the marginal variables are the cost risks (X_is) as set previously (in § 4.1.2) where it was noted that "the cost risk estimates derived by the application of the model are considered additive. The summation of cost risks (X_is) plus the estimates (E_is) leads to the total/final project cost (Y_is)."

Table 48. Summary descriptive statistics – Case Project 10

Elements / Statistics	Land preparation (Y_1 in €)	Foundations (Y_2 in €)	Substructure (Y_3 in €)	Superstructure (Y_4 in €)	Finishes (Y_5 in €)
Mean	26725.95	67948.34	100955.90	76142.50	38568.20
Median	26817.00	68148.27	100030.80	74273.27	38247.91
Variance	8456248	6.858×10^7	7.283×10^8	2.392×10^8	1.37×10^8
St. Deviation	2907.963	8281.516	26988.30	15468.61	11705.26
Min	16054.31	34481.89	24741.38	29222.65	4758.625
Max	36033.98	95469.73	203074.30	140961.10	76792.55
Range	19979.64	60987.84	178332.90	111738.50	72033.93
1st Quartile	24770.31	62325.21	81397.43	65010.27	30111.51
3rd Quartile	28805.58	73594.30	119533.50	86058.23	46644.22
IQR	4035.27	11269.09	38136.07	21047.96	16532.71
Skewness	-0.1571	-0.1005	0.1514	0.4782	0.1305
Kurtosis	2.802	2.904	2.675	3.100	2.694
Coef.Var (%)	10.88	12.18	26.73	20.31	30.34

The table above presents the descriptive statistics of the elemental cost data for the 10th survey participant. The project assessed for this contractor was of € 263000 estimate (pre-ΔM decision) and € 258857 estimate (post-ΔM decision). The data of the table are extracted from the "Results" tab → "Simulation Detailed Statistics" of the @RISK excel sheet.

The mean, median, variance and standard deviation are the usual summary. The 1st quartile, denoted usually as Q_1 expresses the value below which the 25% of the data are falling. The 3rd quartile denoted usually as Q_3 expresses the value below which the 75% of the data are falling. The Interquartile Range (*IQR*) is defined as the difference between the upper quartile (Q_3) and the lower quartile (Q_1). The coefficient of variation is defined as the standard deviation divided by the mean and is used to compare the variability between the cost elements.

From Table 48 the following observations can be drawn:

(1) The marginal distributions of "substructure", "superstructure", and "finishes" are positively skewed. This indicates that these three cost elements have a mean (average) value greater than the median. For "land preparation" and "foundations" cost elements the skewness values were found negative, a fact implying higher median values than the mean values. The largest skewness value was observed for the "superstructure" cost data (equal to 0.4782) and the lowest for the "land preparation" cost data (equal to -0.1571).

(2) The "substructure" has the highest average cost (€ 100955.90) and largest range (€ 178332.90) while land preparation has the lowest average cost (€ 26725.95).

(3) The "finishes" cost data are the ones characterized by the highest coefficient of variation (30.34%), followed by the "substructure" (26.73%) and the "superstructure" (20.31%) cost elemental categories which also score high in terms of variability. This phenomenon of data variability can be seen in the Figure 47.

(4) The "superstructure" cost data score the highest kurtosis value (equal to 3.100) and the "substructure" cost data score the lowest kurtosis value (equal to 2.675). This project-specific finding is validated by the average cost data kurtosis values as provided in Table 51.

Regarding the total number of projects examined, the above three observations (on project-specific level) slightly change. It was found that:

(1) The marginal distributions of "land preparation", "foundations" and "finishes" cost data were found negatively skewed with an average value of skewness equal to -0.04635, -0.04707 and -0.00821, correspondingly. The marginal distributions of "substructure" and "superstructure" were found positively skewed with an average value of skewness equal to +0.02035 and +0.27889, correspondingly. The maximum mean value of skewness was recorded in "superstructure" cost data which is in line with the observation for the 14th project as referred above. The minimum average skewness value was recorded in "finishes" cost data, on the contrary to the observation for the 14th project where the lowest skewness value was observed in "land preparation" cost data.

The table below presents the observations made related to skewness values.

Table 49. Skewness observations on average values (for 22 projects)

Elemental cost data	**Skewness (average values)**	**% of cost data positively skewed**	**% of cost data negatively skewed**
Land preparation	-0.04635	28.58	71.42
Foundations	-0.04707	23.81	76.19
Substructure	+0.02035	47.62	52.38
Superstructure	+0.27889	66.67	33.33
Finishes	-0.00821	38.10	61.90

Given the thumb of rule of Bulmer (Bulmer 1979) implying that:

- If skewness is less than -1 or greater than +1, the distribution is highly skewed.
- If skewness is between -1 and +0.5 or between +0.5 and +1, the distribution is moderately skewed.
- If skewness is between -0.5 and +0.5, the distribution is approximately symmetric.

It can be judged that all cost elemental data are approximately symmetrically distributed without carrying significant long right (positive) or left (negative) tails. The data normality assumption was observed for almost all final project distributions representing the total construction costs. With a frequency of 95% (21 projects out of 22 examined) the normal distribution was fitting better than any other distribution the "final project cost" output cell (similar to total construction costs). The majority of the "substructure" and "finishes" cost elements were represented by the normal distributions. Beta general distribution fitted the majority of the "land preparation" cost data. The observations of distributions fitted are summarized below (Table 50).

(2) The highest average cost is observed for "Superstructure" cost data with a mean value equal to € 98402.19 and the lowest average cost is observed for "Land preparation" with a mean value equal to € 47402.77. "Land preparation" cost data are characterized by the smallest range (€ 28489.27) and "finishes" cost data have the largest range (€ 149808.00).
(3) The "substructure" cost data score the highest variability with an average coefficient of variation of 27.61% and the "superstructure" cost data score the lowest variability with an average coefficient of variation of 11.55%.
(4) An interesting observation regarding the average kurtosis values for the cost elemental data is that all kurtosis values are positive and close to 3.0 a value implying a relative symmetry of data (Table 51). As was noted by DeCarlo (DeCarlo 1997) for symmetric distributions, positive kurtosis indicates an excess in either the tails, the center, or both, whereas negative kurtosis indicates a lightness in the tails or center or both (an excess in the shoulders).

Table 50. Percentage of cost data fitted by marginal distributions (for 22 projects)

Cost elements / Distributions	Land preparation	Foundations	Substructure	Superstructure	Finishes
Normal	23%	50%	68%	23%	59%
Beta General	77%	50%	27%	23%	41%
Gamma	0%	0%	5%	0%	0%
Laplace	0%	0%	0%	0%	0%
Pearson5	0%	0%	0%	9%	0%
LogLogistic	0%	0%	0%	5%	0%
Logistic	0%	0%	0%	14%	0%
ExtValue	0%	0%	0%	5%	0%
InvGauss	0%	0%	0%	9%	0%
Lognorm	0%	0%	0%	5%	0%

Table 51. Average kurtosis values (for 22 projects)

Cost elements	Land preparation	Foundations	Substructure	Superstructure	Finishes
Kurtosis	2.81	2.79	2.70	3.33	2.75
Shape of distribution	Leptokurtic	Leptokurtic	Leptokurtic	Leptokurtic	Leptokurtic

6.1.1 Skewness, kurtosis significance and data normality test

In order to prove whether the obtained and after simulated data are distributed normally (location parameter) and symmetrically (shape parameter), a test of significance for the skewness and kurtosis values is performed.

For the five cost elemental categories, we used as input "scale" variables in SPSS software the following values: "min, 5% Perc, 10% Perc 15% Perc, 20% Perc, 25% Perc, 30% Perc, 35% Perc, 40% Perc, 45% Perc, 50% Perc, 55% Perc, 60% Perc, 65% Perc, 70% Perc, 75% Perc, 80% Perc, 85% Perc, 90% Perc, 95% Perc and Max". Then an analysis of the descriptive statistics was performed with the aid of the SPSS software package. Below the obtained values from the analysis are presented in Table 50.

Table 52. Summary of skewness and kurtsosis statistics (SPSS analysis)

	Land preparation	**Foundations**	**Substructure**	**Superstructure**	**Finishes**
N: Valid	22	22	22	22	22
Skewness	-0.165	0.331	0.917	0.353	-0.254
SE of Skewness	0.501	0.501	0.501	0.501	0.501
Kurtosis	2.067	1.704	3.132	1.592	1.988
SE of Kurtosis	0.972	0.972	0.972	0.972	0.972

To decide if the skewness and kurtosis values obtained are significant in this sample, a simple hypothesis test will be performed based on a 95% confidence level. The hypothesis is the same for both parameters and structured as follows:

$$Null\ Hypothesis\ \rightarrow H_0: Skewness\ and\ Kurtosis\ values\ are\ equal to\ zero.$$

$$Assumed\ Hypothesis \rightarrow H_1: Skewness\ and\ Kurtosis\ values\ are\ different\ than\ zero.$$

To test the hypotheses above, the values of standardized skewness and standardized kurtosis will be checked if they lie in between the range [$-Z_{crit}$, $+Z_{crit}$]. To express it mathematically, the criterion of hypothesis acceptance or rejection is the one as follows:

$$If -1.96 \leq s\,\&\,k \leq 1.96\ \rightarrow\ accept\ Ho\ \rightarrow not\ significant\ values\ at\ 95\%\ c.l.$$

$$If\ (s\,\&\,k\ \leq\ -1.96) or\ (s\,\&\,k\ \geq\ +1.96) \rightarrow reject\ Ho \rightarrow significant\ values\ at\ 95\%\ c.l.$$

The standardized values of skewness and kurtosis are computed as the skewness and kurtosis values divided by their standard error correspondingly (Weinberg & Abramowitz 2008, pp. 77-78).

Table 53. Hypotheses test for skewness and kurtosis significance

		Land preparation	**Foundations**	**Substructure**	**Superstructure**	**Finishes**
Skewness		-0.51	-0.33	0.66	1.83	0.70
Kurtosis		2.05	2.13	1.75	3.22	1.64
Range		[-1.96, +1.96]	[-1.96, +1.96]	[-1.96, +1.96]	[-1.96, +1.96]	[-1.96, +1.96]
Skewness	H_0	Accepted	Accepted	Accepted	Accepted	Accepted
	H_1	Rejected	Rejected	Rejected	Rejected	Rejected
Kurtosis	H_0	Rejected	Rejected	Accepted	Rejected	Accepted
	H_1	Accepted	Accepted	Rejected	Accepted	Rejected

As the "devil hides into the details" it has to be pointed out the fact that if we compare the skewness and kurtosis values computed by the SPSS and the @RISK software, some evident differences will be found, as tabulated below. However this is not seen as a shortfall neither in the statistical analysis nor in the simulation process, because the differences observed are explained due to the limited range of cost data values (22 in total) assessed in our statistical analysis. It is logical that the more data we will embody into our statistical analysis, the closer the skewness and kurtosis values will reach to the values of the simulated cost data. This observation is also important as the significance test above was executed to conclude if the size of the skewness and the kurtosis values is important and not to prove how close these values are to the actual ones derived by the simulation.

Table 54. Comparison of k,s values

	Land preparation	Foundations	Substructure	Superstructure	Finishes
			SPSS		
s	-0.51	-0.33	0.66	1.83	0.70
k	2.05	2.13	1.75	3.22	1.64
			@RISK		
s	-0.162	-0.0955	0.198	0.662	0.129
k	2.82	2.77	2.71	3.37	2.74

◊ **Skewness**

A distribution with an asymmetric tail extending out to the right is referred to as "positively skewed" or "skewed to the right," while a distribution with an asymmetric tail extending out to the left is referred to as "negatively skewed" or "skewed to the left." It can be quickly judged that "land preparation" and "foundations" cost data have a slight left tail, not easily identified as the skewness values -0.51 and -0.33 were found statistically insignificant at a 95% confidence level. For the remaining cost data, the distributions fitted appear positive tails to the right side. However these tails to the right again cannot be easily identified as the skewness were found statistically insignificant at a 95% confidence level.

Only in "superstructure" distribution the skewness can be quite obvious as the skewness value although it's statistically insignificant, it's large enough (equal to 1.83) to be observed. Normal distributions have zero skewness. Given that all skewness values apart from the one of the "superstructure" cost data are close to 0, it can hypothesized that the cost elemental data follow a normal curve.

Although skewness is useful to indicate if data follow a symmetric distribution and push forward examining the existence of outliers in the data sample, it cannot assist in drawing data normality conclusions. For visualizing practically the fitting of normal distributions to the cost data,

Table 56 was constructed. This table however cannot help to judge if the cost data follow a normal pattern. Thus below a data normality test is executed.

□ *"Detection of outliers"*

The distribution of the cost elemental data will be visualized by using box and whisker plots. For constructing these graphs, the well-known "five number summary" statistics values will be needed. hese are minimum, the first (or 25th) quartile, the median (50th quartile), the third (or 75th), and the maximum. To construct the box-whisker plots the Interquartile Range (*IQR*) is needed to compute the inner and outer, upper and lower fences or simply the upper and lower box values as can depicted in.

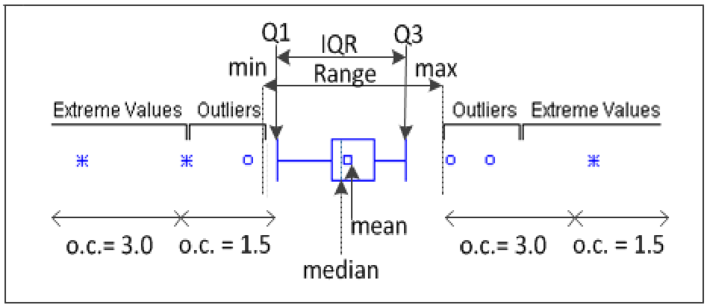


Figure 46: Five number summary statistics

To interpret the presence of possible outliers, the upper inner fence and the lower inner fence, and the upper outer fence and the lower outer fence are computed below. For the calculation of the inner fences the outlier coefficient (o.c.) is considered equal to the default value of 1.5 and for the calculation of outer fences the outlier coefficient (o.c.) is considered equal to a value of 3.0.

The basic formula for specifying the fences is the following:

$$Upper\ inner\ fence = Q3 + (o.c.) \times IQR \tag{25}$$

$$Lower\ inner\ fence = Q1 + (o.c.) \times IQR \tag{26}$$

Table 55. Upper and Lower values (fences) of box plots

Fences		Y_1 (€)	Y_2 (€)	Y_4 (€)	Y_3 (€)	Y_5 (€)
Outliers	Upper	34858.49	90497.94	176737.60	117630.20	71443.29
	Lower	18717.41	45421.58	24193.33	33438.33	5312.44
Extremes	Upper	40911.39	107401.60	233941.70	149202.10	96242.35
	Lower	12664.50	28517.94	-33010.80	1866.39	19486.60

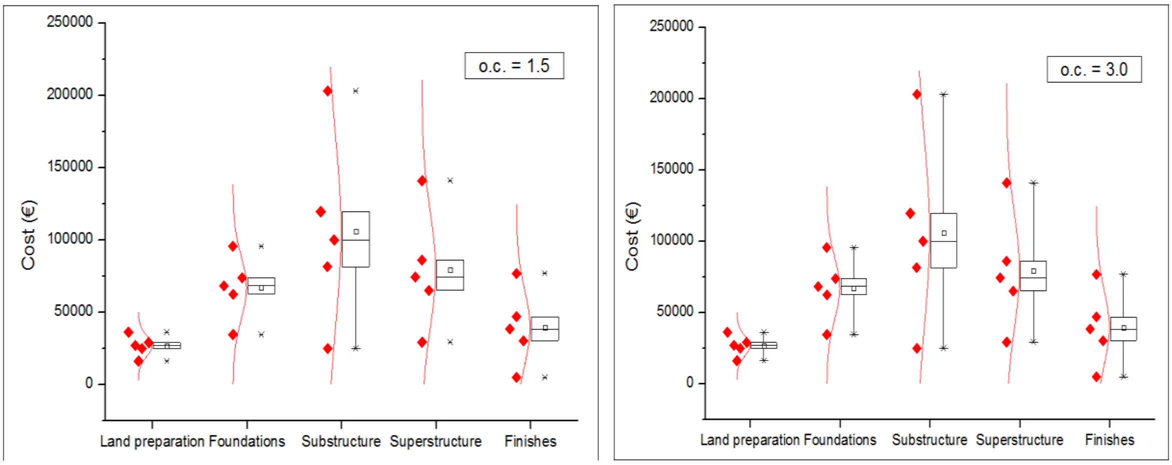


Figure 47: Box and whisker plot for cost elemental data

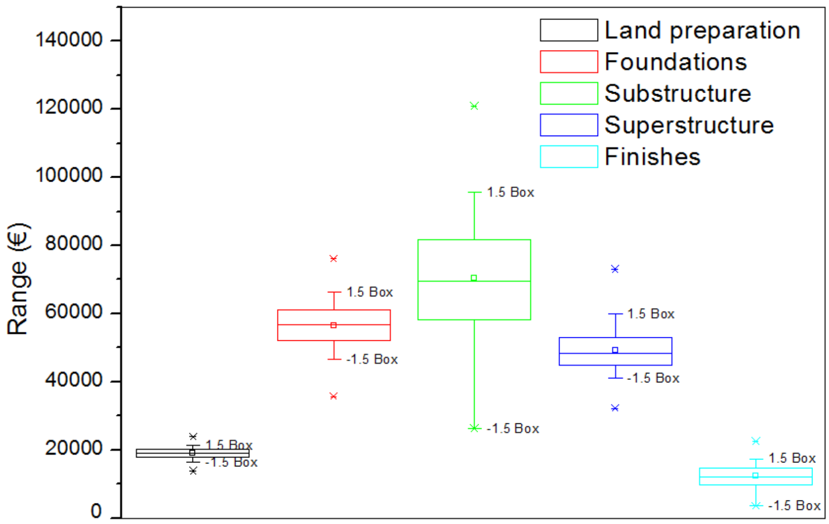


Figure 48: Adjusted box-whisker plot for o.c. equal to 1.5

The box plots above were constructed based on the values of Table 55 and provide a practical visualization of how the cost data (obtained after the simulation) are distributed for each cost element (construction phase). The line between each box represents the median, the small in-side the box square is the mean value, the limit horizontal lines are the min and max values, and the × on these two horizontal limits are the 1%-99% values.

Considering the results of Table 55 and the box plots of Figure 46 and Figure 47 the following observations can be made:

(1) The minimum and maximum values of the fitted distributions to the cost data are outliers. Only the minimum value of substructure is an acceptable minimum value. This can be seen if a default outlier coefficient (equal to 1.5) will be applied and consider the left side of Figure 47.
(2) If extreme values are considered in the cost elemental data then the minimum and maximum are considered as acceptable limit values.
(3) The subjectivity of cost estimations is represented in the adjusted box plots with "foundations", "superstructure" and "finishes" cost elements carrying unrealistic extreme values as limits. This observation could be interpreted as a sign of overestimation.

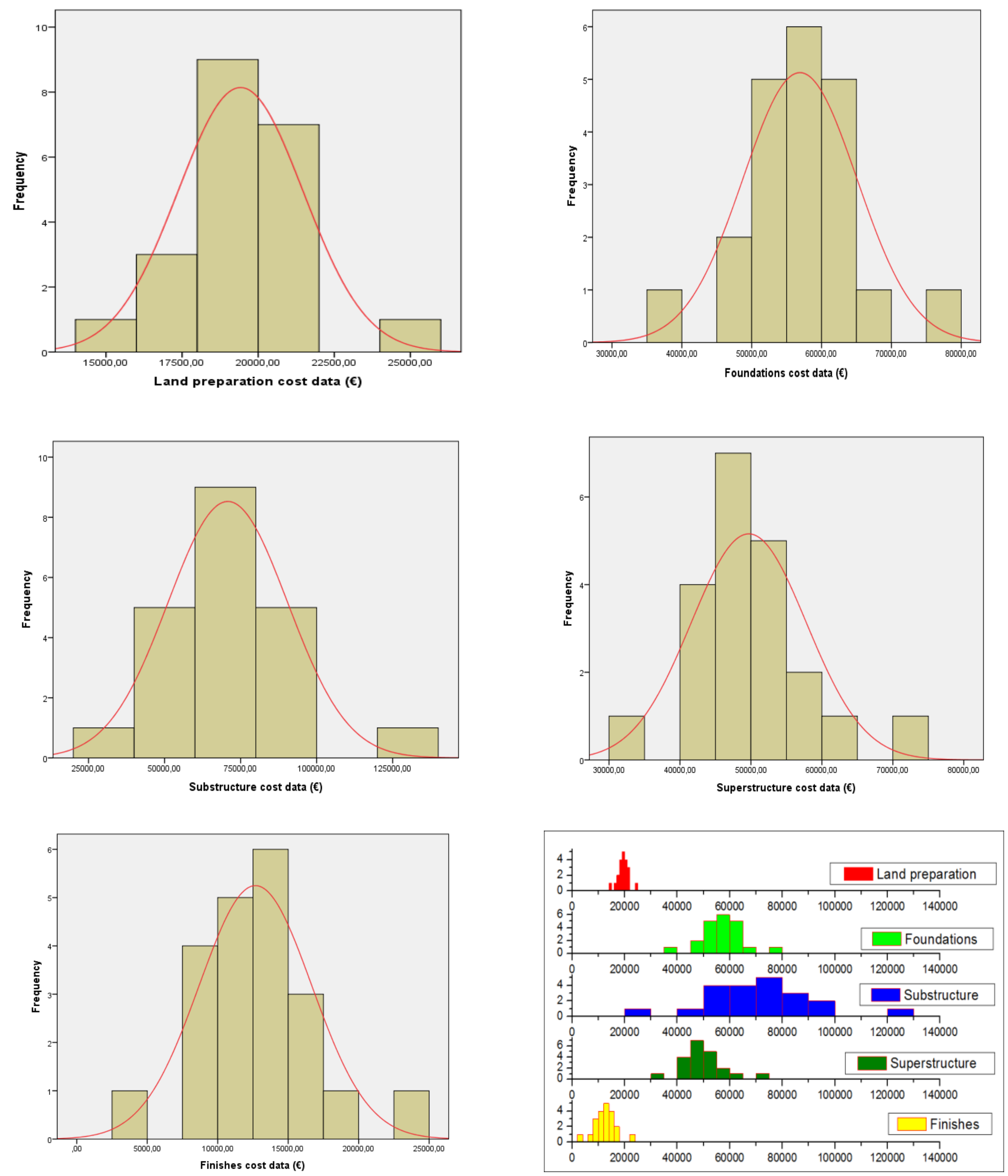
◊ **Kurtosis**

Pearson (Pearson 1905) introduced kurtosis as a measure of how flat the top of a symmetric distribution is when compared to a normal distribution of the same variance. A positive kurtosis value ($\gamma_2 > 0$) implies a "leptokurtic" distribution; meaning a less flat topped curve. A negative kurtosis value ($\gamma_2 < 0$) implies a "platykurtic" curve meaning a more flat-topped curve. If kurtosis is equal to zero ($\gamma_2 \approx 0$), the distribution is equally flat-topped and characterized as "mesokurtic". Simply a leptokurtic distribution is "fat in the tails" and a platykurtic distribution is thin in the tails".

Firstly, it has to be pointed out that all the obtained kurtosis values are positive, a fact implying the "leptokurtic" shape of the distributions with "superstructure" cost data scoring the highest kurtosis value (equal to 3.22). In "superstructure" cost data it is not surprising that we observe the highest peak exceeding the fitted normal curve, a sign of great kurtosis (Table 54). Similarly in "land preparation" and "foundations" cost data the peaks observed show a statistically significant kurtosis values. As was seen in Table 53, the significance hypothesis (H_1) of kurtosis was accepted for the "land preparation", "foundations" and "superstructure" cost data and rejected for the "substructure" and "finishes" cost data.

Kurtosis is usually of interest only when dealing with approximately symmetric distributions. Skewed distributions are always leptokurtic (Hopkins & Weeks 1990). Although the bottom right figure of the table predisposes us for dealing with normally distributed data, a normality test have to be performed to validate the data normality assumption.

Table 56. Normal distribution fitting to the five cost elemental categories (average values)



◊ Data normality test

To verify whether or not the cost data obtained after the simulation are normally distributed two tests for normality were performed at a 95% confidence level. The Kolmogorov-Smirnov and the Shapiro-Wilk are deployed with the aid of the SPSS statistical package. To practically visualize the data pattern around a hypothesized normal cumulative function, the Q-Q plots are provided in Table 58.

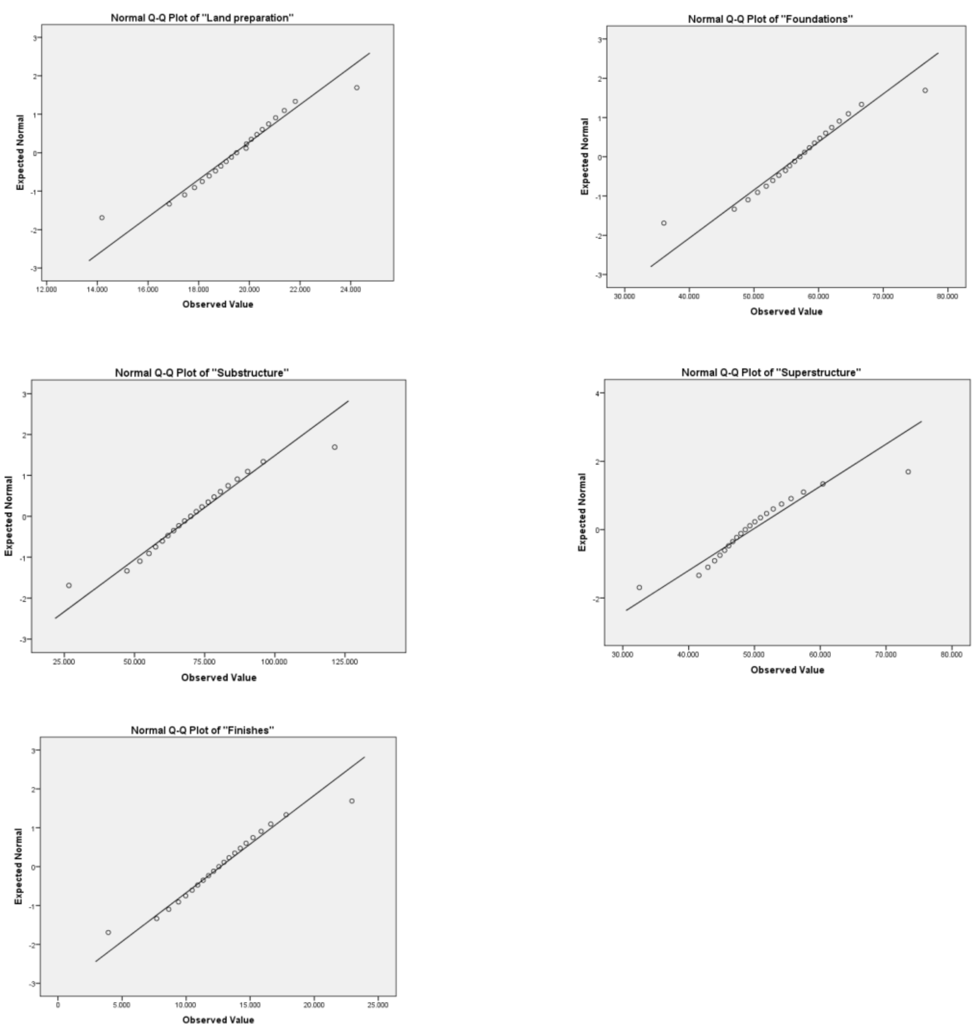
Table 57. Normality tests

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Land preparation	,077	21	,200*	,969	21	,721
Foundations	,079	21	,200*	,967	21	,670
Substructure	,073	21	,200*	,975	21	,832
Superstructure	,111	21	,200*	,929	21	,131
Finishes	,072	21	,200*	,978	21	,886

a Lilliefors correction parameter

* Lower bound of true significance

Table 58. Q-Q plots for the five cost elemental categories



Discussion of normality test results

In a Q-Q plot, the quantiles of the empirical data are compared with the ideal "test" cumulative distribution's quantiles. When using a normal Q-Q plot randomly generated, independent data on the vertical axis are compared to a standard normal population/sample on the horizontal axis (Thode 2002). The Q–Q plots depicted in Table 58 compare the distribution of the sample of cost elemental data to the standard normal distribution N(0,1). A straight forward conclusion is that the linearity of the points implies data normally distributed.

Considering the five Q-Q plots provided above, all cost elements follow a normal pattern except of the "superstructure" cost data which deviate from the linear line.

The normality tests are supplementary to the graphical assessment of normality (Elliott & Woodward 2007). Many tests exist in the statistics bibliography regarding data normality test ing such as Kolmogorov-Smirnov (K-S) test, Lilliefors corrected K-S test, Shapiro-Wilk test, Anderson-Darling test, Cramer-von Mises test, D'Agostino skewness test, Anscombe-Glynn kurtosis test , D'Agostino-Pearson omnibus test, and the Jarque-Bera test. For simplicity, the most frequently used tests are deployed here, the Lilliefors corrected K-S test and the Shapiro-Wilk (S-W) test.

To interpret the K-S and S-W test results we set a simple hypothesis at 95% confidence level (P_0=0.05) as follows:

$$Null\ Hypothesis\ \rightarrow H_0: Significance\ is\ zero\ or\ very\ close\ to\ zero\ (P_1 \approx P_0)$$
$$Assumed\ Hypothesis\ \rightarrow H_1: Significance\ is\ different\ than\ zero\ (P_1 \neq P_0)$$

The rejection or acceptance criterion of the hypotheses above is straight forward. If the significance is approximately zero we conclude non-normality of data and vice versa.

Table 59. Normality hypotheses rejection (×) or acceptance (√) summary

		Land preparation	Foundations	Substructure	Superstructure	Finishes
				K-S		
H_o	×	0.200	0.200	0.200	0.200	0.200
H_1	√	≠0	≠0	≠0	≠0	≠0
				S-W		
H_o	×	0.721	0.670	0.832	0.131	0.886
H_1	√	≠0	≠0	≠0	≠0	≠0

From Table 59, it can be concluded that all cost elemental categories are expressed by normally distributed data.

6.2 Correlation effect – Case Project 14

In some of the literature on the subject of project cost, the impact of correlation between variables is ignored by assuming statistical independence (i.e. empirically tested independence) between uncertain variables (Flanagan et al. 1987). Jaafari (Jaafari 1988) focused on examining how the characteristics of probability distributions of the unit cost can affect the evaluation of economic risks in construction projects. In contingency allocation area for building projects often the interdependencies among separate risk factors are neglected (Ranasinghe, 1994). This decision whether to ignore or not the correlations among was often set as an arbitrary and doubtful issue in cost estimation. Treatment of correlations among variables is necessary to establish realistic quantifications of uncertainty of decision variables (Ranasinghe & Russell 1992).

Distributions in a model will often have to be correlated to ensure that only meaningful scenarios are generated. For example the construction costs of land preparation activities will maybe strongly affect foundations estimates and actual costs. In terms of risks, for example, the rework costs due to incomplete dewatering (R5) will probably be positively correlated to rework costs of permits due to water inrush (R9).

It becomes evident that the distributions of the cost elements need to be correlated. The programming technique used, to generate rank order correlated input distributions, was invented by Iman and Conover (Iman & Conover 1982). The mathematical details of the technique are left out of this study's context but it should be notified the benefits this technique offers:

- The input distributions are correlated according to the rank of the values generated for each distribution. This means that all correlated distributions preserve their shape and the properties of the sampling method being used, in this study MC sampling.
- The technique is therefore also distribution-free, meaning that it can be equally applied to any type of distribution.
- The technique is based on defining a correlation matrix, which means that any number of distributions can be correlated together. This is the most significant benefit of the specific programming technique as @RISK performs stochastic analysis when the user defines a multiple-distribution correlation matrix.

An important step in a probabilistic risk assessment is the recognition of the statistical correlation among cost components. Ignoring the correlation results in an underestimation of total cost variance. This fact even becomes more significant when we are dealing with a portfolio of projects; such case is valid in the present study wherein 22 projects are examined. Neglecting the correlation among the five cost elements, may finally lead to the underestimation of budget for the desired confidence level.

The negative effect of excluding correlation between variables in cost or schedule estimation is frequently highlighted in academic bibliography and was previously discussed in § 4.1.4.3. Table 58 aggregates more in-detail the publications exploring this issue. This thesis will take into account an example case project with and without rank correlations and will proceed into research findings based on this project, which is namely the 14th building project.

Table 60. Correlation effect in cost risk estimation

Research focus	Main findings	Reference
Provide an alternative MC simulation for subjectively assessed multivariate normal distributions.	A capital investment simulation was applied with 10 variables. Correlation and no-correlation among the variables was found not significant.	(Ince & Buongiorno 1991)
Analyze the impact of correlation among cost components on the total cost variance of a construction project.	A proposed method capable of predicting the variance of the total cost with good accuracy.	(Touran & Wiser 1992)
Investigate the use of rank correlations in simulating construction costs.	(1)The use of rank correlations for generating correlated random variables results in simulated distributions that are close to actual distributions. (2)The use of rank correlations was at least as effective as using Pearson	(Touran & Suphot 1997)

	correlations in modeling dependencies.	
Prove the importance of the choice of which distribution to use to represent input variables and the importance of assessing and including correlations between the variables.	(1)Correlations must be included in the MC cost model rather than excluded. (2)The effect of excluding correlations is more profound than the effect of the choice between lognormal and beta distributions.	(Wall 1997)
Derive theoretical distributions of the project cost of buildings by treating (incorporating) correlations.	The theoretical requirements necessary to demonstrate and treat the correlations in the estimation of moments in theoretical distribution of project costs.	(Ranasinghe 2000)
Develop a cost-related model satisfying the three conditions: (1) not requiring excessive input from management, (2) introducing correlations indirectly and (3) recognizing factor-based correlations when they occur in the field.	A factor-based computer simulation model (COSTCOR) for evaluating project costs given correlations among cost items.	(Wang 2002)
Present a general method to incorporate correlations between cost elements in the process of cost estimation.	(1)Neglecting the correlations can lead to an error such serious as ignoring a cost element. (2)The proposed method helps cost estimators assess the true impact of correlations between cost elements on the project unit cost.	(Yang 2005)
The treatment of correlations inherent in the repetition of same crews working at various locations.	A new MC simulation model implementing a Gaussian copula to generate correlated duration samples in repetitive projects that have prespecified marginal distributions and pair wise rank correlations.	(Yang 2006)

Spearman's Rank Coefficient (ϱ) is a non-parametric measure of statistical dependence between two variables and is an indication of correlation between ranks of the values of random numbers instead of correlation between values (Kurowicka & Cooke 2006). Pearson product-moment correlation (r) is the most commonly used method of computing a correlation coefficient between variables that are linearly related. In other words, trusting the Pearson coefficient implies an assumption that the quality of a least squares fitting to the original data is present.

In general, Spearman correlation benchmarks the *monotonicity* of a relationship and Pearson benchmarks the *linearity* of a relationship. In this study, the interest was paid on measuring the strength of the association among the cross-paired variables and not the strength of the linearity-fiiting among the cross-paired variables. For this reason, the spearman rank correlation coefficient was computed with the aid of the SPSS statistical package. Rank correlation is often preferred to product-moment correlation as a measure of dependence for two reasons as explained in (Ghosh & Henderson 2003). First, Spearman coefficient is always defined, even if the random variables involved have infinite variance. Second, it is invariant with respect to strictly increasing transformations of the random variables involved.

The Spearman coefficient values were obtained and used to structure the correlation matrix in the excel-based risk model. The Spearman coefficient values were computed and found all of them, equal to 1.0; a result showing a perfect monotonic relationship. For this reason, we used the values of the Pearson coefficient to obtain a more realistic figure of these inter-dependencies.

After structuring and inserting the correlation matrix in the excel-based cost risk analysis sheet, @RISK checks and adjusts the correlation matrix to be self-consistent. Self-consistency is defined when the matrix is positively defined. The adjusted matrix is presented below (Table 62). The self-consistent correlation matrix differs only from the initial one (Table 61) by a very small average reduction of values in columns of -0.036% and a very small average increase of values in rows of +0.016%. Overall, the average total reduction is equal to -0.0104% of all matrix's values. Two main observations can be made here, firstly no negative correlations were observed; a fact of arbitrary judgement if had occurred and secondly, the initial matrix was almost self-consistent; a fact indicating realistic correlation among the five cost elements.

Table 61. Initial non self-consistent correlation matrix

	Land preparation	**Foundations**	**Substructure**	**Superstructure**	**Finishes**
Land preparation	1	1.000**	0.994**	0.977**	0.993**
Foundations		1	0.995**	0.981**	0.995**
Substructure			1	0.992**	1.000**
Superstructure				1	0.991**
Finishes					1

**(Pearson) Correlation is significant at a 0.01 level (2-tailed).

Table 62. Adjusted self-consistent correlation matrix

	Land preparation	**Foundations**	**Substructure**	**Superstructure**	**Finishes**
Land preparation	1	0.9993	0.9993	0.9763	0.9923
Foundations		1	0.9943	0.9803	0.9943
Substructure			1	0.9913	0.9993
Superstructure				1	0.9903
Finishes					1

Both spearman and person correlation test were run to determine the strength of the association among the five cost variables. It was found that there is a significant positive relationship between all cost elements. The strongest (Pearson) relationship was observed between the "land preparation" costs and the "foundations" costs, with $r=1.00$, $p<.01$ and similarly between the "substructure" costs and the "finishes" costs with $r=1.00$, $p=0.001$. The less strong among all positive relationships was found between the "land preparation" costs and the "superstructure" costs with $r=0.977$, $p<.01$.

Figure 49 provides a practical visualization of the scatter plots between every single cost element with each other. It can be seen, there is a positive and strong correlation among all cost elements. Both *monotonicity* and *linearity* can be graphically observed and were also validated as the spearman coefficient was computed equal to one and linear data assumption was validated by the Q-Q plots.

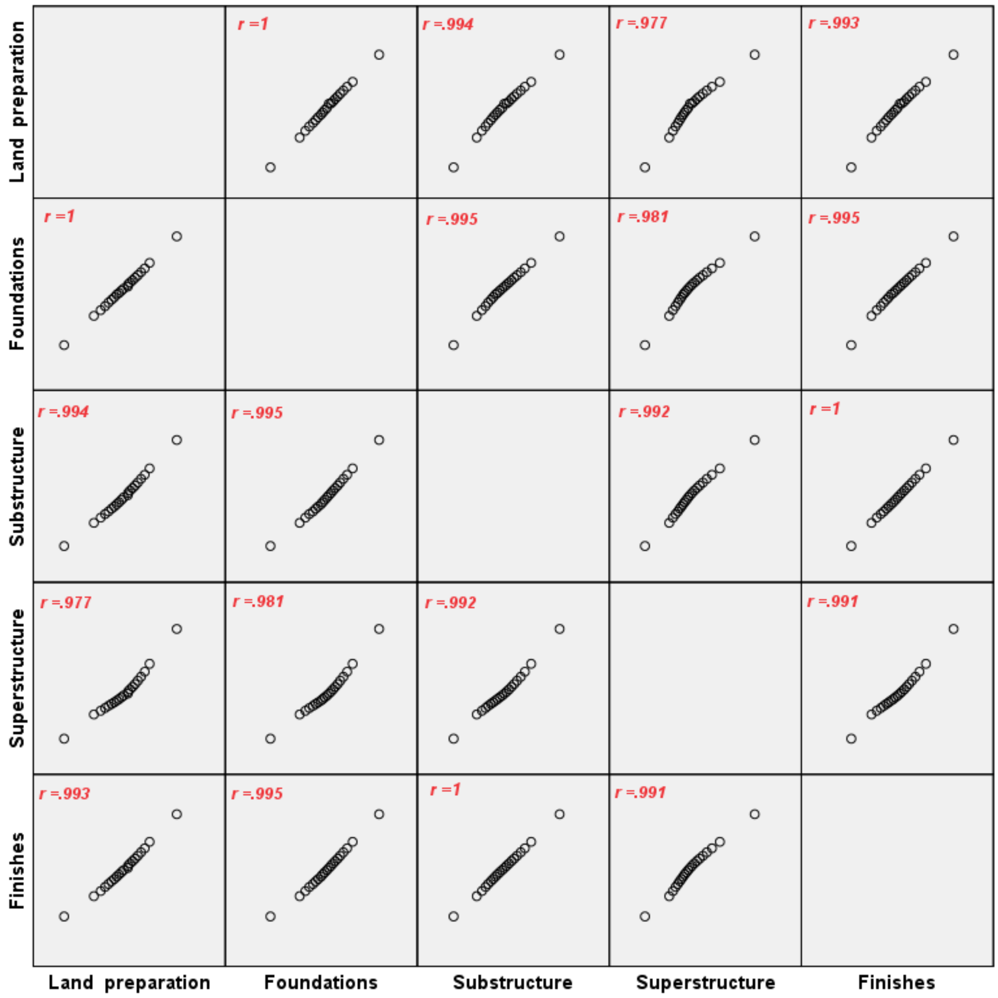


Figure 49: Scatter plots pairs for the five cost elements

6.3 Simulation results – Case Project 14

6.3.1 The correlation effect

When taking into consideration the correlation matrix as structured in Table 61 the following pictures of project cost performance are derived.

From Figure 50 the following two observations can be made:

(1) The probability meeting the cost estimate without correlations considered is 6.51% and the probability meeting the cost estimate with correlations considered is 6.97%. This indicates a 7% increase in the probability meeting the project cost estimate. For the calculation of these probabilities Table 63 values were used with the aid of Excel commands[11].

(2) The cost data in 90% range for uncorrelated elements is € 56241 and for correlated elements is € 102479. This indicates that when correlations are included more cost data are captured and better estimates can be produced. Almost double cost data (+94.67%) are included in the 90% data range when correlations are assessed among the five cost elements. This is not surprising if we notice the shape of the red curve.

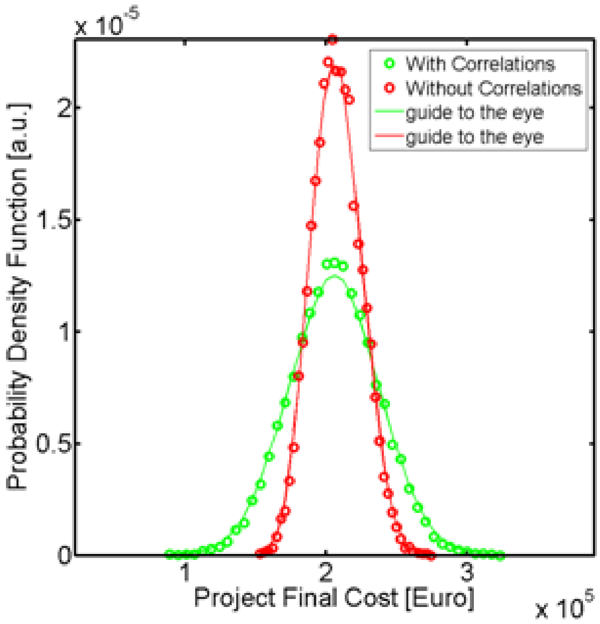


Figure 50: PDFs comparison

From Figure 51 the following three observations can be made:

(1) The correlations when included produce a cost image moved towards higher cost values. This implies a serious effect of correlations meaning that if they are assessed in the model. The tendency for underestimation if correlations are excluded is supported. Especially when a study deals with a portfolio of 22 construction projects. This will put forward some discussion onwards.

(2) Examining closer the cumulative graphs, it is observed that on the project's confidence level which is equal to 71.57% (0.7157), the cost estimate with correlations is € 226154.28 and without correlations is € 218727.05. Consequently when correlations are included a higher by 3.39% total estimate should be expected.

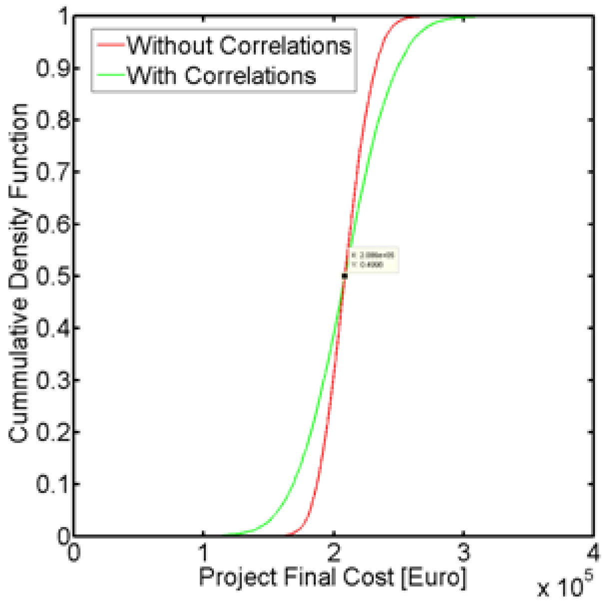


Figure 51: CDFs comparison

(3) It's interesting to showcase also that the two cumulative distributions on a level of 50% cross each other. Below a 50% cumulative probability (representing the confidence level of a project) the correlated S-curve estimates less than the uncorrelated the project cost. On the contrary, after the 50%

[11] Without correlations: P(Ci≤Ei)=P(209087≤183000)=NORMDIST(183000;209087;17239,85;1)=6.51%
With correlations: P(Ci≤Ei)=P(208901.20≤183000)=NORMDIST(183000;208901,2;17527,42;1)=6.97%

confidence level the project cost estimate is increased comparing to the one produced by the uncorrelated S-curve. This indicates a phenomenon implying that: "the greater the confidence level (risk exposure level) a contractor wants to accomplish the specific project the higher the expected project total cost". This implication establishes some ground for future research on the cumulative level the two S-curves cross each other and how contingencies setting could be optimized in a projects portfolio. This is however a topic out of the report's scope and is not examined.

Table 63. Summary statistics for the Final Project Cost

Statistics	Final Project Cost (non-correlated elements)	Final Project Cost (correlated elements)
Mean	209087.00	208901.20
Median	208567.30	208435.80
Mode	215352.70	209466.30
St. Deviation	17239.85	17527.42
Variance	2.9721×10^{8}	3.072×10^{8}
Skewness	0.1417	0.1379
Kurtosis	2.8277	2.7653
Coef.of Variability	8.245%	8.261%
Minimum	153076.80	89238.52
Maximum	274476.60	323480.72
Range Width	121399.80	234242.20
Mean Std. Error	3675.55	3736.85

The table above assists in drawing the following useful observations regarding the correlation effect in the cost risk estimation procedure:

(1) When correlations are included in the risk model the mean final (total) cost of the project was found slightly smaller than the one in the uncorrelated model, which reveals a tendency for slight cost overestimation. The cost difference was equal to € 185.8 representing only the 0.101% of the total cost estimate (€ 183000) as provided by the respondent in the survey. This finding was validated in the study of Yang (Yang 2005, p.280) who found the mean value in the scenatio of "excluding correlations" overestimated by 0.301% against the scenario "including correlations".

(2) The standard deviation with correlations included was recorded 1.7% higher than the one without correlations included. This leads to the conclusion that correlations have an effect in the spreading of the cost data, which probably will drive to normality behavior. However standard deviation is not a "primary statistic", consequently the variance will lead to more safe conclusions. This finding is line with the one of Wall (Wall 1997, p. 250) wherein the standard deviation was found underestimated by 0.75%, when correlations were not included. For a typical bridge replacement project, a study revealed a similar pattern of underestimating standard deviation by 16.27% when correlations were excluded from the cost estimation model (Chou et al. 2009, p.575).

(3) Correlated cost elements are characterized by a higher variance than uncorrelated cost elements. The variance of the project's final cost with correlations was observed larger by € 9,990,000 (0.999×10^{8}) than the variance of the one without correlations and as a percentage of the no-correlations one was larger by 3.36%. This leads to two conclusions: (a) The spread of data around the mean value is less dense; meaning more spread data to the tails of the fitted distribution and (b) the higher variance hides the curtain of a more risky profile of the project. A potential investor (client) would be de-motivated in this estimate, as the higher variance would be perceived as high price volatility. This finding implies that Greek contractors apart from being inexperienced in including correlations in their cost estimating models also tend to

strategically ignore them so to produce more attractive offers for their potential clients. The underestimation effect is also understood with the use a simple formula[12].

(4) The correlation effect was not significantly powerful in terms of kurtosis values. The simulation results provided a project final cost with correlations, with a kurtosis value slightly decreased by -2.25% comparing to the one of the uncorrelated cost elements.

(5) The coefficient variability was slightly increased by 0.016% which is line with the higher variance observed when correlations were included.

(6) The range of limit values was significantly increased (almost doubled: +92.95%) from € 121399 (without correlations) to € 234242.20 (with correlations). It's interesting also the fact that the peak value (max) was increased by +17.85% and the minimum value was decreased by -41.70% correspondingly, meaning a less peaked marginal distribution.

(7) The standard error when correlations were included was increased by 55.1 units or by -1.67% comparing when correlations were not considered. This indicates that when correlations are included, the sample size is less representative for a potential population. It is expected then that with correlations included the outliers will be more than the ones in the initial condition of not including correlations (Figure 52).

(8) The comparison of the Q-Q plots for the normal distributions of the Project final cost when correlations are excluded and included showed that in both cases short tails exist at both distributions' ends. However Figure 53 does not prove if tails become heavier or thinner in the "with correlations" condition. This will be enlightened by transforming the normal values to the natural logarithmic values. Figure 54 shows the actual correlation effect and the outliers' role. The shape of the right Q-Q plot, when correlations are included, follows a curved pattern above the linear line with slope decreasing from left to right. This means that the distribution when correlations are included is more skewed to the left; a finding validated by the skewness values of Table 63 where the skewness was decreased by 2.68% when correlations where considered among the cost elements. In other words, Figure 54 assists to prevent that during processing cost data, outliers were left untouched after natural log transformation and thus their true effect will be revealed. This proposition was also followed for a much more extensive and complicated project examining 546 highway projects (Chou et al. 2009, p.574).

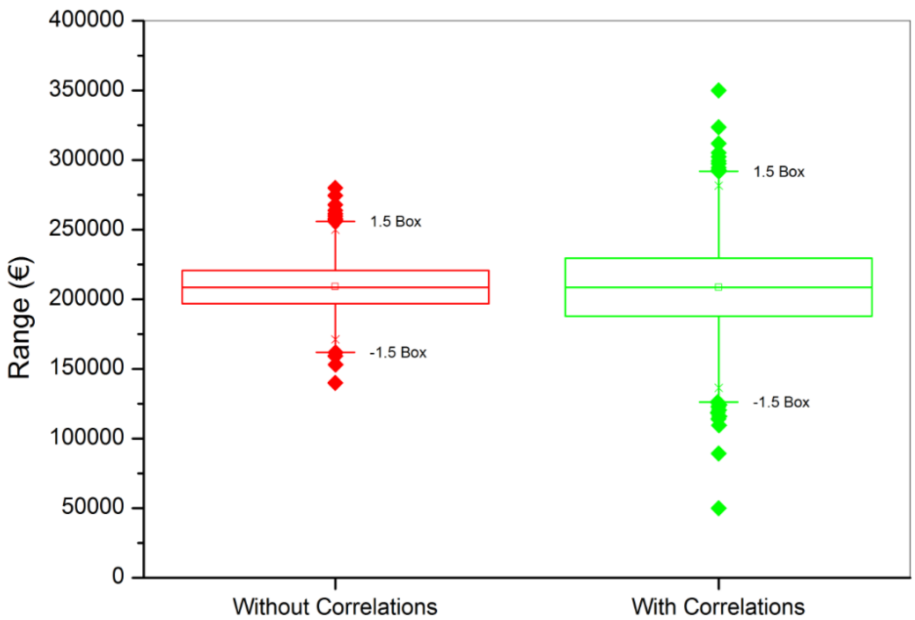


Figure 52: Box and whisker plot for final (total) project cost – without & with correlations

[12] $\sigma^2(A+B) = \sigma^2(A) + \sigma^2(B) + 2 \times R \times \sigma(A) \times \sigma(B) \Rightarrow Var\,(A+B) = Var(A) + Var(B) + 2 \times R \times \sqrt{Var(A) \times Var(B)}$

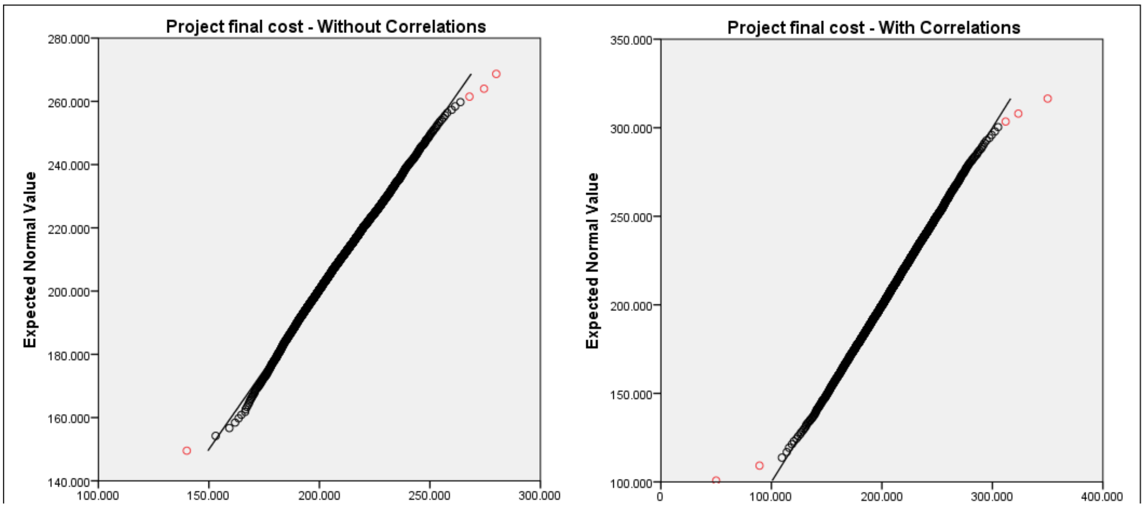


Figure 53: Q-Q plots for the "Project final cost" Normal distribution

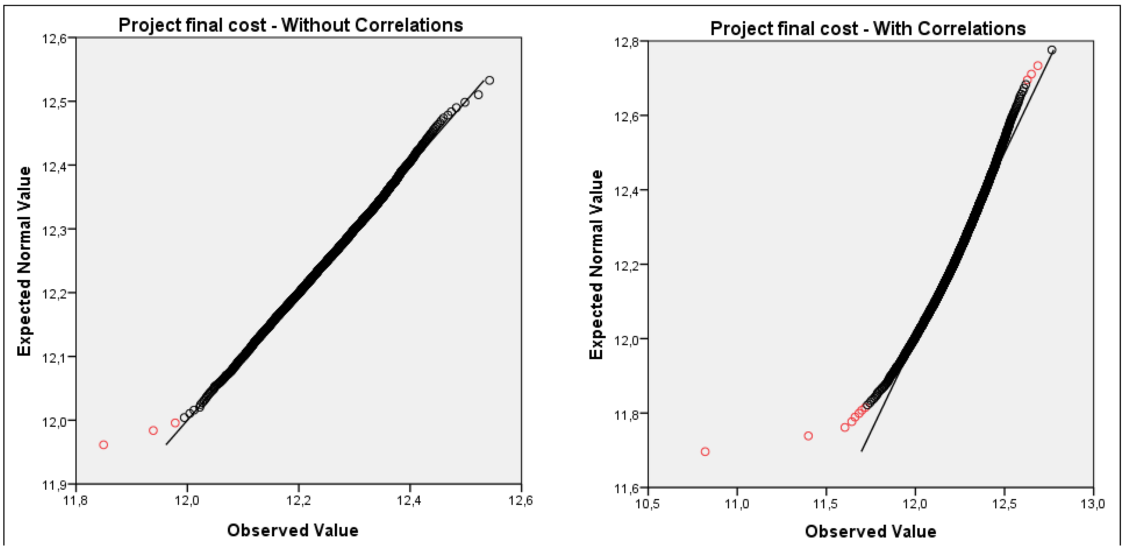


Figure 54: Q-Q plots for "Project final cost" Log distribution

6.3.2 Risk factors assessment

Three topics will be discussed in this section: Firstly, the <u>scatter plots</u> created by the cost estimated after the MC simulation was performed, secondly the <u>tornado graphs</u> and <u>correlation graphs</u> of all risk factors for each category and thirdly, the ranking of the "risk levels" for each single risk factor will be outlined, too.

Figure 55 compares in the shape of scatter plots with the surrounding curve of range values. It can be seen that the "substructure" cost element has the largest standard deviation (SD_x = € 15018.91) which is represented by the green curve. This indicates that project's final cost will be affected mostly by the spread of values in "substructure" activities. "Land preparation" costs, on the contrary, carry the smallest standard deviation (SD_x = € 1536.28) which indicates a minimum impact on the project's final cost. This finding is validated by the summary of the descriptive statistics as was provided in Table 48. In terms of rank correlation, "substructure" was mostly positively correlated to the "final project cost" with a coefficient of 0.9996 and "land preparation" was the least, positively correlated to the "final project cost" with a coefficient of 0.9937. All cost elements were found strongly and positively correlated to the final project cost.

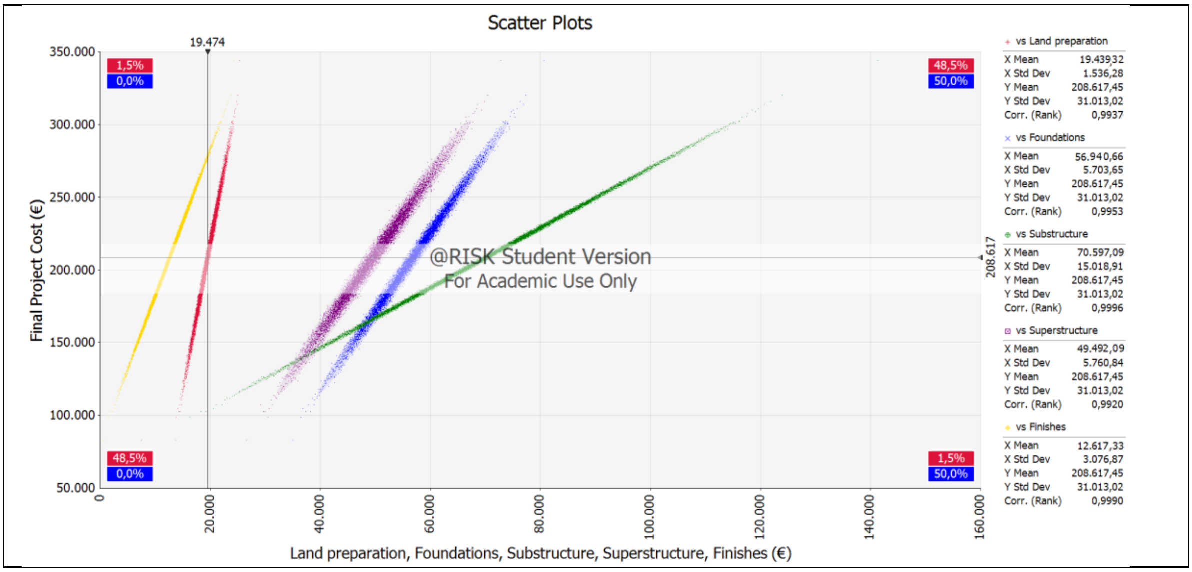


Figure 55: Comparative scatter plots against final project cost

Table 66 provides the tornado graphs showing how each risk individually would have affected the mean value of the cost estimate, obtained after the simulation end. The correlation coefficient values (spearman-rank) are also seen on the right side of the table. The coefficient values depict

The examination of the tornado graphs produced the following observations as tabulated below. From Table 64 it can be seen that the risks provoking the maximum or minimum cost changes on the mean of the cost estimates are not the same in terms of relative percentage.

For example, in "land preparation" the fourth risk (Costs of damages due to ground subsidence in existing projects) is the most influential in terms of absolute change on the mean value (€ 3454.97) but the least influential in terms of the average change as percentage of the mean value (-0.85%). On the contrary, the first risk which was ranked as a low influence risk in terms of absolute change on the mean value (€622.20) but the most influential in terms of the average change as percentage of the mean value (+0.45%). This observation leads to the conclusion that should not rely on the absolute change a risk could provoke on a cost estimate. The only cost category which carries the same risks as top and bottom ranked in both criteria (absolute change and percentage change) was "superstructure".

Another finding is that on average terms, the "superstructure" cost category was observed with the highest average percentage change of 2.27% and the "foundations" with the lowest average percentage change of -0.19%. The "substructure" cost category was observed with the highest average range of change of € 15810 and the "land preparation" cost category the lowest one with € 1800.03. This finding validates the fact that how risks are ranked based on their change on the mean cost estimates does not imply the same ranking pattern in terms of average percentage change. To conclude, it can be very significant for a potential contractor while judging his/her cost estimates to know the average expected percentage change in each of the five cost estimates so to enable him/her in estimating a realistic contingency and minimizing over-estimating attitude. Table 65 assists towards this direction, but it does not imply the same observations can be made for a portfolio of projects, as in this study.

Table 64. Top-Down ranking of risks' cost change on the mean cost estimate.

	Range of change on mean (€)		Average change on mean as %	
Land preparation	3454.97	R4	+0.45	R1
	3435.95	R3	+0.34	R2
	873.87	R5	-0.18	R5
	622.20	R1	-0.57	R3
	613.14	R2	-0.85	R4
Foundations	14119.40	R12	+0.63	R6
	10649.20	R10	+0.34	R11
	7193.30	R8	-0.07	R8
	7169.90	R6	-0.37	R7
	1285.16	R11	-0.52	R12
	1063.74	R7	-0.64	R9
	490.50	R9	-0.70	R10
Substructure	41527.50	R17	+4.80	R16
	20983.80	R16	+1.70	R17
	13591.10	R13	-0.04	R13
	11168.70	R18	-0.06	R14
	4139.65	R15	-0.09	R15
	3449.16	R14	-0.92	R18
Superstructure	14178.00	R19	+4.83	R19
	7045.77	R21	+3.56	R20
	6810.29	R20	+3.47	R21
	6107.52	R22	-0.25	R22
	5764.81	R23	-0.28	R23
Finishes	7034.94	R24	+1.73	R25
	6878.66	R25	+1.54	R24
	2317.64	R27	-0.28	R27
	2290.74	R26	-1.21	R26

Table 65. Average values of risk's cost changes on mean values of cost estimates

Cost categories	Av. (Range of change on mean: €)	Av. (Average % change on mean)
Land preparation	1800.03	-0.16
Foundations	5995.88	-0.19
Substructure	15810.00	0.90
Superstructure	9781.28	2.77
Finishes	4630.50	0.44

Table 66. Tornado graphs and correlation coefficients for risk factors

Figure 56 shows a ranking of all risks according to their "risk effect levels" as computed in the @RISK-based cost risk analysis model. Providing this image assists in understanding which cost risk drivers; meaning Quantity – Unit Cost – Schedule – Global are more important to affect the amount of the cost risks.

It is found, that schedule risks are by far the most influential with an average risk effect level equal to 0.1254 (12.54%), second are ranked the quantity risks with an average risk effect level equal to 0.0178 (1.78%), followed by the unit cost risks with an average risk effect level of approximately 0.0022 (0.22%) and last are ranked global risks with an average risk effect level of approximately 0.0017 (0.17%). This finding for the specific project is validated by the contribution of each cost risk driver in the total cost risk amount (Table 67).

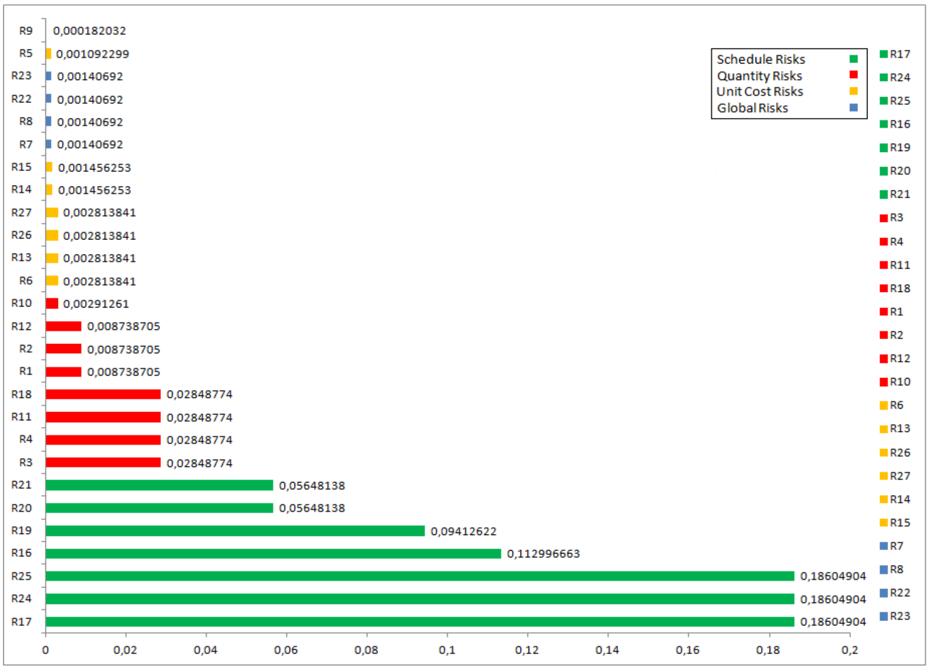


Figure 56: Ranking of individual risk levels

Table 67. Contribution of each cost ris driver to total cost risk amount

Cost risk drivers	Total cost risks (€)	Individual cost risks (€)	Contribution (%)
Quantity	26185.54	4426.47	17
Unit Cost	26185.54	430.41	2
Schedule	26185.54	21044.45	80
Global	26185.54	284.21	1

Figure 56 and Table 67 provided useful findings regarding the level of influence of each risk factor separately and more importantly the risk effect level of the four cost risk drivers. These findings are based on the cost risk analysis sheet. To which extent these finding will be in agreement with the direct (subjective) evaluation of the cost risk drivers performed by the study's participants will be examined below. It has to be pointed out that the next section is not a product of the MC simulation, but it was chosen to be included and discussed in this section of the report to facilitate a comparison between the simulation-based assessment of the cost drivers and the AHP-based assessment of the cost drivers.

6.3.3 Direct rating of cost risk drivers

◊ Outline of the AHP method

The Analytical Hierarchy Process (AHP) was used to evaluate the priority importance of each cost risk driver against each other. Multi criteria decision analysis methods (e.g. AHP, MAUT, SMART) are used to evaluate and select among various alternative methods. The use of AHP in this study aims to create a mindset in contractors to score directly the most important cost risk drivers so to enable the author explaining how the participants prioritize their cost estimations.

The advantages of AHP, which lead to its selection, are:

(1) The comprehensive prioritization among different pre-selected models (Saaty 2008)
(2) The reciprocity principle is easy to be validated and adjusted if violated. The term of reciprocity was defined by Saaty (Saaty 2003). The intensity of importance of an action i compared to an action j is defined as a_{ij}. Recirpocity implies the relation: $a_{ij} = \frac{1}{a_{ji}}$
(3) The 9-numbers judgment scale is easily explained or used by participants. The judgments were made on one only criterion; "the riskiness of each cost risk driver". comparing two drivers at a time. The scale of the judgment runs from one to nine, where a one stands for equal importance and a nine for extremely more important, as provided by Saaty (1977, p. 345) and shown in Table 68.
(4) Check of the consistency property by calculating the Consistency Ratio (CR) and if CR < 0.10 then accept the pair-wise comparisons.

Table 68. Importance scale for prioritization

Intensity of Importance	Definition	Linguistic meaning
1	Equal importance	Two activities contribute equally to the objective.
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another.
5	Essential or strong importance	Experience and judgment strongly favor one activity over another.
7	Demonstrated importance	An activity is strongly favored and its dominance demonstrated in practice.
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation.
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed.

◊ Criteria on which the cost drivers are assessed

The fours cost risk drivers (Q, UC, S, G) will be evaluated based on three main criteria which will be divided into relevant sub-criteria. Below, the logic of structuring the AHP is present in Table 69 and Figure 57 explains the criteria and sub-criteria used in the pair-comparisons as showed below. Table 69 was structured based on the bibliography available on the topic of risk behavior determinants (as shown in Figure 18) and drivers of realistic risk allocation (as shown in Figure 33) plus the performance criterion as was seen in the Problem scope section (see in § 2.4).

The four cost risk drivers: Quantity, Unit Cost, Schedule, and Global will be evaluated against the three selected criteria. The end-result of the AHP will be the ranking of each cost risk driver as subjectively assessed by the contractors participating in the study.

Table 69. Criteria to be used in the AHP method

Criteria	Sub Criteria	Explanation
Propensity	Reasoning of risk assessment	Technical capacity performing a realistic and competitive cost risk assessment.
	Sharing agreements	Contractual knowledge of cost sharing rates and the implications of their setting on bid winning.
Perception	Sensitivity	The set of individual risk ratings are correlated in each cost element.
	Attitude	Corporate beliefs and managerial values leading to design and apply a compensation mechanism (contingency package).
	Fear	Thoughts about specific fear-arousing elements, such as uncompensated additional costs.
Performance	Ability	Financial ability to afford the costs of risks.
	Motivation	Trust to client in fairly and mutually transferring costs of risks.

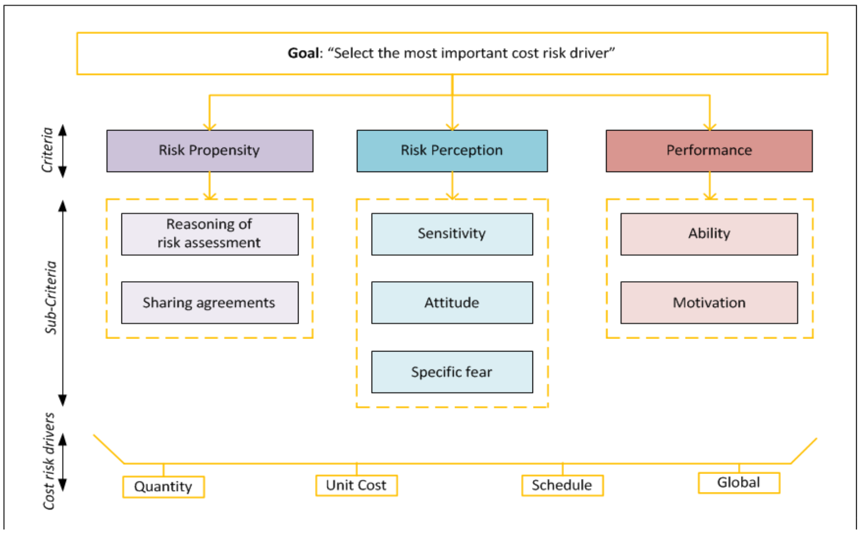


Figure 57: Overview of the AHP method

The steps that will be taken are to make eleven pair wise comparison matrices. The logic is simple, one matrix will compare the three criteria, three matrices will compare the sub criteria, and last the goal will be compared to each sub criterion individually, so seven matrices will be computed. All the priority vectors derived will be synthesized into one main table for specifying the relative priority that contractors of the survey judge the "importance" the four cost drivers.

◊ **Consistency check**

When respondents to a survey are called to make judgments on rating some factors or elements use their logic and intuition. This often may lead to irrational and non-consistent numerical scales. Thus checking the consistency of answers is a fundamental step in AHP method. In Saaty (2003) consistency implies reciprocity. Consistency obligates that if A is more important than B and B more important than C, then A should be more important than C. A positive reciprocical matrix $A = (a_{ij})$ implies a_{ij} =

$1/a_{ji}$ and to be consistent needs to fulfill the condition: $a_{ij} \times a_{jk} = a_{ik}$ with i, j, k= 1,..,n. Thus consistency implies in parallel reciprocity; mathematically expressed as:

$$a_{ji} = \frac{a_{jk}}{a_{ik}} = a_{ij}^{-1} \qquad (27)$$

To check the consistency, the Consistency Ratio (CR) has to be computed. If CR is found smaller than 0.10 (or 10%) then the answers in pair-comparisons are consistent. Below, the step by step process of structuring the AHP is outlined.

■ Step 1: Structure the comparison matrix ($n \times n$).

■ Step 2: Sum the rows individually.

■ Step 3: Sum the columns individually.

■ Step 4: Sum the individual sums of rows, as computed in step 2.

■ Step 5: Compute the relative priorities for the *n* matrix elements by dividing the values of step 2 with the values of step 4.

■ Step 6: Compute the principal eigenvalue (λmax) as the multiplication of the relative priority times the sum of column for each element individually and after compute the total sum of them. Mathematically this is expressed as follows:

$$\lambda_{max} = \sum_1^n step\ 3_j \times step\ 5_i \qquad (28)$$

■ Step 7: Compute the Consistency Index (CI) as follows:

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad (29)$$

■ Step 8: Compute the Consistency Ratio (CR) as follows:

$$CR = \frac{CI}{RI} \qquad (30)$$

Where:
RI=Random Index, taken from Table 70 as cited in Saaty (Saaty 1988, 1991, 2000):

Table 70. Values of Random Consistency Index (RI)

n	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

It is out of the study's scope to discuss the mathematical properties of the principal eigenvalue and the method with which the RI values were produced from a very large dataset of random number.

◊ **Application of the AHP method**

Having clarified the procedure of planning the AHP method, this part will present the a short example of the matrices designed and the final table synthesizing all the priority vectors so to conclude how the contractor rated the four cost risk drivers.

Table 71. Comparison among the three criteria

	Propensity	Perception	Performance	Relative Priorities
Propensity	1	7	3	0.65
Perception	1/7	1	1/3	0.09
Performance	1/3	3	1	0.26
Sum (columns)	1.476	11	4.333	1.00

The relative priorities, for the propensity criterion, are computed as follows:

$$\frac{(1+7+3)}{(1+7+3)+\left(\frac{1}{7}+1+\frac{1}{3}\right)+\left(\frac{1}{3}+3+1\right)}=\frac{11}{16.809}=0.6544\ \cong 0.65$$

The same method is followed for the remaining two criteria of the perception and performance.

The principal eigenvalue is computed now as follows:

$$\lambda_{max}=(0.65\times 1.476)+(0.09\times 11)+(0.26\times 4.333)=3.049$$

The Consistency Index is computed as follows:

$$CI=\frac{3.049-\ 3}{3-1}=0.0245$$

The Consistency Ratio is computed as follows (for n=3, RI=0.90):

$$CR=\frac{0.0245}{0.90}=0.042\ <0.10$$

The table on the right summarizes the numbers required to compute the CR and check the matrix's consistency. With a CR equal to 0.042 and smaller than 0.10, it is obvious that the matrix's results are reliable and consistent.

n	3
λ_{max}	3.049
CI	0.0245
CR	0.042

The priorities of the three main criteria are known. The second phase is to compute the priorities of the five sub-criteria. This implies to structure three comparisons matrices: one matrix cross-comparing the "reasoning of risk assessment - sharing agreements" sub-criteria, a second matrix cross-comparing the "sensitivity – attitude – specific fear" sub-criteria and a third matrix cross-comparing the "ability – motivation" sub-criteria.

Table 72. Example of comparing sub-criteria of Propensity criterion

	Reasoning RA	Sharing agreements	Relative Priorities
Reasoning RA	1	7	0.88
Sharing agreements	1/7	1	0.12
Sum (columns)	1.142	8	1.00

Since the matrix above is a by definition consistent 2×2 matrix there is no need for consistency check. This why also for n=2, the RI=0 so the CR tends to be infinitive.

From Table 72 it is seen that technical capacity executing a "a reasoned risk assessment (RA)" was found 88% important and the contractual knowledge of "sharing agreements" was found 12%

important for the propensity criterion. This means that the sub-criterion of "reasoning a RA" counts for 0.65 (criterion importance) × 0.88 (sub-criterion importance) making a 0.572 (or 57.20%) contribution for a cost driver. With this method all sub-criteria were evaluated as it is shown in the Appendix 17.

The priorities of the five sub-criteria are now known. The third phase is to compute the priorities of the four cost risk drivers against each criterion separately. For this purpose, seven matrices will be constructed as many as the sub-criteria. A worked example is provided below in regard to the "reasoning a risk assessment" sub-criterion.

Table 73. Example of comparing the four cost drivers against the "reasoning a RA" sub-criterion

	Q	**UC**	**S**	**G**	**Relative Priorities**
Q	1	2	1/2	6	0.31
UC	1/2	1	1/4	3	0.15
S	2	4	1	8	0.49
G	1/6	1/3	1/8	1	0.05
Sum(columns)	3.67	7.33	1.88	18.00	1.00

Similarly as executed above for computing the CR of

Table 71, the same procedure was followed for Table 73. The table was found consistent with the summary of the required number shown aside.

n	4
λ_{max}	4.114
CI	0.0382
CR	0.0424

The matrix tells that the contractor for the sub-criterion of having the technical capacity to perform a "reasoned a risk assessment" ranked the schedule cost risk drivers as the most important by representing almost the half (equal to 49%) of all drivers contribution to his/her cost estimate decisions. Global cost risk drivers are ranked with the lowest importance of 5%. This process was repeated in total seven times and the detailed calculations can be seen in Appendix 18.

The synthesized results are derived by multiplying, for each cost risk driver (alternative), the score criterion with the score of the sub-criterion and then by the relative priority. To express this mathematically, it is as follows:

$$\sum_{i}^{3}\sum_{j}^{3}\sum_{1}^{4}(w_i \times v_j \times x_{jk}) \quad (30)$$

Where:
w_i is the weight of the criterion i (with i=1,..3),
v_j is the weight of the sub-criterion j (with j=1,..,3)
x_{jk} is the score of relative priority of the sub-criterion j for the k cost risk driver (with k=1,…,4).

Table 74 presents the synthesized results as derived from the matrices structured after performing the relevant calculations. It can be seen that schedule cost drivers are prioritized as the most important, second in the ranking are the quantity cost drivers, followed by the unit cost drivers and the less important are judged the global cost drivers. This is an important observation as it validates the finding of Table 67.

Table 74. Synthesized results of all comparison matrices

	Risk Propensity (0.65)		**Risk Perception (0.09)**			**Performance (0.26)**		**Overall Priority**	**Normalized Overall Priority**
	Reasoned RA (0.88)	Sharing agreements (0.12)	Sensitivity (0.70)	Attitude (0.08)	Specific fear (0.22)	Ability (0.75)	Motivation (0.25)		
Q	0.31	0.06	0.46	0.35	0.08	0.28	0.08	0.057	0.583
UC	0.15	0.11	0.38	0.14	0.08	0.14	0.09	0.033	0.328
S	0.49	0.45	0.11	0.46	0.58	0.54	0.38	0.130	1.00
G	0..05	0.38	0.05	0.05	0.25	0.05	0.45	0.039	0.226

CONCLUSIONS & IMPLICATIONS

Chapter 7

In this chapter, the researcher presents the findings which came out from the data analysis part. Before providing any direct answers to the three main research questions and the relevant sub-questions, some additional analysis on the cost performance of the case project 14 will be executed. Thereafter the chapter will deal with tracking back to each research question.

The answers of to the two first research sub-questions are summarized into a table and discussed. Second, the answers to the two second sub-questions are summarized into a table and the numerical results and the implications are discussed. The last two research sub-questions are again answered with the use of a table.

All the research questions are replied on a project-specific level. To generalize however the findings the average observations for the total number of projects will be summarized and discussed, too.

7.1 Evaluation of project-specific measures – Case Project 14

The evaluation of the cost risk assessment model will be grounded on two main measurable factors:

a) The probability of meeting the (pre-ΔM) initial cost estimate comparing to the (post-ΔM) probability of meeting the revised cost estimate (Figure 58). This criterion will illustrate towards which direction the model will benefit a contractor if applies it.

b) The level of expected contingencies set in both conditions: pre-ΔM and post-ΔM are calculated from the tables below (Table 78, Table 80). Figure 59 assists in visualizing the pattern of total ascending cost behavior.

After comparing the PDFs[13] and CDFs as provided aside; the following findings for each of the two factors can be reported:

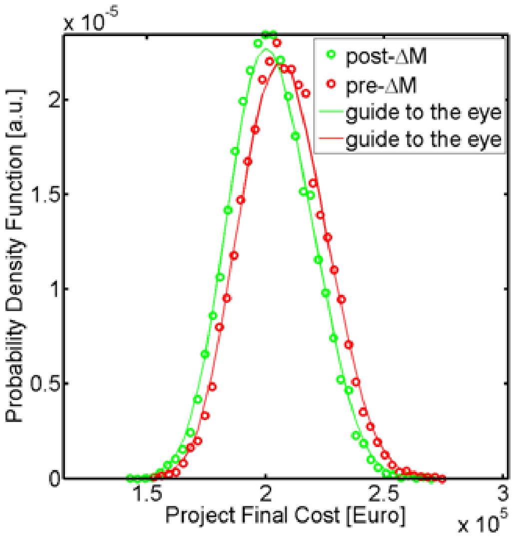


Figure 58: PDFs comparison

a.1) The probability of meeting the budgeted estimate when the model is applied by the contractor, followed the pattern below (Table 75). The most important finding is that the overall project's probability of meeting the base estimate is very slightly decreased by -0.61%. Only for the specific project (Case Project 14) this implies that the model does not improve the probability of meeting the base estimate.

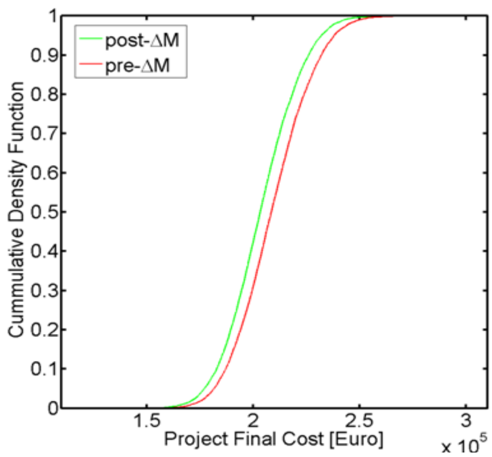


Figure 59: CDFs comparison

[13] PDF=Probability Denscity Function, CDF=Cumulative Density Function

Table 75. Probability meeting the cost estimate

	pre-ΔM (%)	post-ΔM (%)	Change (%)
Land preparation	22.70	28.45	+25.33
Foundations	53.90	51.25	-4.91
Substructure	14.55	14.33	-1.51
Superstructure	27.18	26.83	-1.28
Finishes	20.95	22.50	+7.39
Project final cost	6.51	6.47	-0.61

a.2) The second observation deals with the size of the initial and revised cost estimate compared to the base estimate. Based on Table 77 and Table 79, it was found that the contractor before (pre-ΔM) and after (post-ΔM) taking the profit-related decision achieved a revised cost estimate which very slightly smaller by 0.02% (=14.25% - 14.23%) than the base estimate. This shows that the cost risk assessment model produces very more slightly tight estimates. Although this finding does not sound astonishing for the specific portfolio of the 22 building projects with an average value of € 355820.30, it would be very significant for a portfolio of multi-million projects. Consequently the 0.02% cost saving (as a percentage change of the cost estimate) it would benefit the contractor with some thousands of Euros savings.

b.1) The contingency amounts have a direct impact in the cost estimates of contractors as was previously explained. The smaller the contingencies in a cost estimate the more attractive to the client's view. From Table 76, it can be seen that the model applied reduces the total project's contingency by 2.82% comparing to the initial contingency included.

Table 76. Contigency amounts

	pre-ΔM (%)	post-ΔM (%)	Change (%)
Land preparation	1575.82	1425.90	-9.51
Foundations	2845.70	2755.70	-3.16
Substructure	30630.40	29256.70	-4.48
Superstructure	7049.20	6801.55	-3.51
Finishes	7123.90	6996.35	-1.79
Project final cost	35790.00	34779.55	-2.82

b.2) The second observation deals with the size of the initial and revised contingency amount compared to the expected cost estimate at the specified confidence level. It was found that the contractor before (pre-ΔM) the profit decision applied a contingency representing the 19.56% of the initial estimate (35790/183000) and after (post- ΔM) the profit decision the contingency amount was representing the 19.49% of the revised estimate (34779.55/178423). The revised contingency was very slightly smaller by the initial one as a percentage of the estimate by 0.07% (=19.49%-19.56%). This shows that the cost risk assessment model produces very slightly more tight estimates. Although this finding does not sound astonishing for the specific portfolio of the 22 building projects it would be very significant for a portfolio of multi-million projects. Consequently the 0.07% less contingency setting (as a percentage change of the expected cost estimate) it would benefit the contractor with some thousands of Euros savings.

b.3) The last observation is that "finishes" cost element scores the highest contingency amount as percentage of the expected cost estimate, followed by the "substructure", thirdly the "superstructure", and last the "land preparation" and "foundations" elements. This observation is partially validated by the values of Table 65. Consequently, "land preparation" and "foundations" related activities are considered the less risky thus they are charged by the lowest contingencies and "superstructure" and "finishes" related activities are considered the most risky thus they are charged with the highest contingencies.

Pre-ΔM condition (No correlations assessed in model)

Table 77. Results obtained from the simulated PDFs

	Base Estimate (E_i) in €	Distribution fitted	Probability meeting estimate $P(X_i \leq E_i)$ %	Most likely expected value: mean in €	Higher estimation (%) on estimate
Land preparation	18300	Weibull	22.70	19439.32	6.22
Earthworks	54900	Beta G.	53.90	56940.66	3.72
Substructure	54900	Weibull	14.55	70597.55	28.59
Superstructure	45750	Pearson5	27.18	49492.09	8.18
Finishes	9150	Beta G.	20.95	12617.33	37.89
Final Project	183000	Normal	6.51	209086.95	14.25

Table 78. Results obtained from the simulated CDFs

	Expected confidence level (=50 %+Overall risks effect %)	Expected estimation at confidence level in €	Contingency set (Exp. Estimation – Base estimate)	Contingency % on E_i
Land preparation	50+7.55=57.55	19875.8	1575.8	8.61
Earthworks	50+4.45=54.45	57745.7	2845.7	5.18
Substructure	50+33.33=83.33	85530.4	30630.4	55.79
Superstructure	50+24.75=74.75	52799.2	7049.2	15.41
Finishes	50+37.77=87.77	16273.9	7123.9	77.86
Final Project	50+21.57=71.57	218790	35790	19.56

Post-ΔM condition (No correlations assessed in model)

Table 79. Results obtained from the simulated PDFs

	Base Estimate (E_i) in €	Distribution fitted	Probability meeting estimate $P(X_i \leq E_i)$ %	Most likely expected value: mean in €	Higher estimation (%) on estimate
Land preparation	17842.3	Weibull	28.45	18951.78	6.22
Earthworks	53526.9	Beta Gen.	51.25	55513.26	3.71
Substructure	53526.9	Weibull/Normal	14.33	68809.81	28.55
Superstructure	44605.75	Pearson5	26.83	48257.57	8.18
Finishes	8921.15	Beta Gen.	22.50	12278.99	37.64
Final Project	178423	Normal	6.47	203811.81	14.23

Table 80. Results obtained from the simulated PDFs

	Expected confidence level (=50 %+Overall risks effect %)	Expected estimation at confidence level in €	Contingency set (Exp. Estimation – Base estimate)	Contingency % on E_i
Land preparation	50+7.55=57.55	19268.2	1425.9	7.99
Earthworks	50+4.45=54.45	56282.6	2755.7	5.15
Substructure	50+33.33=83.33	83053.6	29526.7	55.16
Superstructure	50+24.75=74.75	51407.3	6801.55	15.25
Finishes	50+37.77=87.77	15917.5	6996.35	78.42
Final Project	50+21.57=71.57	213202.55	34779.55	19.49

7.2 Evaluation of economic measures – Case Project 14

As was discussed previously contingencies setting is a stereotypical tactic of contractors to cover unexpected or uncompensated risk events. Contractors tend to behave as their clients by transferring the economic value of risks occurred to their clients after often setting a 10% of estimate as contingency amount. This frequently leads to increased claims and litigation costs; a reason pushing contractors towards more innovative procurement methods. In parallel however, as was argued in the first chapter (see in § 1.1.3) this reality opens a window for improvement into the traditional (DBB) procurement.

This section will examine the risk transfer problem and its implications regarding the potential benefits derived from the model's application. The project's cost performance will be also evaluated and compared in both conditions (pre-ΔM and post-ΔM). Given the effectiveness of graphical (geometrical) evaluation representation as noted by Ginevičius and Podvezko (Ginevičius & Podvezko 2008), the author adopts this scope for visualizing the project's economic performance.

◊ **Description of terms used**

Project delivery efficiency is indicated by a project's co-ordinates in relation to the origin. An efficiently delivered project is one which satisfies both parties' expectations by achieving its anticipated price, cost and margin so that ΔP=ΔM=ΔC and the project co-ordinates are (0,0). Risk transfer is defined by a project's coordinates in relation to the ΔP and ΔM axes (Witt & Liias 2011, pp. 179-180).

The following formulas will be used for the calculation of the risk transfer degree and the project delivery inefficiency:

$$Degree\ of\ risk\ transfer = |\Delta M| - |\Delta P| \quad (31)$$

$$Project\ delivery\ inefficiency = \sqrt{(\Delta M)^2 + (\Delta P)^2} \quad \text{Hypoteneuse of triangle (32)}$$

Where:
P (Price) = C (Cost) + M (Margin profit)
ΔP=the difference in price between the two conditions of assessment (pre-ΔM and post-ΔM)
ΔC=the difference in cost between the two conditions of assessment (pre-ΔM and post-ΔM)
ΔM=the difference in margin between the two conditions of assessment (pre-ΔM and post-ΔM)

In Table 81 the required co-ordinates, to sketch a similar to the one of Figure 60 and examine the trajectory of project cost performance, are provided.

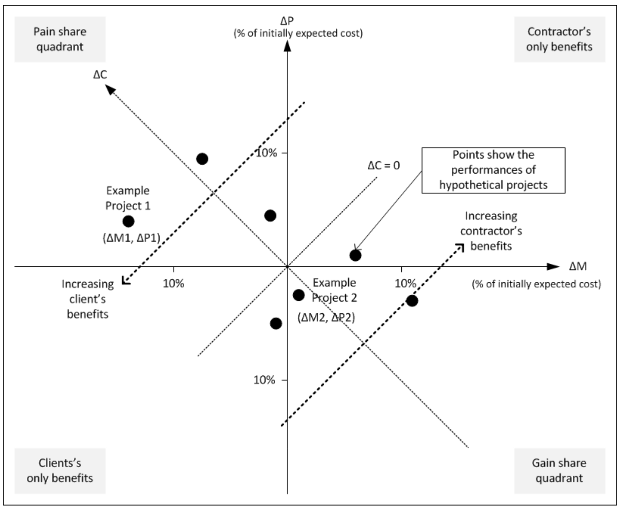


Figure 60: Graph of ΔM vs ΔP showing ΔC and hypothetical project performance

Table 81. Summary of economic values

% of the initially expected cost		Land preparation	Foundations	Substructure	Superstructure	Finishes
Pre-ΔM	ΔM	5	5	-5	-5	-10
	ΔP	11.226	8.717	23.593	3.179	27.894
Post-ΔM	ΔM	5	5	-5	-5	-10
	ΔP	11.218	8.710	23.551	3.186	27.639

The table above was calculated as follows:

■ Step 1: ΔC was calculated as the difference between the obtained (after the simulation) cost (C_i) and the base estimate (E_i) provided by the participant. This is as follows: $\Delta C = C_i - E_i$

■ Step 2: ΔM was provided by the participant as a percentage (%) of the E_i.

■ Step 3: ΔP was calculated as the sum of ΔC plus ΔM. This is as follows: $\Delta P = \Delta C + \Delta M$

■ Step 4: (ΔM, ΔP) quantities were both divided by E_i and then multiplied by 100% to express them as percentage of the initially expected estimate; the base estimate.

To clarify the underlying process the next two tables present how the co-ordinates were produced Table 82, Table 83).

Table 82. Pre-ΔM economic values for cost performance evaluation

	Economic values					Co-ordinates	
	E_i (€)	C_i (€)	ΔC (€)	ΔM (€)	ΔP (€)	ΔM[14] (%)	ΔP (%)
Land preparation	18300	19439.32	1139.32	915	2054.32	5	11.226
Foundations	54900	56940.66	2040.66	2745	4785.66	5	8.717
Substructure	54900	70597.09	15697.55	-2745	12952.55	-5[15]	23.593
Superstructure	45750	49492.09	3742.09	-2287.50	1454.59	-5	3.179
Finishes	9150	12617.30	3467.33	-915	2552.33	-10	27.894

Table 83. Post-ΔM economic values for cost performance evaluation

	Economic values					Co-ordinates	
	E_i (€)	C_i (€)	ΔC (€)	ΔM (€)	ΔP (€)	ΔM (%)	ΔP (%)
Land preparation	17842.30	18951.80	1109.48	892.11	2001.59	5	11.218
Foundations	53526.90	55513.30	1986.36	2676.35	4662.71	5	8.710
Substructure	53526.90	68809.80	15282.91	-2676.35	12606.57	-5	23.551
Superstructure	44605.75	48257.60	3651.82	-2230.29	1421.53	-5	3.186
Finishes	8921.15	12279	3357.84	-892.11	2465.73	-10	27.639

[14] As obtained by the respodent's reply in questionnaire.
[15] ΔM = -5% × € 54900 = € 2745 (reduction)

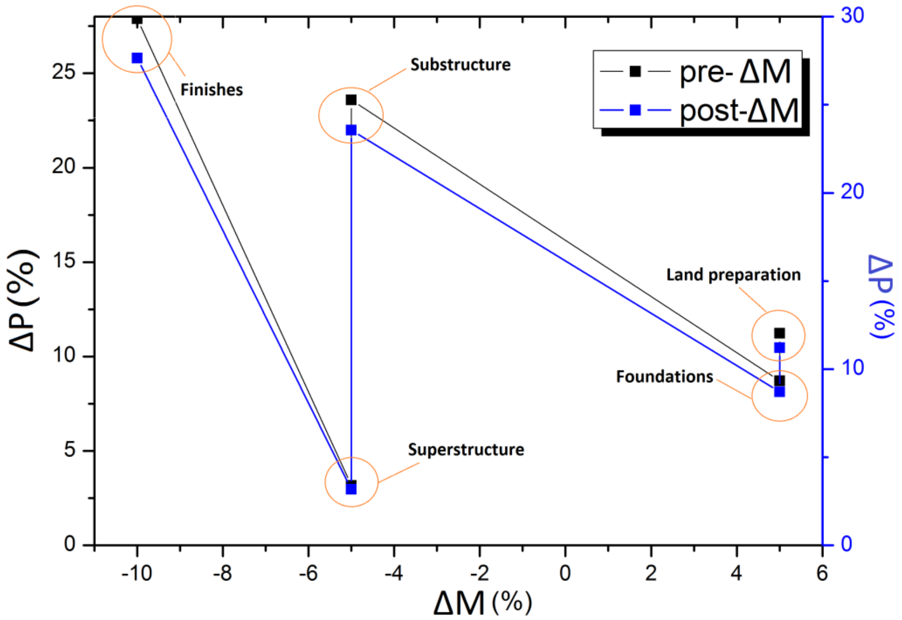


Figure 61: Co-ordinates comparison

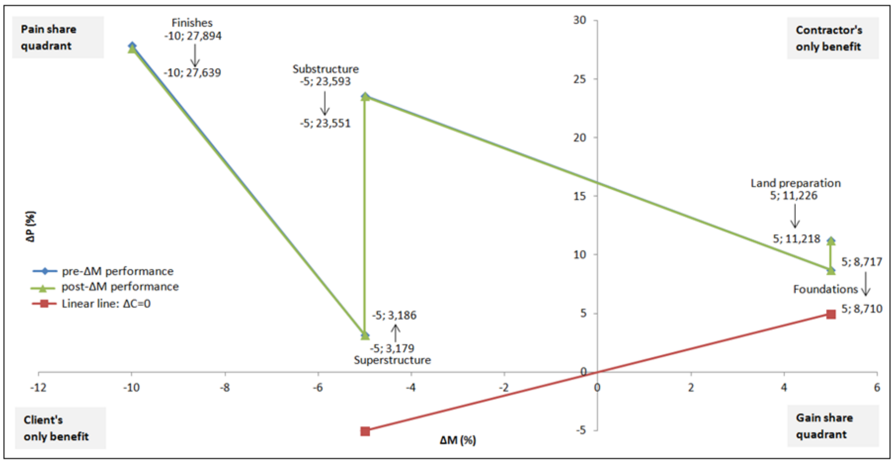


Figure 62: Geometrical representation of benefits from risk transfer

The coordinates obtained (pairs of ΔM, ΔP) were plotted in a common graph so to be cross-compared as the difference is hard to be visually observed (Figure 61). The most important finding is seen in Figure 62. This finding indicates that the model proposed becomes slightly more efficient in the post-ΔM phase where contractors are anticipated to produce a revised, still competitive cost estimate. Consequently, this finding improves the risk transfer mechanism in traditional procurement method. However it does not reveal very practical and comprehensive measurable results for potential contractors.

Grounded on the previous observation, the degree of risk transfer and the project delivery inefficiency were computed in-between the two conditions; before and after the contractor revises his/her cost estimate.

Table 84 reveals that there is a potential for the contractor to transfer in total €401.40 less cost risks to the client and again win the project. Although this amount seems insignificant comparing to the initial total base estimate of €180000 if it is compared with the average hourly salary of an arbitrator it gains another meaning. According to the American Arbitration Association (AAA) an arbitrator is hourly compensated between $100 and $300 and more than 80 hours is likely to be needed only for the case discovery (Figure 63). This finding then gains another meaning for a contractor who will have to weigh the average compensation to be paid to an arbitrator instead of reducing the cost risk transferred to the client.

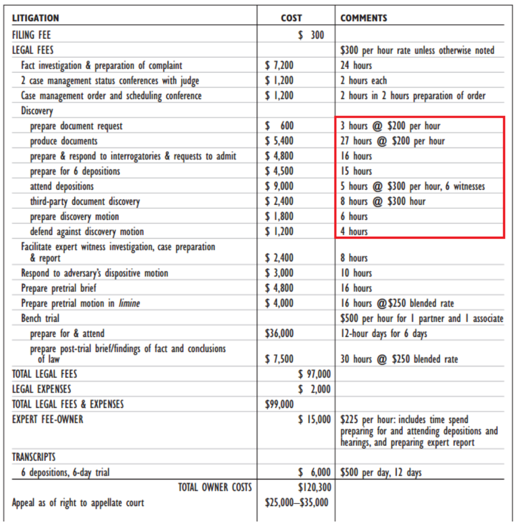
Table 85 confirms the above finding as it implies that an improvement can be achieved in term of reducing by 2.70% the project delivery inefficiency.

Table 84. Evaluation of the risk transfer degree

	Pre-ΔM (€)	Post-ΔM (€)	Improvement (€)
Land preparation	-1139.32	-1109.48	29.84
Foundations	-2040.66	-1986.36	54.30
Substructure	-10207.55	-9930.22	277.33
Superstructure	832.91	808.75	-24.15
Finishes	-1637.33	-1573.61	63.72
			Sum= € 401.40

Table 85. Evaluation of project delivery inefficiency

	Pre-ΔM (€)	Post-ΔM (€)	% change
Land preparation	2248.88	2191.40	-2.55
Foundations	5517.02	5376.21	-2.55
Substructure	13240.23	12887.53	-2.66
Superstructure	2710.81	2644.79	-2.43
Finishes	2711.38	2622.15	-3.29
			Average≈ -2.70%



LITIGATION	COST	COMMENTS
FILING FEE	$ 300	
LEGAL FEES		$300 per hour rate unless otherwise noted
Fact investigation & preparation of complaint	$ 7,200	24 hours
2 case management status conferences with judge	$ 1,200	2 hours each
Case management order and scheduling conference	$ 1,200	2 hours in 2 hours preparation of order
Discovery		
prepare document request	$ 600	3 hours @ $200 per hour
produce documents	$ 5,400	27 hours @ $200 per hour
prepare & respond to interrogatories & requests to admit	$ 4,800	16 hours
prepare for 6 depositions	$ 4,500	15 hours
attend depositions	$ 9,000	5 hours @ $300 per hour, 6 witnesses
third-party document discovery	$ 2,400	8 hours @ $300 hour
prepare discovery motion	$ 1,800	6 hours
defend against discovery motion	$ 1,200	4 hours
Facilitate expert witness investigation, case preparation & report	$ 2,400	8 hours
Respond to adversary's dispositive motion	$ 3,000	10 hours
Prepare pretrial brief	$ 4,800	16 hours
Prepare pretrial motion in *limine*	$ 4,000	16 hours @$250 blended rate
Bench trial		$500 per hour for 1 partner and 1 associate
prepare for & attend	$36,000	12-hour days for 6 days
prepare post-trial brief/findings of fact and conclusions of law	$ 7,500	30 hours @ $250 blended rate
TOTAL LEGAL FEES	$ 97,000	
LEGAL EXPENSES	$ 2,000	
TOTAL LEGAL FEES & EXPENSES	$99,000	
EXPERT FEE-OWNER	$ 15,000	$225 per hour: includes time spend preparing for and attending depositions and hearings, and preparing expert report
TRANSCRIPTS		
6 depositions, 6-day trial	$ 6,000	$500 per day, 12 days
TOTAL OWNER COSTS	$120,300	
Appeal as of right to appellate court	$25,000–$35,000	

Figure 63: Estimated costs of litigating a hypothetical construction claim (Zuckerman 2007)

The last economic measure to examine <u>how much</u> the model applied can improve the project cost performance is the Cost Performance Index (CPI). The CPI is defined as follows:

$$CPI = \frac{BCWP}{ACWP} \quad (33)$$

Where:
$BCWP$ = Budgeted Cost of Work Performed (€) = Base Estimate (E_i)
$ACWP$ = Actual Cost of Work Performed (€) = Mean Cost from simulation (C_i)

Table 86 indicates a very slight improvement in the 10^{th} project's CPI which counts for only a +0.02% improvement in the CPI of the "project final cost". To gain a more complete and general finding, for all projects examined, the CPI values were calculated in the pre-ΔM and post-ΔM conditions as can be seen in Table 88 and Table 89. It was found that 14 out of the 22 projects assessed, which represents a 63.63% of projects, score an improved PCI with an average CPI positive change of +2.00% (Table 87).

Table 86. CPI evaluation - Case Project 14

	pre-ΔM			post-ΔM		
	E_i (€)	**C_i (€)**	**CPI (%)**	**E_i (€)**	**C_i (€)**	**CPI (%)**
Land preparation	18300	19439.32	94.10	17842.30	18951.8	94.10
Foundations	54900	56940.66	96.40	53526.90	55513.3	96.40
Substructure	54900	70597.55	77.80	53526.90	68809.8	77.80
Superstructure	45750	49492.09	92.40	44605.75	48257.6	92.40
Finishes	9150	12617.33	72.50	8921.15	12279	72.70
Project final cost	183000	209087	87.52	178423	203812	87.54

Table 87. CPI imporvement (Project Final Cost) – Portfolio level

	Cost Performance Index		
	pre-ΔM (%)	**post-ΔM (%)**	**Change (%)**
Project 1	90.98	91.10	+0.13
Project 3	100	100.10	+0.10
Project 6	97.96	98.04	+0.08
Project 9	86.68	86.76	+0.09
Project 10	84.75	99.55	+17.46
Project 13	88.09	88.64	+0.62
Project 14	87.52	87.54	+0.02
Project 15	98.97	99.11	+0.14
Project 16	85.26	88.33	+3.60
Project 17	95.98	96.27	+0.30
Project 18	98.59	98.79	+0.20
Project 20	93.10	93.22	+0.13
Project 21	77.61	78.18	+0.73
Project 22	77.11	80.53	+4.44
			Average=+2%

Table 88. CPI values for pre-ΔM condition (%)

pre-ΔM	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Land preparation	86.45	80.89	89.01	90.02	98.36	97.30	98.32	78.73	86.03	98.41	98.84	88.13	88.10	94.14	99.96	99.17	99.58	99.75	96.23	87.56	99.00	93.86
Foundations	90.25	90.48	95.56	94.14	98.88	97.71	91.04	91.61	88.99	96.76	90.03	98.70	93.83	96.42	99.7	99.44	98.92	99.65	97.84	95.08	99.07	96.73
Sub-structure	89.20	90.83	96.00	94.81	98.61	97.71	93.02	83.29	81.81	78.15	85.45	96.23	81.29	77.76	97.71	77.96	92.59	97.92	76.20	87.53	79.90	76.65
Super-structure	99.45	103	108.6	99.82	99.61	99.27	91.00	98.65	91.23	86.35	90.16	99.27	91.34	92.44	99.68	92.67	97.23	99.26	92.15	98.49	89.04	89.58
Finishes	91.70	94.69	100.7	98.89	99.02	97.35	88.84	81.52	84.19	68.19	76.27	96.04	82.74	72.52	96.82	65.69	89.45	97.14	65.06	80.79	73.22	68.46
Project final cost	90.98	95.19	100	95.20	98.96	97.96	92.21	88.74	86.68	84.75	88.70	97.20	88.09	87.52	98.97	85.26	95.98	98.59	85.27	93.10	77.61	77.11

Table 89. CPI values for post-ΔM condition (%)

post-ΔM	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Land preparation	86.58	80.85	89.97	90.18	98.24	97.98	97.10	78.44	86.02	98.41	98.90	88.34	88.22	94.15	100	99.22	99.46	99.75	95.77	87.81	100	93.78
Foundations	90.04	90.53	95.84	94.10	98.78	97.56	90.93	91.76	89.15	100.1	89.99	98.45	93.92	96.42	99.66	99.39	99.15	99.53	98.03	92.62	99.18	96.61
Sub-structure	89.15	90.78	96.21	94.29	98.37	97.55	93.19	83.12	81.88	100.1	85.36	96.29	81.60	77.79	98.28	77.69	93.22	98.49	76.01	78.54	79.89	77.49
Super-structure	99.58	102.7	108.4	99.74	99.62	99.32	90.94	98.75	91.29	100	89.82	99.25	91.65	92.43	99.55	92.72	97.31	99.47	92.17	97.06	88.70	91.98
Finishes	91.70	94.83	101.1	98.93	98.88	97.42	88.96	81.53	84.27	96.76	75.98	96.27	83.09	72.65	96.98	66.38	89.36	97.31	65.01	67.10	73.14	69.26
Project final cost	91.10	95.09	100.1	94.82	98.83	98.04	92.06	88.72	86.76	99.55	88.55	97.13	88.64	87.54	99.11	88.33	96.27	98.79	85.19	93.22	78.18	80.53

This section concludes with the figure below showing the improvement path of CPI for approximately the 64% of projects examined. Some projects, such as project 1 and project 3 score a slight improvement in the CPI, just +0.13% and +0.10% change. On the contrary, other projects such as project 10 and project 16 score a high improvement in the CPI, with a +17.46% and +3.60% change. This shows that in a portfolio of building projects traditionally procured the average positive improvement does not follow a stable pattern and on a project-specific level no safe conclusions can be drawn for the moment (Figure 64).

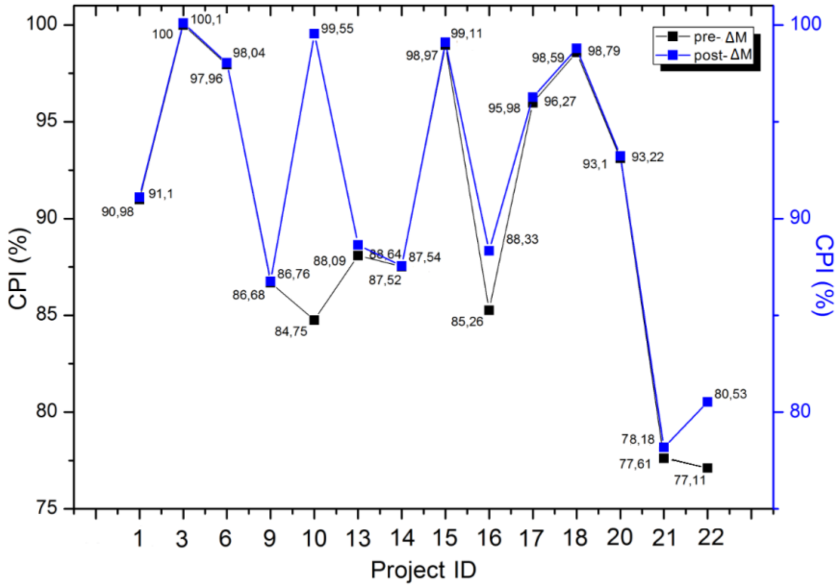


Figure 64: CPI improvement – Project Final Cost

7.3 Incentive profit elements and contingencies

On portoflio-level for the project final cost, it was found that the model applied is able to produces an additional positive average incentive profit element of € 6707.42 (

Table 90), which represents the 1.91% of the average portfolio's value (€ 349994.32). If this amount is compared to the average risk transferred amount, equal to € 401.40, it is seen the contractor is more profitable to accept an additional € 401.40 amount in his cost risk package for gaining an incentive profit element almost 17 times higher than the transferred risk to himself.

The second fundamental observation is that, when all projects are examined, an average reduction of total project's contingencies by -3.68% can be achieved (Table 91). This finding shows that the model is operating towards the direction of contingencies reduction; an indication of higher cost performance as was proved above. To which extent a relationship between the optimal contingency reduction and the desired project cost performance can be built remains out of the report's scope.

Table 90. Evaluation of incentive profit elements – Project Final Cost

	pre-ΔM	post-ΔM	Change (€)
Project ID	**b×(E-C)**	**b'×(E'-C')**	**Δ (incentive profit)**
1	-3365.27	-5193.15	-1827.88
2	-12214.64	-12253.64	-38.65
3	1087.46	63.97	-1023.49
4	-4029.31	-948.66	3080.65
5	915.71	-140.47	775.24
6	-645.09	-121.43	523.66
7	-3816.10	-1007.83	2808.27
8	-11605.68	-1601.58	10004.10
9	-9366.39	-2283.52	7082.86
10	-14524.03	-3433.48	11090.55
11	-46245.14	-22675.80	23569.30
12	-1243.19	-329.20	913.99
13	-13776.86	-4482.99	9293.87
14	-7419.13	-1960.13	5458.99
15	-4165.99	-1228.13	2937.85
16	-41619.68	-18365.10	23524.58
17	-2165.82	-611.63	1554.20
18	-493.53	-28.43	465.11
19	-23918.83	-14719.64	9199.18
20	-5535.54	-4135.05	1400.49
21	-121662.33	-96137.58	25524.76
22	-14251.51	-2736.29	11515.22
			Mean= € 6707.42

Table 91. Evaluation of contingencies – Project Final Cost (Level: Total Project)

	pre-ΔM	post-ΔM	Change	Improvement
Project ID	**Contigency (€)**	**Contigency (€)**	**Δ (Contingency)**	**% Change**
1	39503.40	34779.20	-4724.20	-11.96
2	37358.42	37290.02	-68.40	-0.18
3	3134.93	5439.93	2305.00	73.53
4	15057.82	13607.94	-1449.88	-9.63
5	4601.73	5122.38	520.65	11.31
6	3548.68	2748.53	-800.15	-22.55
7	28139.81	33820.82	5681.01	20.19
8	71270.91	66799.45	-4471.46	-6.27
9	35746.23	35136.95	-609.28	-1.70
10	67153.60	5682.00	-61471.60	-91.54
11	103241.20	99320.90	-3920.30	-3.80
12	4884.30	10872.79	5988.49	122.61
13	51335.30	41406.40	-9928.90	-19.34
14	35790.00	34779.50	-1010.50	-2.82
15	18391.41	13193.68	-5197.73	-28.26
16	126819.76	62490.22	-64329.54	-50.73
17	9047.79	8057.59	-990.20	-10.94
18	9855.67	9097.49	-758.18	-7.69
19	66914.56	59576.69	-7337.87	-10.97
20	7410.36	6908.80	-501.56	-6.77
21	228178.03	211300.50	-16877.53	-7.40
22	145178.44	121776.82	-23401.62	-16.12
				Mean= -3.68%

7.4 Tracking back to research questions

The research questions will be addressed on project-specific level (Case Project 14) and where the data allowed the entire portfolio to be examined; more general recommendations will be provided.

◊ Research question 1 & 2

Firstly, when the degree of risk transferred is examined for each building phase or cost elemental category it is noticed that the proposed model to contractors delivers an improvement of 35.65% less cost risks transferred from the contractor to the client. "Finishes" construction phase scores the highest change in risk transfer equal to -167.35%, which shows a large opportunity for the contractor to minimize the cost risks transferred to the client and remain competitive by minimizing the relevant contingency. Not surprisingly a reduction on the "finishes"-related contingency of -1.79% is observed. "Land preparation" phase scored the minimum risk transfer degree with an average change of -2.62%. In "land preparation" the contingency change was the highest among all, equal to -9.51% (Table 93). This pattern shows that there is no strong evidence for structuring a clear mathematical relationship between the cost risks transferred and contingencies set.

The important conclusion derived from this section is that the model proposed reveals the opportunity of an average reduction of risk transferred by -36.65% from the contractor to the client compensated by an improvement of +5% in the probability of meeting the base estimate.

Table 92. Research question 1 and Research question 2 – Case Project 14

	Risk transfer (€)		% meeting the E_i		Contingencies (€)	
	pre-ΔM	**post-ΔM**	**pre-ΔM**	**post-ΔM**	**pre-ΔM**	**post-ΔM**
Land preparation	-1139.32	-1109.48	22.70	28.45	1575.80	1425.90
Foundations	-2040.66	-1986.36	53.90	51.25	2845.70	2755.70
Substructure	-10207.60	-9930.22	14.55	14.33	30630.40	29526.70
Superstructure	832.91	808.75	27.18	26.83	7049.20	6801.55
Finishes	-1637.33	1102.74	20.95	22.50	7123.90	6996.35

Table 93. Changes (in %) of the three parameters examined – Case Project 14

	Risk transfer	% meeting the E_i	Contingencies
	% change	**% change**	**% change**
Land preparation	-2.62	+25.33	-9.51
Foundations	-2.66	-4.91	-3.16
Substructure	-2.72	-1.51	-3.60
Superstructure	-2.90	-1.28	-3.51
Finishes	-167.35	+7.39	-1.79
Mean	-35.65	+5.00	-4.32

Not surprisingly, the "land preparation" construction phase scored the highest change in the contingency set equal to a reduction of -9.51%. This is shows that the contractor tended to reduce the contingency applied in the estimate when the cost category is not judged as much as risky as other. Table 65 confirms this finding; meaning that:

"The more risky the cost category is perceived by the contractor, the less is the expectation of contingency reduction".

For example the "land preparation" cost category was found having the lowest average change on the mean value, equal to -0.16% comparing to the "superstructure" scoring a contingency reduction change of -3.51% and an average mean change of +2.77%. To which extent a mathematical relationship can be structured for exploring how these two parameters are interrelated remains out of this report's scope.

Another interesting finding is regarding the model's implications on the contingency amounts and the probability of meeting the base estimates (Table 93). When comparing the "land preparation" to "substructure" again, it is seen that the probability of meeting the base estimate for the "land preparation" is increased by +25.33% and for the "substructure" is decreased by -1.28%. The contingencies are reduced by -9.51% and by -3.51% for both cost categories, correspondingly. This finding leads to the following statement:

"The more risky the cost category is perceived by the contractor, the relationship between the change in the probability meeting the base estimate and the change in contingency levels is more steeply inversely proportional."

To which extent the aforementioned statement can be supported by a mathematical formula or a test of a statistical hypothesis remains out of this report's scope. To put all together, after gathering and analyzing the case-project's results it was proved that for every construction phase the contractor can exploit an opportunity of 36.65% less risk transferred to the client compensated by an increase in the probability meeting the initial base estimate by 5% and retaining a completive cost estimate (on which he may bid) by reducing contingencies by 4.32%.

The aforementioned approach to the research questions is based on project-level (Case Project 14). Due to the high processing time not all projects could be separately examined and this would reduce the readability of the report. It is left for further research to examine how the entire portfolio of projects would have reacted in the assessed factors.

◊ **Research question 3**

From Table 92 it can be seen that "Foundations" cost category scored the second lowest change (-26.60%) on the incentive profit element; a fact in line with the observation that "foundations" also scored the minimum percentage change on the probability of meeting the base estimate (equal to -4.91%). The model applied operates to the direction of providing more financial incentives to contractor to accomplish in-budget the project. Thus this finding could lead to formulate the following statement:

"Low incentive profit elements are associated with reduced probability of meeting base estimates."

Looking now in-detail how the percentage change of incentive profit elements and the percentage change of contingencies could be related, not safe conclusions can be drawn on a project-specific level. Consequently a general and maybe arbitrary statement could be drawn such as follows:

"High changes in incentive profit elements are associated with low changes in contingencies."

On a project-specific level from Table 94 it was found that the contractor if applies the model twice (pre-ΔM and post-ΔM) he/she will be benefited by an improved incentive profit element in by 6.17% pre-assuming although an average reduction in contingencies of 4.32%.

Table 94. Research question 3 – Case Project 10

	Incentive profit (€)			Contingencies (€)		
	pre-ΔM	**post-ΔM**	**% change**	**pre-ΔM**	**post-ΔM**	**% change**
Land preparation	-341.79	-432.69	-26.60	1575.80	1425.90	-9.51
Foundations	-422.42	-780.64	-84.80	2845.70	2755.70	-3.16
Substructure	-7723.19	-5226.76	+32.32	30630.40	29526.70	-3.60
Superstructure	-785.84	-350.57	+55.39	7049.20	6801.55	-3.51
Finishes	-738.54	-335.78	+54.53	7123.90	6996.35	-1.79
Mean			+6.17%			-4.32%

Given the insufficiency of data collected and study's scope, no conclusion on the relationship between the incentive profit elements and the contingencies can be made for only one case-project. Consequently, a switch to the whole portfolio of projects was needed. A correlation analysis was performed to indicate whether the second statement has a grounded basis or not.

"High changes in incentive profit elements are associated with low changes in contingencies."

For the correlation analysis, the "Final Project Cost" contingencies and incentive profit elements were used. The choice of the specific results is based on the final project cost so to create a more generic recommendation. The correlation analysis indicated an overall strong and significant correlation among all four variables. Specifically:

Pre-ΔM condition (Before the profitability decision)

Strong, negative correlation between the incentive profit and the contingency amount (R=-.886, N=22, $p < .01$).

Post-ΔM condition (After the profitability decision)

Strong, negative correlation between the incentive profit and the contingency amount (R=-.843, N=22, $p < .01$).

Pre- and Post-ΔM conditions

Strong, positive correlation between the two incentive profit elements (R=.974, N=22, $p<.01$).

Strong, positive correlation between the two contingency amounts (R=.974, N=22, $p<.01$).

Table 95. Pearson correlation matrix between incentive profits and contingencies

		Incentive (pre-ΔM)	Contigency (pre-ΔM)	Incentive (post-ΔM)	Contigency (post-ΔM)
Incentive (pre-ΔM)	Pearson Correlation	1	-,886**	,974**	-,887**
	Sig. (2-tailed)		,000	,000	,000
	N	22	22	22	22
Contigency (pre-ΔM)	Pearson Correlation	-,886**	1	-,805**	,947**
	Sig. (2-tailed)	,000		,000	,000
	N	22	22	22	22
Incentive (post-ΔM)	Pearson Correlation	,974**	-,805**	1	-,843**
	Sig. (2-tailed)	,000	,000		,000
	N	22	22	22	22
Contigency (post-ΔM)	Pearson Correlation	-,887**	,947**	-,843**	1
	Sig. (2-tailed)	,000	,000	,000	
	N	22	22	22	22

**. Correlation is significant at the 0.01 level (2-tailed).

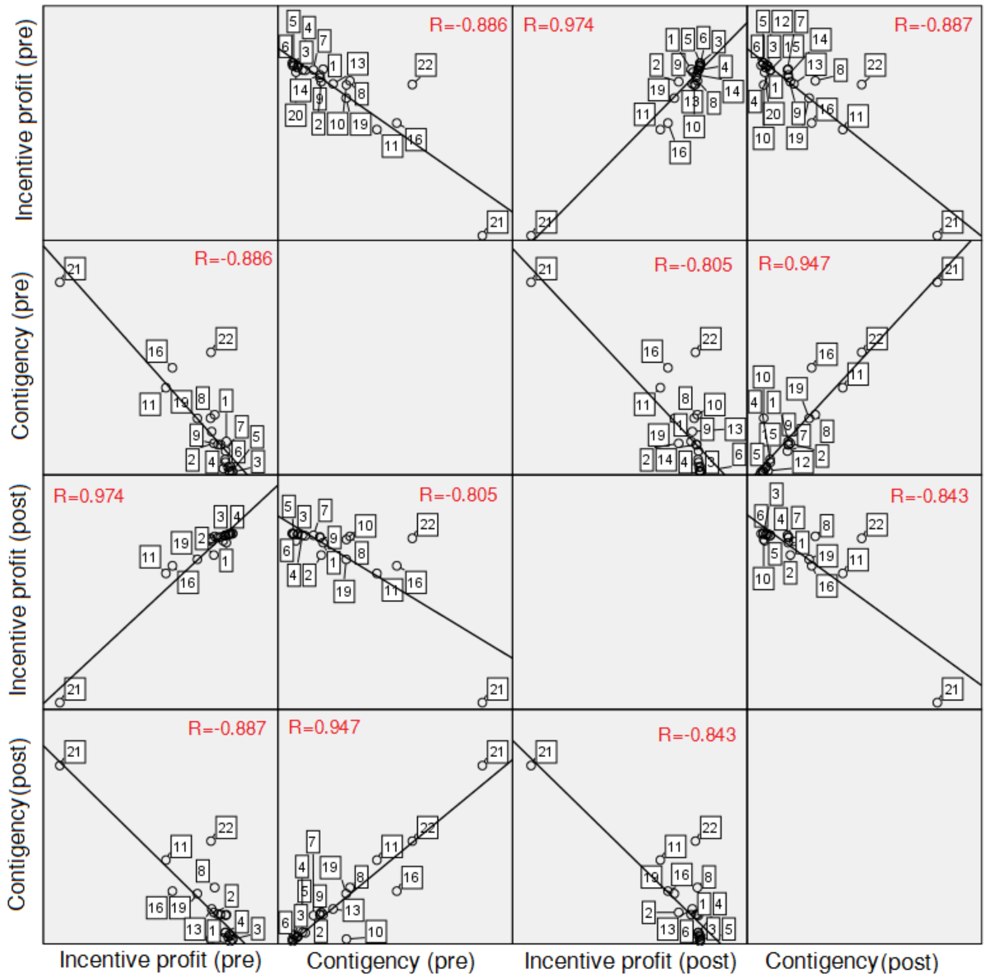


Figure 65: Correlation scatter plot matrix

Three fundamental findings can now be drawn regarding the contingencies and the incentive profit elements with the aid of Table 95 and these are:

(1) The hypothesized statement implying: *"High changes in incentive profit elements are associated with low changes in contingencies."* was validated as true after the correlation analysis was performed. The statement is supported by the strong, negative correlation found among contingencies and incentive profits in both conditions; pre-ΔM and post-ΔM. However as correlation does not lead to causation, it remains out of this report's scope to prove if a mathematical relationship exist between the two elements. A multi-linear regression model is suggested to be invetstiagted by other researchers.

(2) The correlation between the contingency amounts and the incentive profit elements was computed for both equal to 0.974. This means that if a contractor uses the model proposed, he/she will have the power to predict to which direction the contingencies and the profit elements will tend to move (increase or decrease) when a revised cost estimate and a decision on the margin will have to be made.

(3) Figure 65 shows a clear grouping of almost all projects around a specific area of the fitted linear line. However if the projects portfolio examines a much higher number of building projects, namely 300 to 400 projects, then the impact of extreme-projects such the *project 21* the correlation coefficients will vary significantly.

7.5 Conclusions: A summary

Meeting financial objectives is of central importance for all contractors especially when they enter into traditional, Design-Bid-Build contracts which are often criticized for low cost risk sharing flexibility. Market pressures impose to contractors an underestimation or overestimation strategy in order to remain competitive against other bidders. In the post-bid situation many risks may arise on-site which are frequently not included in the technical contract documents and this leaves space for contractual negotiations on the maximum risk allowance imposed by clients to contractors.

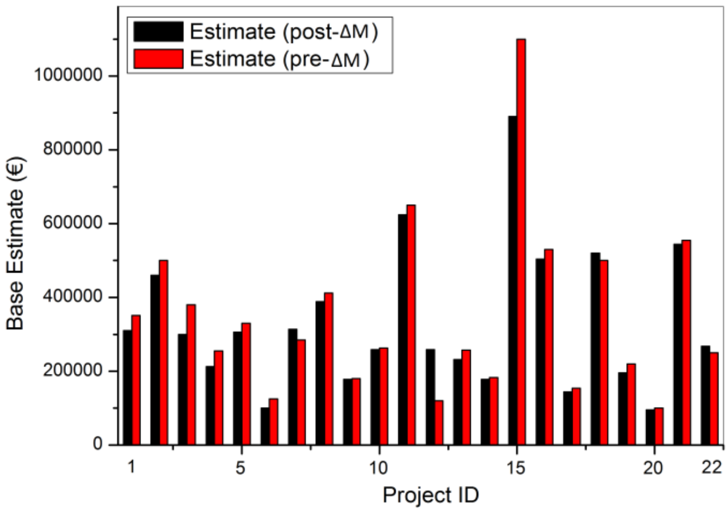


Figure 66: Base estimates

Contractors claim to be often uncompensated against these risks and in addition transferred unfair extra costs. Consequently they embody high contingencies in their base estimates so to be covered. This market dynamics lead towards other procurement methods. With this research project the author aimed to showcase that there is a significant window of improvement in traditional procurement. If contractors reduce the set contingencies into their offers by revising their estimates and their margin profit requirements, they can reap some very specific benefits. The results achieved, gain more value if it is considered that the 18 out of 22 examined projects (81.8% of sample) were characterized by an overestimated initial base estimate, indicating a tendency of contractors towards overestimating their offers (Figure 66).

The benefits and the corresponding requirements to achieve them are summarized below. The author uses the two dimensions developed for approaching the problem (behavioral and technical) as shown in Figure 13 so to facilitate understanding of the practical implications of the results achieved.

Perception – Behavioral dimension

"Superstructure" construction phase was found to be the riskiest as it scored +2.77% average change on the mean value of cost estimate and "land preparation" was found the less risky as it scored -0.16%, respectively (Table 65). On the ranking of the four cost risk drivers, it was found that the "schedule" drivers were ranked as the most important, second were the "quantity", followed by the "unit cost" and last the "global" ones. Both rankings derived from the simulation-based process (Table 67) and the AHP method (Table 74) were in agreement with however different importance weights. The use of the simulation and AHP weights will be utilized in the upcoming chapter.

Cost Variation – Technical dimension

During gathering the cost data for the five cost elemental categories (Land preparation, Foundations, Substructure, Superstructure, Finishes) no correlations was feasible to be collected as the survey's participants were not familiar with providing realistic correlation coefficients. Consequently, a fictitious case with correlated cost elements was built. The two project cases were afterwards compared. It was found that on a project-specific level the correlation effect was significant. When correlations were included the following key-points were observed:

- A +7% increase in the probability meeting the base estimate.
- Double cost data were captured in the 90% range.

- The cost estimate was higher than the one without correlations by 3.39%.
- Variance and Standard Mean Error were increased by +3.36% and +1.67% correspondingly.

All the findings regarding the cost data pattern when the two scenarios were compared "including correlations" and "excluding correlations" were validated by previous studies.

Efficiency – Behavioral dimension

From

Table 90 and Table 91 it was found that the model delivers in average terms for the entire portfolio a positive change in the total incentive profit elements of € 6707.42 which represents the 1.91% of the average portfolio's value (€ 349994.32). In parallel it was implied that a reduction of -3.68% for contingency amount has to be applied, given that 18 out of 22 contractors, after their profit-decision, reduced the set contingencies in their offers (Figure 67). Once again, it has to be pointed out that all these results pre-assume the contractor to be able and willing to reconsider his/her base estimates by revising the minimum acceptable change of Margin profit (denoted as ΔM in the questionnaire) which is the centre of decision.

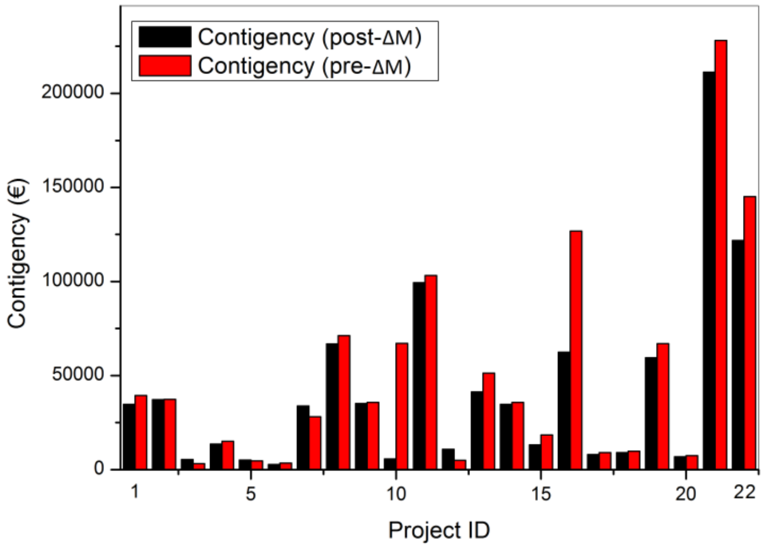


Figure 67: Contigencies

Taking all findings together, it was proved that contractors can remain competitive and win the bid of a project, if on average terms (a) reduce total contingency by -3.68%, and (b) reduce by one third the cost risk transferred to the client. Then they will be benefited by achieving a positive change in their incentive profit element by +1.91% of the average portfolio's value.

Finally, some statements were developed (see in § 7.4) which can lead to the formulation of potential statistical hypotheses. It remains out of this report's purposes to develop and test these hypotheses. Interestingly, it was proved that the "contingencies" and "the incentive profits" were strongly and negatively correlated before and after contractors have revised their estimates. This finding can assist contractors to predict towards which direction his/her cost estimation will lead contingencies and incentive profits.

Cost performance – Technical dimension

The model applied, revealed the opportunity of improving on average terms by +2% the CPI of the 22 projects examined in this study. This indicates although the model is very slightly reducing project delivery inefficiency on a project-specific level (Figure 62), on average terms can enhance an improved cost performance in a portfolio of building projects.

LIMITATIONS & FURTHER RESEARCH

Chapter **8**

8.1 Study limitations

8.1.1 Limitations of the industry

This report was fully constructed by the author's motivation in exploring whether improvement opportunities exist in traditional building procurement. Consequently, to understand how contractors take margin-related decisions sensitive cost data were required, such minimum change in margin profits and risk sharing choices. This made even more difficult for the researcher to attract and commit to this study a sufficient number of participants. For this reason personal contacts and networking in the origin country (Greece) of the researcher was used to collect the 22 valid questionnaires. The following limitations were raised due to this choice.

■ The study's sample is judged small. The questionnaire booklet was sent to 35 potential participants, with a 63% response rate which was judged sufficient. However a larger target group should be approached to derive stronger statistical representation of the construction population. It although has to be pointed out, that the reason of not attracting a higher number of participants can be explained due to the non-familiarity of contractors with probabilistic or simulation-based cost risk estimation techniques.

■ The structure of the Greek construction industry is significantly fragmented as the majority of operating firms are small-medium enterprises (SMEs) level corporations under the legal entity of Technical Societe Anonym. No more than 5 corporations (i.e. Consolidated Contractors Group, AKTOR, J&P–Avax Group, TERNA, EGNATIA ODOS S.A.) have a multi-million annual turnover and are experienced with risk management models.

■ The majority of the contractors use cost control accounting based on evaluating overall profit or loss at the end of the project. In essence the operational cost is monitored, evaluated and corrected (cost control) using judgmental and subjective approaches (Dawood & Dalakleidis 2002, p. 46).

■ The nature of the Greek construction industry has been changing significantly after the Olympic Games 2004 (Pantouvakis 2004) and thus more local and regional contractors are becoming increasing familiar with probabilistic and simulation-based techniques for cost risk estimation. Approximately half of the participants were employed or running a firm with over 20 years' experience in the building market. However during the preliminary meeting with the researcher, all participants required a very in-depth analysis of the survey. The limitation here is that the participants may under- or over-estimate the assigned values in probabilities and impact of risk factors; a fact that could not be controlled by the researcher.

■ From Panas, Pantouvakis, & Edum-Fotwe I cite the following very indicative paragrapgh about the nature of the Greek construction industry (Panas et al. 2005, p. 857): "*The framework within which Greek projects are delivered is defined by a number of technical regulations and laws which together comprise the Greek technical legislative system. Its origins go back to the middle of the 19th century when the first regulations for the construction of public works were promulgated. It has since been revised and evolved constantly to accommodate changes in the industry (1932, 1972, 1984, 2001, and 2003). The legislative system covers various aspects of the design, procurement, construction and management of projects (compensation of the participants, specific procedures to be followed throughout a project's life cycle, contractual relationships, quality assurance, documentation of the project's activities, and compliance with technical regulations). The existence of such a clearly defined technical legislation provides considerable clarity for the management of projects. However, it also presents a rigid system for how the industry should manage the delivery of its projects. While the technical legislation has evolved to accommodate EU guidelines, it still forms the backbone for delivering projects in Greece.*"

It can now be seen that many legislative transitions are to be implemented within the Greek construction market. This indicates another limitation on the report's results as potentially the risk sharing perception of contractors will probably differ than the present one.

A general judgment can now be made based on the aforementioned industry-specific limitations. The study's results are highly sensitive to the participants' understanding of the model's working method and potential improvement. The Greek construction industry remains on a decreasing profitability path during the last decade; a fact implying a specific underestimation view in contractors' estimating efforts. To provide an indication on the construction industry's performance in Greece, we have to consider the following three indicative facts:

1. The contribution of the industry to the national GDP between 2008 and 2013 has declined by more than 100% (Figure 68). The values used to construct the graph were obtained from the most recent industrial study performed by the Foundation for Economic & Industrial Research (IOBE 2015) and a study reported by the Association of Greek Contracting Companies (SATE 2012).
2. During the period 2003 – 2013, the construction output across the country was decreased by –78.93% meaning that in a decade 45700 less construction projects were executed (Figure 69). Both Figure 69 and Figure 70 are retrieved from a presentation given by the Bank of Greece (BoG) in a national conference for the section of Real Estate Market Analysis in Athens (BoG 2014).
3. The capital investment as percentage of GDP from 2007 and onwards had been following a declining trajectory (Figure 70).

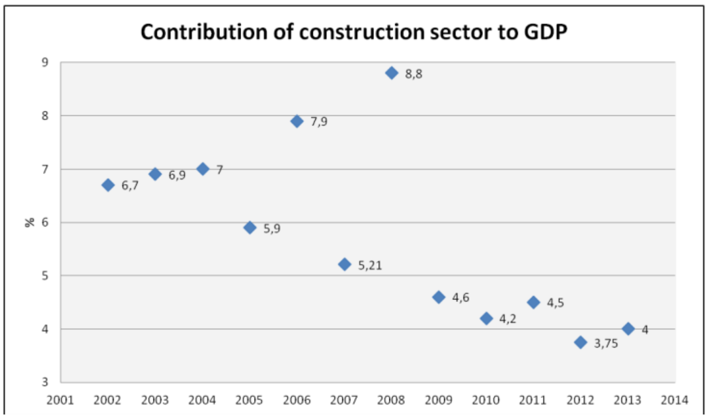


Figure 68: Pattern of construction's contribution to Greece's annual GDP

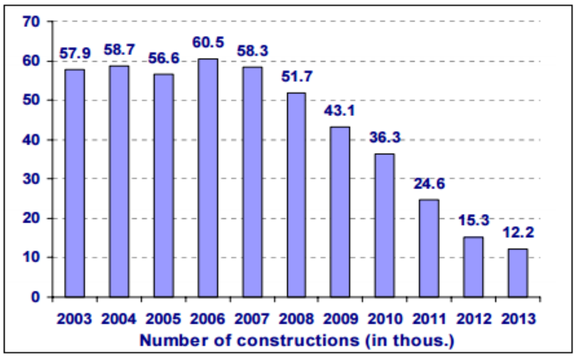


Figure 69: Construction output (in thousands)

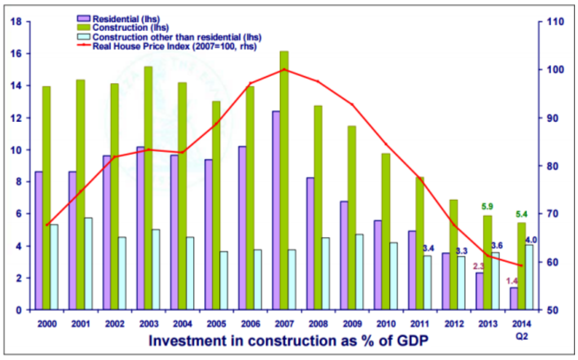


Figure 70: Capital investment in construction

8.1.2 The model's limitations

Given that this a partially simulation-based study when the cost risk estimation model was run in @RISK software the following steps should be checked and realized (Figure 71). However, *verification* (step 6) and *validation* (step 7) of the model were not executed. This goes beyond the study's purposes and it is left as a part for further research. All steps are briefly described below.

Table 96. Key deliverables in simulation steps for the applied model

Simulation steps	**Description**
1. Problem formulation	Contingency estimation
2. Setting objectives and overall project plan	Cost risk analysis
3. Model conceptualization	Line by line cost assessment of individual risks
4. Data collection	Import input values from survey template
5. Model translation	No simulation language, @RISK use
6. Vefication?	Building the model right?
7. Validation?	Building the right model?
8. Experimental design	Independent sampling Vs. Correlated sampling
9. Production runs and analysis	Specify the minimum iterations number
10. More runs?	If runs were sufficient "go on", if not redefine
11. Documentation and reporting	Program details and results presentation
12. Implementation	Vigorous, representative results

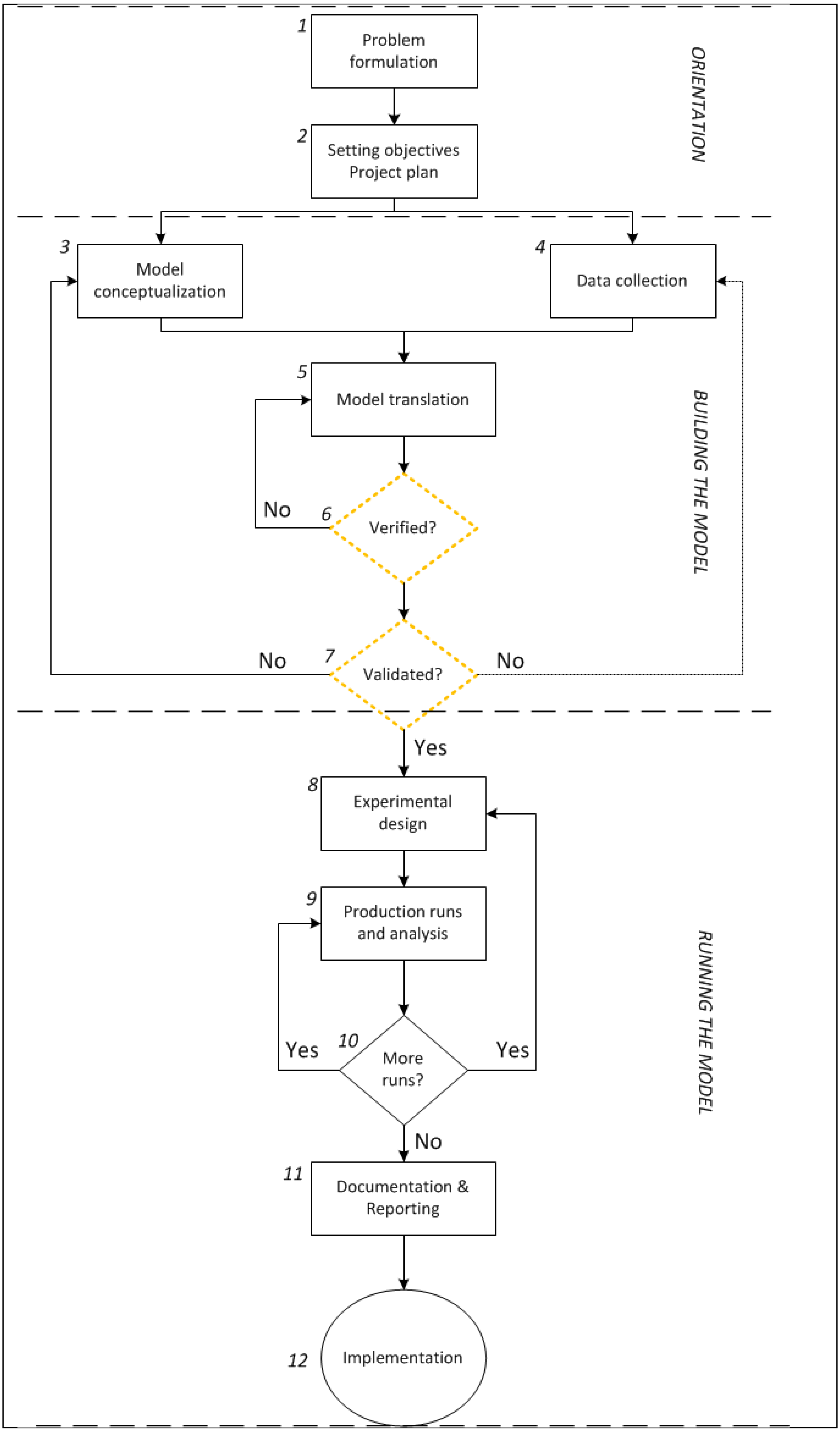


Figure 71: Steps in a simulation study (Banks et al. 2001, p. 14)

8.1.3 The AHP limitation

The use of verbal comparisons is intuitively appealing, user-friendly and more common in our everyday lives than numbers. For this reason the Analytical Hierarchy Process was build based on verbal comparisons transformed into numerical scales. The judgmental scales are important to derive priority vectors when pairs of alternatives are compared. Although the linear 9-numbers scale of Saaty (Saaty 1977) was applied for the purposes of this report several other judgmental scales exist as Table 97 shows.

The 1-9 scale followed in the AHP method sets a limitation to the synthesis of the table showing the total importance weights for the cost drivers. If another scale, as is seen Table 97 was applied different results may be expected. To which extent another scale could be applied and how much the new importance weights would deviate from the already obtained ones remains out of this report's scope.

Table 97. Scales for comparing two alternatives

Scale	Values								
Linear	1	2	3	4	5	6	7	8	9
Power	1	4	9	16	25	36	49	64	81
Geometric	1	2	4	8	16	32	64	128	256
Logarithmic	1	1.58	2	2.32	2.58	2.81	3	3.17	3.32
Root square	1	1.41	1.73	2	2.23	2.45	2.65	2.83	3
Aymptotical	0	0.12	0.24	0.36	0.46	0.55	0.63	0.70	0.76
Inv. Linear	1	1.13	1.29	1.5	1.8	2.25	3	4.5	9
Balanced	1	1.22	1.5	1.86	2.33	3	4	5.67	9

8.2 Further research

8.2.1 Optimal contigency setting with @RISK

One of the core findings after the model's application was the potential contingencies' reduction on total project level by -3.68% (Table 91). This finding implies that the cost risks should be minimized if multiplied by 0.9632 (=100%-3.68%). Given that contractors tend to embody a contingency by default equal to the 10% of the base estimate, the following stepwise process is written in order to provide contractors with a practical, comprehensive tool of assessing the level of their cost risks and then check if the total cost risks amount is below a proposed threshold. Potentially the proposed integrated contingency control methodology will lead to further research in exploring optimal thresholds for contingency setting. A flowchart is also provided in Figure 74 enabling the development of a pseudo-code or potentially an algorithm couple to @RISK package.

<u>Assumptions:</u>

(1) It is assumed that the total cost risks ($C_{R,tot}$) monetary value is set by the contractor equal to the 10% of the base estimate (E_i).
(2) This total value has to be minimized by applying the following threshold:
$C_{R,tot} \leq 0.9632 \times 0.10 \times E_i$
(3) The importance weights of the four cost risk drivers: (quantity) Q – (unit cost) UC – (schedule) S – (global) G are not constant and can be optimized. For choosing the optimal importance weights a contractor has to consider the simulation-derived weights and the AHP-derived weights. With this method, the worst case scenario or simply the maximum priority values will be applied and the total cost risk amount will be realistically calculated.
(4) The stepwise process below is not a stand-alone solution as it is based on the model built in @RISK. Consequently, the risk analysis model and the "pseudo-code" proposed are interlinked and go hand-in-hand.
(5) The improvement threshold of 0.9632 is obtained with the specific sample of projects examined. It does not imply that this value will not change in another setting of projects or another construction industry.
(6) The methodology proposed assumes and uses fitted data from the contractor's database of past projects.

Stepwise description of the proposed pseudo-code; supporting Figure 74:

Step 1
START: Run the proposed model in @RISK for a project j

Step 2
Compute the partial cost risk amounts for the four drivers by summing up the relevant amounts and dividing them by the total cost risk amount.

Step 3
Insert the partial cost risk amounts as: $C_{R,Q}, C_{R,UC}, C_{R,S}, C_{R,G}$

Step 4
Insert the proposed average (mean values) importance weights $\{\bar{a}, \bar{b}, \bar{c}, \bar{d}\}$ and their corresponding standard deviations $\{s_a, s_b, s_c, s_d\}$ for each cost risk driver.

Cost risk drivers	Importance weights
$C_{R,Q}$	$\bar{a} = 0.3895$
$C_{R,UC}$	$\bar{b} = 0.0633$
$C_{R,S}$	$\bar{c} = 0.6433$
$C_{R,G}$	$\bar{d} = -0.0961$

Cost risk drivers	Importance weights
$C_{R,Q}$	$s_a = 0.6597$
$C_{R,UC}$	$s_b = 0.2253$
$C_{R,S}$	$s_c = 0.4173$
$C_{R,G}$	$s_d = 0.7213$

In Appendix 18 it can be seen how the importance weights above were computed.

Step 5
Fit with @RISK command "Fit Distribution" a distribution to 22 past data of a, b, c, d from your database (Figure 72) and obtain the mean and standard deviation values for each a, b, c, d.

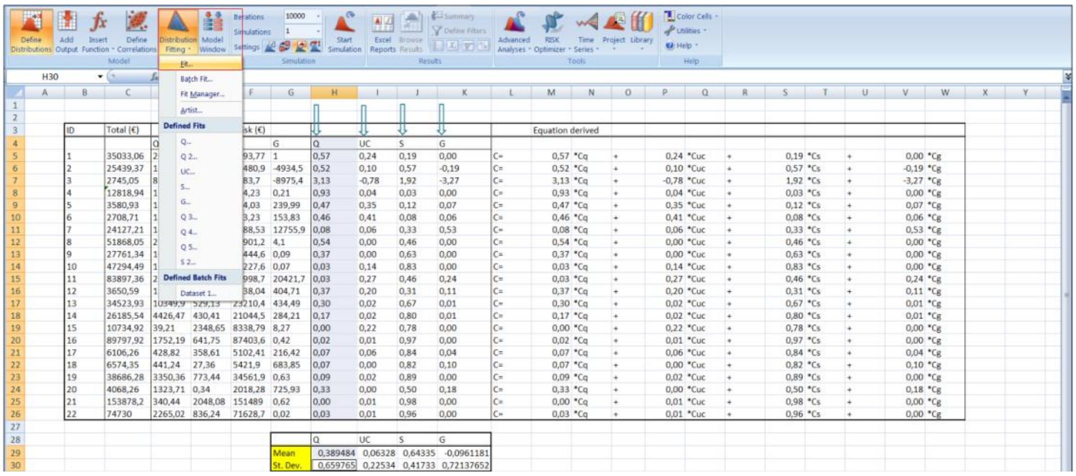


Figure 72: Fitting distribution to importance weights for 22 past projects with the use of @RISK

Step 6
At the desired confidence level choose the most appropriate distribution to fit based on the two following criteria:

► *Criterion 1: For historical analysis purposes and future cost forecasting*
Select the distribution fitted which captures the majority (largest % range) of cost data.

Define and insert the mean and standard deviation values obtained from the fitted distributions for each of the importance weight as follows:

$mean\ values = \{\bar{a}', \bar{b}', \bar{c}', \bar{d}'\}$

$standard\ deviation\ values = \{\ s'_a, s'_b, s'_c, s'_d\}$

► *Criterion 2: For project-specific cost analysis purposes*
Select the distribution fitted which provides the user with the closer values of mean and standard deviation of {ai, bi, ci, di} to the proposed ones mean values: {0.3895, 0.0633, 0.6433, -0.0961} and standard deviation values: {0.6597, 0.2253; 0.4173; 0.7213}, as in step 4.

$mean\ values = \{\bar{a}'', \bar{b}'', \bar{c}'', \bar{d}''\}$

$standard\ deviation\ values = \{\ s''_a, s''_b, s''_c, s''_d\}$

This criterion mathematically can be written as followed:

$\min\{(\bar{a} - \bar{a}''), (\bar{b} - \bar{b}''), (\bar{c} - \bar{c}''), (\bar{d} - \bar{d}'')\}$

$\min\{(s_a - s''_a), (s_b - s''_b), (s_c - s''_c), (s_d - s''_d)\}$

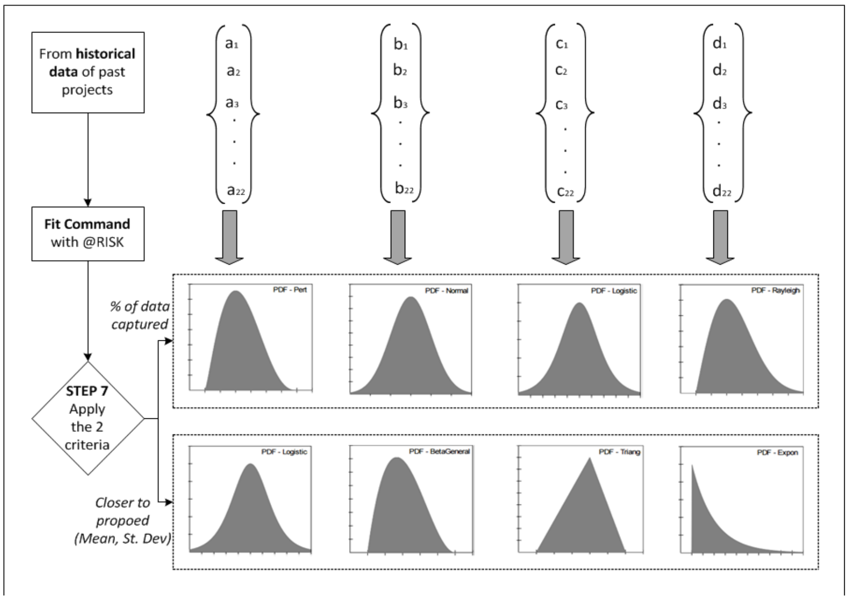


Figure 73: Visualisation of step 6 logic

Step 7
Run an Analytical Hierarchy Process (AHP) as was shown in Appendix 18.

Obtain the mean importance weights from the Direct Rating performed for each cost risk driver.

Define and insert the values obtained as follows:

$mean\ values = \{\bar{a}''', \bar{b}''', \bar{c}''', \bar{d}'''\}$

Step 8
Select the <u>maximum</u> importance weights vector from Step 7 and Step 8. This choice is grounded on the fact that the worst-case or the most overestimated scenario will be considered and the most overestimated cost risk amount will be mitigated.

Step 9
Insert the importance weights vector chosen, as follows:

$\{\tilde{a}, \tilde{b}, \tilde{c}, \tilde{d}\} = \max(step\ 7, step\ 8)$

Step 10
Compute the total cost risk amount as follows:

$$C_{R,tot} = \tilde{a} \times C_{R,UC} + \tilde{b} \times C_{R,UC} + \tilde{c} \times C_{R,S} + \tilde{d} \times C_{R,G} \quad (34)$$

Step 11
If $C_{R,tot} \leq 0.9632 \times (10\% \times E_j)$ then accept contigencies level and share risks as model proposes.

Step 12
If $C_{R,tot} > 0.9632 \times (10\% \times E_j)$ then return to:

Step 6: re-consider selection criterion

Step 7: check AHP consistency

Step 8: check your choice.

Step 13
END

A flowchart of the 13 steps described above, is following. It could be potentially used for the construction and the integration of a structured algorithm within the @RISK functions.

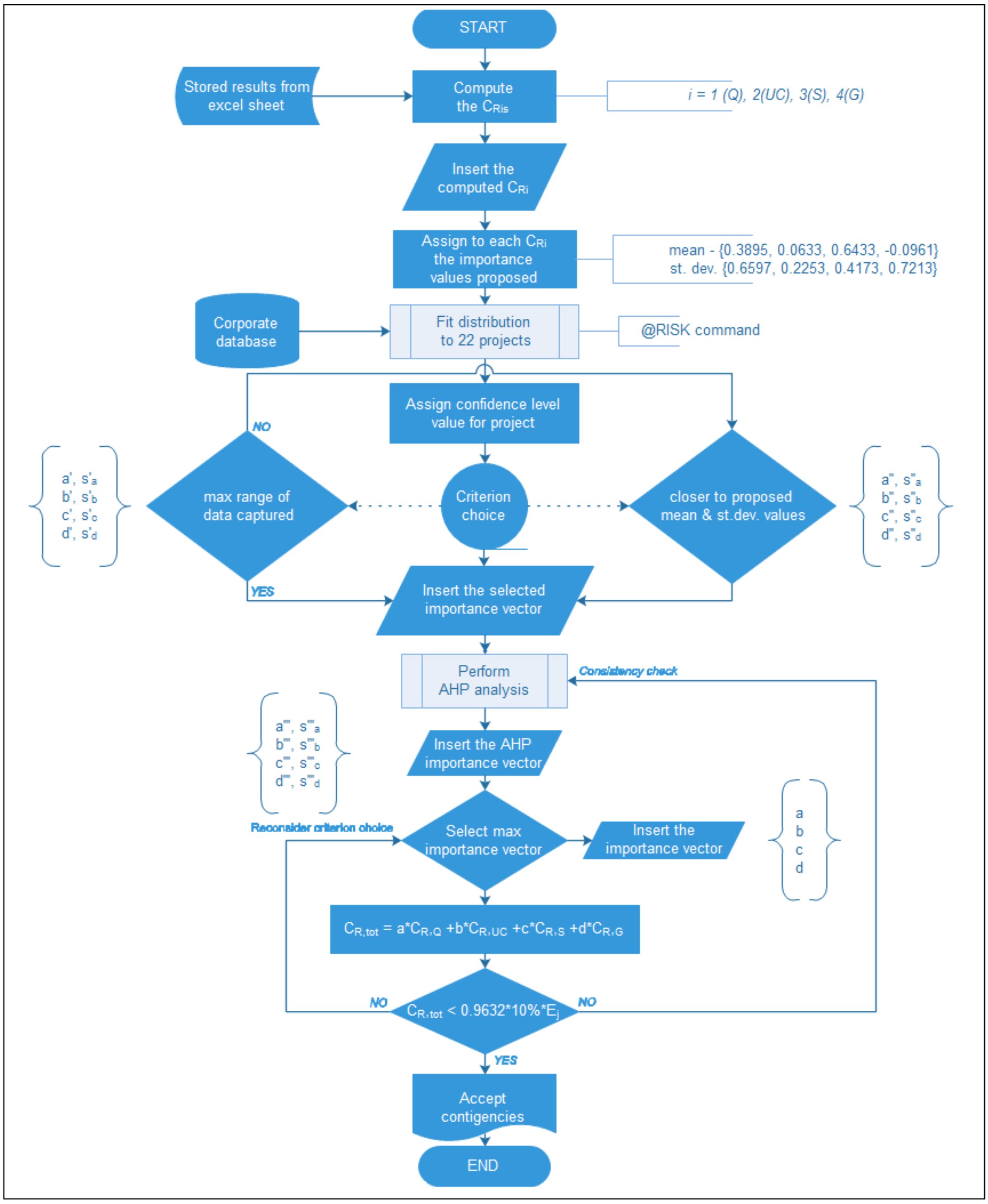


Figure 74: Flowchart for a potential pseudo-code construction

8.2.2 Reccomendation for the client

Contigency has not only been a subject for research from a contractor's view but also from the side of clients. Clients given that are aware of the probability of experiencing cost overruns due to risky incidents or change order events. The riskier a project's phase the higher the contingency amount will be set by clients so to cover the total cost overrun that they will be expected to compensate their contractors.

The model applied in this study enables contingency estimation for contractors. A model is now needed so to enable comparison with contigecny estimations from a client's view. If this is achieved, the study will facilitate both parties when they "open their books" in the post-bid phase to failry assess their contingency amounts and mutually negotiate on their risk sharing agreements.

Touran (Touran 2003b) developed such a model for contingency estimation performed by clients. In this section, there is no aim to apply or explain in detail Touran's model but the author proposes a common ground for contingency cross-comparison between the two parties. The idea preassumes that in the post-bid context both parties will be willing to be fully transparent regarding their cost strategy.

Given that a client may not fully trust a potential contractor, then he has to ask for two main cost parameters pre-bid and then calculate the expected contingency, as will be shown below. If this expected contingency value is violated by contractor then the client will be compensated as much as the violation was found.

To express mathematically this idea, I follow Touran's method of calculation of contigency only for "cost-driven" risk indicents (schedule indicents are excluded because of the study's scope).

Initially, it is assumed that risk events, in this case cost adjustments (change orders) occur randomly in time and follow a Poisson process. Thus we have:

$$P[X = x] = \frac{e^{-aT} \times (aT)^x}{x!}, \quad x = 0, 1, 2, \ldots, n \qquad (35)$$

Where:
X=random variable denoting the number of change orders
α=the mean rate of occurrence per unit of time
T=the original estimated project duration

The cost of change of a risk event *i* is denoted as C_i a random variable. The total cost of changes is defined as follows:

$$C_{ch} = \sum_{i=1}^{x} C_i \qquad (36)$$

We further proceed with deriving the Probability Mass Function (PMF) of C_{ch}. It is assumed that costs of change orders are independent of costs of delays and they are identical normally distributed random variables, then:

$$C_i \sim N(\mu_c, \sigma_c^2) \qquad (37)$$

The total cost of changes is also normally distributed because they are a linear sum of x normal variables. This implies the following relationship:

$$for\ x = n \Rightarrow C_{ch|X=n} = \sum_{i=1}^{n} C_i \qquad (38)$$

The Equation (40) represents a conditional distribution for C_{ch} given that $X = n$ thus:

$$C_{ch|X=n} \sim N(n\mu_c, n\sigma_c^2) \tag{39}$$

$$E[C_{ch}] = E[\textstyle\sum_{i=1}^{x} C_i] = E[X]\mu_c \tag{40}$$

For the calculation of the Poisson PMF we take:

$$P[X = n] = P[C_{ch} = N(n\mu_c\ , n\sigma_c^2)] = \frac{e^{-aT} \times (aT)^n}{n!} \tag{41}$$

For the calculation of contingency, we assume that the client desires a confidence level of p against cost overruns; he/she would need a contingency of β amount. The following relationships assist in specifying the level of contingency.

$$P[C_{ch} \leq \beta] \geq p \tag{42}$$

$$P[C_{ch} \leq \beta] = \sum_{x=0}^{\infty} P[C_{ch} \leq \beta | X = \chi] P[X = x] \Rightarrow$$

$$= \textstyle\sum_{x=0}^{\infty} \Phi[\frac{\beta - x\mu_c}{\sqrt{x\sigma_c^2}}] \frac{e^{-aT} \times (aT)^x}{x!} \geq p \tag{43}$$

Where:
$\Phi(\cdot)$ = the cumulative distribution function of a standard (mean=0, var.=1) normal distribution

The client maybe with the aid of an external consultant can now calculate his/her expected contingency. For doing so the Equation (45) has to be solved for β. The client has to determine the following values so to compute the expected contingency amount:

- T=original estimated duration (in months)
- a=mean rate of occurrence per unit of time (i.e. 2 risk events per month)
- x=number of change orders (n cost risks)
- p=confidence level against risks (i.e. 50% to avoid risk effects on cost estimates)
- μ_c=mean value of change orders (in €)
- σ_c=standard deviation of change orders (in €)

The author's suggestion for the client is to follow the next steps so to be proactive in solving possible disputes post-bid with his/her contractor:

(1) Bid not only for the price but include the estimated duration T with providing range limits of performance.
(2) Specify and bid for a maximum threshold for a. This choice will push contractors not to neglect cost risks in their bids and produce more proactive estimates based on historical data.
(3) If the client is a public body it is adviced to bid also for a maximum threshold of x obtained from the historical database. If the client is private, then he has to accept the proposal of the external consultant. In case of an unrealistic x estimation the consultant has to bear the additional costs not the contractor.
(4) After "opening their books" the two parties have to agree on a realistic p based on the submitted design studies.
(5) μ_c and σ_c: either have to be specified from the historical database for a public client, or from an external consultant for a provate client.

After specifying the contingency amount (β), the client has to check whether its value is within the legal range of maximum cost risk allowance as was explained in the paradigm in the first chapter (see in §1.1.3).

To conclude, a client cannot be fully aware neither of the risk sharing strategy of a candidate contractor nor of the expected contingency he/she will embody into the bid offer. However if a client follows the five steps above, this will enable a transparent cross-comparison between the two parties; a situation missing till this moment in traditional building procurement.

To which extent the Poisson distribution represents realistically random change order events, the assumption of normally distributed incidents always holds and how feasible is for a client to bid for a and T thresholds remains out of the study's scope.

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Appendix 1 – SFCA & Cost Plan

Detailed (Elemental) Cost Analysis

	ELEMENT	Element				
		Total Cost (£)	Cost per m²	Unit Quantity		Unit Rate
1	**SUBSTRUCTURE**				m²	
2	**SUPERSTRUCTURE**					
2.1	Frame				m²	
2.2	Upper Floors				m²	
2.3	Roof				Nr	
2.4	Stairs and Ramps				Nr	
2.5	External Walls				m²	
2.6	Windows and External doors				m²	
2.7	Internal Walls and Partitions				m²	
2.8	Internal Doors				Nr	
	Total Superstructure					
3	**INTERNAL FINISHES**					
3.1	Wall Finishes				m²	
3.2	Floor Finishes				m²	
3.3	Ceiling Finishes				m²	
	Total Internal Finishes					
4	**FITINGS, FURNISHINGS AND EQUIPMENT**				m²	
5	**SERVICES**					
5.1	Sanitary Installations				Nr	
5.2	Services Equipemnt				Nr	
5.3	Disposal Installations				Nr	
5.4	Water Installations				m²	
5.5	Heat Source				kW	
5.6	Space Heating and Air Conditioning				m²	
5.7	Ventilation Systems				m²	
5.8	Electrical Installations				m²	
5.9	Fuel Installations				m²	
5.10	Lift and Conveyor Installations				Nr	
5.11	Fire and Lightning Protection				m²	
5.12	Communication, Security and Control Installations				m²	
5.13	Specialist Installations				m²	
5.14	Builder's Work in Connection with Services				m²	
	Total Services					
6	**PREFAB. BUILDING AND BUILDING UNITS**				m²	
7	**WORK TO EXISTING BUILDING**					
7.1	Minor Demolition and Alteration Works				m²	
	Total Work to Existing Building					
	BUILDING SUB-TOTAL					
8	EXTERNAL WORKS					
8.1	Site Preparation Works				m²	
8.2	Roads, Paths, Pavings and Surfacings				m²	
8.3	Soft Landscaping, Planting and Irrigation Systems				m²	
8.4	Fencing, Railings and Walls				m²	
8.5	External Fixtures				m²	
8.6	External Drainage				m²	
8.7	External Services				m²	
8.8	Minor Building Works and Ancillary Buildings				m²	
	Total External Works					
0	**FACILITATING WORKS**					
0.1	Toxic/Hazardous/Contaminated Material Treatment				m²	
0.2	Major Demolition Works				m²	
0.3	Temporary Support to Adjacent Structures				m²	
0.4	Specialist Ground Works				m²	
0.5	Temporary Diversion Works				m²	
0.6	Extraordinary Site Investigation				m²	
	Total Faciltating Work					
9	**MAIN CONTRACTOR'S PRELIMINARIES**					
10	**MAIN CONTRACTOR'S OVERHEAD & PROFIT**					
	CONTRACT TOTAL (excluding contingencies and fees)					
11	**PROJECT/DESIGN TEAM FEES**					
12	**OTHER DEVELOPMENT/PROJECT COSTS**					
13	**RISK (CLIENT'S CONTINGENCIES)**					
	TOTAL CONTRACT/PROJECT COST					

 Standard Form of Elemental Cost Analysis

Front sheet of a typical cost plan

COST PLAN

PROJECT: (Type), (Location)
DATE OF COST PLAN: X/X/2015
ASSUMED DATE OF TENDER: X/X/2015
TOTAL INTERNAL FLOOR AREA: 2,390 m²

Note: **This cost plan is based upon the attached outline specification, and both documents should be read together.**

			Cost		
	Unit Quantity	**Unit Cost (£)**	**Subtotal (£)**	**Total (£)**	**Elemental cost (£) / m²**
1. WORK BELOW LOWEST FLOOR FINISH					
Ground floor area	390 m²	321.00		125,19	52.38
2. STRUCTURAL FRAME					
	2,390 m²			125,6	52.55
3. UPPER FLOORS					
225 mm Hollow pot	386 m²	60.00	23,16		
150 mm in-situ RC	1,585 m²	41.00	64,985		
			88,145		36.88
4. STAIRCASES					
RC Staircases	25 m	1225.00	30,625		
1 No 25 m rise					
1 No secondary					
21.5 m rise	21.5 m	900.00	19,350		
			49,975	49,975	20.91

Appendix 2 – RBS

Detailed Risk Breakdown Structure for building projects

Phase	Driver	Risks (Risk events)	Type	Uncertainty source
Land preparation	Q	R1: Removal of obstructions and existed structures	F	Incomplete engineering approach in geological investigations
	Q	R2: Additional costs for inspection and removal of buried contaminants	F	Uncertainty in the definition of what is excluded or included in the underground inspection activities
	Q	R3: Costs of stabilizing sloped or landslide ground parts	V	Uncertainty in the rock quality or incomplete geological survey
	Q	R4: Costs of damages due to ground subsidence in existing projects	V	Uncertainty in the engineering technique of stabilizing and isolating the excavation boarders from neighboring projects
	UC	R5: Rework costs due to incomplete dewatering	F	Uncertainty coming either from rock porosity
Foundations	UC	R6: Deflection of earth retaining walls in deep excavations	V	Uncertainty in the engineering approach regarding formwork use and reuse
	G	R7: Protection costs due to unsafe access to site	V	Uncertainty deriving from site conditions changes
	G	R8: Additional costs of permits related to safety and health issues	V	Uncertainty deriving from changes in regulatory processes
	G	R9: Rework costs of permits due to water inrush	F	Cost implications of acceptable (penalized) design changes
	Q	R10: Underestimated stiffness of support systems	V	Uncertainties in design costs arising from minor miscalculations
	Q	R11: Settlements in the surrounding due to vibration during pit-wall construction or due to deformation of the pit-wall	V	Uncertainties due to significant over break during pit-walls' construction implying compensation of additional quantities of materials
	Q	R12: Additional costs due to finding of cultural buried heritages	F	Cost implications due to incomplete definition of what precisely is included or excluded in the cost line
Substructure	UC	R13: Rework costs due to wrongly connected formwork and inappropriate scaffolding	V	Uncertainty deriving from mis-reuse of formworks
	UC	R14: Fixing costs of deflected earth retaining walls	F	Uncertainty in the cost estimates for labor costs
	UC	R15: Additional costs of waterproofing box type basements	F	Uncertainty in the estimates for equipment, material and labor costs
	S	R16: Liability costs of damages after the excavation	F	Cost implications of wrongly estimated time-reserved period

		to existing third party structures		
	S	R17: Leaking substructure due to insufficient inspection	V	Cost implications of wrongly estimated time-reserved period
	Q	R18: Costs of reinforcing under-designed diaphragm walls	V	Uncertainties in design costs arising from minor miscalculations
Superstructure	S	R19: Costs of installation delays of prefabricated or in-situ elements	F	Uncertainty of misestimating labor productivity ratio
	S	R20: Costs of transportation delays of prefabricated or in-situ elements	F	Cost implications due to materials or elements delivery
	S	R21: Additional transportation costs due to unavailability of "purpose-built" plant	F	Cost implications due to non-optimal production and sourcing locations
	G	R22: Costs of re-planning waste management practices and determining proper locations	V	Uncertainty deriving from changes in regulatory processes
	G	R23: Accident costs due to incorrect lifting practices or lack of handling equipment	V	Uncertainty in human perception of HSE standards leading to labor problems
Finishes	S	R24: Rework costs due to inaccurate installation of insulations	V	Cost implications of wrongly estimated time-reserved period
	S	R25: Rework costs due to faulty adjustments of electrical components	V	Cost implications of wrongly estimated time-reserved period
	UC	R26: Incomplete surface treatment (e.g. flooring, plastering, painting)	V	Uncertainty deriving from the processing of finishing materials
	UC	R27: Inefficient tightness test (e.g. gas, air leakage, acoustics, heating system, drainage water)	V	Cost implications due to variations in contract variations between engineering and management teams

Appendix 3 – Risk definitions

Chronological sequence of "RISK" definitions

Study	Definition of risk
(Fullwood 1977)	$$risk = \sum_{i=1}^{N} P_i\, C_i$$ Where: P_i = the probability per unit time of accident type, C_i = the consequences, N = the total number of accident types.
(Erikson 1979)	Exposure to possible economic loss or gain arising from involvement in the construction process.
(Parry & Winter 1981)	$$risk = \sum_{i=1}^{N} P_i\, C_i^K$$ Where: P_i = the probability per unit time of accident type, C_i = the consequences, N = the total number of accident types, K = a parameter to be selected to provide a greater weight to high-consequence accidents than to smaller ones occurring so frequently that the physical effects on the whole on the whole population are the same (NUREG/CR-2300 1983).
(Kaplan & Garrick 1981)	a. $risk = uncertainty + damage$ $b. R = \{\langle Si, \quad Pi, \quad Xi\rangle\}$, $i = 1, 2, \dots, N.$ a. Both uncertainty and some kind of loss or damage that might be received are involved in the classic K&G risk definition. b. Three basic questions are asked: • What can happen? (Si: Scenario) • How likely is that to happen? (Pi: Probability) • If it does happen, what are the consequences? (Xi: Evaluation measure)
(Hertz & Thomas 1983)	A lack of predictability about structure, outcomes, or consequences in a planning or decision situation.
(March & Shapira 1987)	Risk is the reflecting variation in the distribution of possible outcomes, their likelihoods and their subjective values.
(Sherif 1991)	$$risk = \frac{hazard}{safeguards}$$ The risk can be minimized by increasing safeguards against hazards or sources of danger.
(Sitkin & Pablo 1992)	Three dimensions define the risk: outcome uncertainty, outcome expectation, and outcome potential.
(Titarenko 1997 p. 11)	$R = f(A, P, u)$

	Risk (R) can be defined as a trinity of an event (A), a risk probability (P) and a function of risk losses (u).
(Rosa 1998)	A situation or event where something of human value (including human themselves) is at stake and where the outcome is uncertain.
(del Caño & de la Cruz 2002)	The exposure to the chance of occurrences of events adversely or favorably affecting project objectives as a consequence of uncertainty.
(Hillson 2002)	An umbrella term incorporating two notions; an opportunity with positive effects and a threat with negative effects.
(ISO, 2002)	The combination of probability of an event and its consequences.
(Raz et al. 2002)	Undesired event that may cause delays, excessive spending, unsatisfactory project results, safety or environmental hazards, and even total failure.
(Nilsen & Aven 2003, p. 312)	Risk is related to an activity within a spectrum of consequences or discrete outcomes that may follow from an undesirable event and the associated probabilities.
(Campbell 2005)	The expected disutility. 'Expected harm' which implies that *risk = e(h)* utilizes both subjective and objective probabilities.
(Willis 2007)	Mathematically risk is the expected loss. Conceptually risk is the intersection of threat, vulnerability and consequences.
(Aven 2010)	*Risk = (A, C, P)* where: A represents the events, scenarios, C represents the consequences (outcomes) and P the associated probabilities.
(Antón et al. 2011)	The probability of an event that impairs the viability of the project.

Appendix 4 – RM standards

A summary of international or national and professional RM standards

Producer	Standard
International & National	
ISO (International Organization for Standardization)	31000:2009 Risk management – Principles and guidelines. ISO/IEC Guide 73:2002 Risk Management Vocabulary Guidelines for use in standards. CIE/IEC 62198:2001 International standard, Project Risk Management: Application Guidelines. Author: International Electro technical Commission, Switzerland. ISO/IEC Guide 51:1999 Safety aspects – Guidelines for their inclusion in standards. ISO 17776:2000 Petroleum and natural gas industries – Offshore production installation - Guidelines on tools and techniques for hazard identification and risk assessment.
CSA (Canadian Standards Association)	CSA Q 850:1997 Risk Management Guidelines for Decision Makers.
JSA (Japanese Standards Association)	JIS Q 2001:2001 Guidelines for development and implementation of risk management system.
AS/NZS (Australian Standards/New Zealand Standards)	AS/NZS 4360:2004 Risk management.
BSI (British Standards Institution)	BS 31100:2008 Code of practice for risk management. BS 6079-3 Project Management – Part3: Guide to the management of business related project risk.
ON (Austrian Standards)	ONR 49001 - Risk Management for Organizations and Systems: Implementation of ISO 31000. ONR 49000 Risk management for organizations and systems – Terms and principles. ONR 49002-1 Risk management for organizations and systems – Part 1: Guidelines for risk management ONR. 49002-2 Risk management for organizations and systems – Part 2: Guidelines for the integration of risk management. Into the

	general management system.
IEEE (Institute of Electrical and Electronics Engineers), USA	IEEE Standard 1540-2001 Standard for Software Life Cycle Processes – Risk Management.
DoT: PHMSA (Department of Transportation: Pipeline and Hazardous Materials Safety Administration), USA	Risk management definitions – Hazardous Materials Safety (2005).
EPA (Environmental Protection Agency), USA	Framework for Cumulative Risk Assessment (2003).
Professional Bodies	
IRM (Institute of Risk Managers) ALARM (National Forum for Risk Management in the Public Sector) AIRMIC (Association of Insurance and Risk Manager), UK	Risk Management Standard (2002) – adopted by the Federation of European Risk Management Associations (FERMA 2003).
COSO (Committee of Sponsoring Organizations of the Tread way Commission), USA	COSO Enterprise Risk Management (2004) – Integrated Framework (COSO 2004).
OSPMI (Office of Statewide Project Management Improvement), USA	Project risk management Handbook (2007) – Threats and Opportunities (Caltrans 2007).
APM (Association for Project Management), UK	RAMP (1997) – Project Risk Analysis and Management (Simon et al. 1997).
ICE (Institution of Civil Engineers), UK	RAMP (2005) – Risk Analysis and Management for Projects.
PMI (Project Management Institute), USA	PMI Practice Standard Project Risk Management (PMI 2009).
PMI (Project Management Institute), USA	Guide to the Project Management Body of Knowledge (PMBoK) – Chapter 11: Project Risk Management (PMI 2004).
SEI (Software Engineering Institute), USA	The Risk Management Process Area of CMMI (2002).

Appendix 5 – Quantitative risk allocation

Quantitative risk allocation approaches

Research focus	Outcome of study	Reference
	Fuzzy theory	
Demonstrate a potential use of fuzzy set theory and provide its formal procedure in the quantification of the uncertainties of accident progression event trees.	√ Computational algorithms suitable for application of the fuzzy set theory to the accident progression event tree analysis are identified and illustrated. √ The fuzzy set theory model is applied in a real case: a typical plant damage state. √ The results are compared with the one obtained from probabilistic methods.	(Chun & Ahn 1992)
Develop a decision model which transforms the linguistic principles and experiential expert knowledge into a more usable and systematic quantitative-based analysis.	√ 7 risk allocation criteria were produced. √ a set of knowledge-based fuzzy inference rules was established. √ Risk events are assessed on each criterion and the relevant rules. √ The risk allocation decisions between the owner and contractor were applied in a practical case.	(Lam et al. 2007)
Specify the risk responsibilities of project participants by evaluating the risk carrying capacity of all the project participants.	√ The integrated risk allocation coefficients of all project participants are calculated. √ The method of the risk loss allocation of each project participant is proposed.	(Yun-li & Lei 2008)
	Adaptive systems	
Develop a mechanism to facilitate the risk allocation decision-making (RADM) process.	√ Fuzzy inference systems (FISs) developed to incorporate two frameworks; the TCE and the RBV. √ FISs are more suitable for forecasting efficient risk allocation strategy.	(Jin & Doloi 2009)
Develop a fuzzy synthetic evaluation model for determining an equitable risk allocation between the government and the private sector.	√ 23 principles and factors for risk allocation were specified. √ 9 critical Risk Allocation Criteria (RACs) are set. √ Weight the RACs. √ A set of knowledge-based inference rules was established to set up membership function for the 9 RACs.	(Xu et al. 2010)

Transform the neuro-fuzzy inference system of (Xiao-Hua Jin & Doloi, 2009) into a neuro-fuzzy model enabling the combination of fuzzy logic and artificial neural networks.	The neuro-fuzzy models developed over perform the multiple regression models and the fuzzy inference systems because they can more accurately forecast efficient risk-allocation strategies for privately financed public infrastructure projects.	(Jin 2011)
Develop a fuzzy adaptive decision making model for selection of balanced risk allocation.	The proposed model integrates fuzzy logic qualitative approach and AHP adaptive capabilities to evaluate allocation of project risks and determine best party to bear each one.	(Khazaeni et al. 2012a)
Provide a quantitative model for the risk allocation process.	A model which supports decision-making in risk management in a way that addresses the concerns of inappropriate risk allocation.	(Khazaeni et al. 2012b)
Develop an optimization approach to enhance risk allocation process in PPP projects.	√ The development and application of a generic algorithm to solve the multi-objective problem of risk allocation approached as a knapsack problem. √ Results are combinations of risk percentages for shared risks in PPP projects.	(Alireza et al. 2013)
Construct an integrated fuzzy-system dynamics approach for quantitative risk allocation.	√ Fuzzy logic integrated into a Systems Dynamics model to account the uncertainties. √ The optimal percentage of risk allocation is determined as a fuzzy number.	(Nasirzadeh et al. 2014)
Develop a fuzzy risk assessment model for construction projects procured with target cost contracts and guaranteed maximum price contracts (TCC/GMP) using the fuzzy synthetic evaluation method.	√ An objective and a holistic assessment of of individual Key Risk Groups (KRG). √ A solid platform to measure, evaluate and reduce the risk levels of TCC/GMP projects based on objective evidence instead of subjective judgements.	(Chan et al. 2014)
Game theory		
Study opportunistic bidding and construction claims.	The Claims Decision Model is developed (CDM).	(Ho & Liu 2004)
Model renewal of construction objects.	Selecting of rational renewal variants of derelict buildings from the viewpoint of sustainable development is Presented based on the rules of Bayes and Laplace.	(Antuchevičiene et al. 2006)

Analyze unfairness, resulting from using the commonly used Equal Price (EP) method, for allocating gains under the assumption of continuous quantity discounts.	√ Develop two fairness ratios and tie them to fairness properties. √ Prove *how* EP leads to unfair outcomes. √ Show *when* EP leads to unfair outcomes.	(Schotanus et al. 2008) *Applicable only when clients and contractors are seen as two purchasing groups trying to allocate cooperative gains.*
Model contractors' selection with consideration on risk levels based on multi-attribute methods.	A model based on metric scores for assessing the attributes of contractors' evaluation. The contractors' optimality criterion values are calculated according to Hodges-Lehman rule.	(Tamošaitienė et al. 2008)
Negotiate to solve disputes in conflicting situations.	An overview of applications is given.	(Peldschus 2008)
Allocate the cost of risk capital based on value-at-risk (VaR) for performance measurement in a decentralized organization with several divisions. Fair risk capital allocation schemes.	Analysis of several well-known allocation schemes in the context of a model based on cooperative game theory. Prove that the *beta method* and the *nucleolus method* are the most well performing allocation methods.	(Homburg & Scherpereel 2008)
Construct a multi-risk control (non-cooperative) information game model, for allocating risks, while considering risks as individual players competing with other players for the allocation of risk control resources that are available in limited quantities within a given measure set.	An efficient algorithm is proposed to solve the allocation solution based on Nash equilibrium, and an experiment is presented to illustrate the effectiveness of the proposed game model.	(Jiang & Zhao 2009)

Appendix 6 – (Construction) Risk sharing

Risk sharing approaches as identified in construction procurement literature

Procurement model	Research focus	Outcome	Reference
Joint Venture	Reduce financial risks of contractors when entering a strategic partnership.	Risk sharing as a vehicle to create competitive advantages for JV contractors against individual contractors.	(Ashley 1980)
Public construction contracts (Project: Milwaukee Water Pollution Abatement Program)	Achieve equitable risk sharing, dispute resolution and claims resolution.	Prove that "if risks shared the contractor can reduce the contingency costs".	(Wieland & Meinholz 1983)
Underground construction contracts	Investigate the role of risk sharing as impact factor on design conservatism.	An estimate of savings enabling adaptation of technical and non-technical variables.	(Levitt et al. 1984)
Underground tunneling contracts	Comparison of risk sharing practices between US and Germany based contractors.	Risk sharing model for structural and functional risks.	(Duddeck 1987)
Underground tunneling contracts	Norwegian risk sharing principles are reviewed.	√ Equivalent Construction Time principle √ Eliminating time-wasting discussions √ Reducing costs	(Karlsen & Kleivan 1989)
Variable quantity procurement model	Investigate how renegotiation can mitigate the contractual incompleteness as a root of risk sharing inefficiencies.	Design of optimal contract.	(Chung 1991)
Target Cost Contracts (TCCs)	How clients and contractors set risk sharing ratios in their agreements.	√Agency theory used to interpret risks. √Selection of risk sharing ratios. √Perceived level of risks determined.	(Badenfelt 2008)

		√Impact of long-term relationships on the contractual design.	
Domestic public construction contracts	Evaluate the risk sharing performance of contract clauses.	A Fuzzy Set Decision Model combining AHP for enabling the choice of optimal risk sharing decision.	(Lee et al. 2009)

Appendix 7 – Iterations required (R)

Estimation of iterations number for "Land Preparation" – Output cell 1

ID	Confidence level (%)	α	α/2	1-(α/2)	Zα/2	St. Dev.	**R**
1	68,74	0,313	0,156	0,844	1,010	5979,77	0,003
2	76,09	0,239	0,120	0,880	1,177	4371,98	0,002
3	63,25	0,368	0,184	0,816	0,901	2200,20	0,000
4	62,59	0,374	0,187	0,813	0,889	6119,91	0,002
5	52,3	0,477	0,239	0,762	0,711	3569,75	0,001
6	53,41	0,466	0,233	0,767	0,729	5145,16	0,001
7	52,28	0,477	0,239	0,761	0,711	7102,25	0,002
8	78,07	0,219	0,110	0,890	1,228	7397,90	0,007
9	69,97	0,300	0,150	0,850	1,036	1338,15	0,000
10	52,33	0,477	0,238	0,762	0,712	2907,96	0,000
11	51,73	0,483	0,241	0,759	0,702	13429,95	0,007
12	65	0,350	0,175	0,825	0,935	1914,53	0,000
13	66,09	0,339	0,170	0,830	0,956	2513,26	0,000
14	57,55	0,425	0,212	0,788	0,799	1517,62	0,000
15	50,06	0,499	0,250	0,750	0,675	3600,79	0,000
16	51,24	0,488	0,244	0,756	0,694	8646,80	0,003
17	50,87	0,491	0,246	0,754	0,688	3895,78	0,001
18	50,37	0,496	0,248	0,752	0,680	2645,68	0,000
19	54,8	0,452	0,226	0,774	0,752	7957,50	0,003
20	64,83	0,352	0,176	0,824	0,931	761,14	0,000
21	51,55	0,485	0,242	0,758	0,699	47,86	0,000
22	58,07	0,419	0,210	0,790	0,808	2102,50	0,000

Estimation of iterations number for "Foundations" – Output cell 2

ID	Confidence level (%)	α	α/2	1-(α/2)	Zα/2	St. Dev.	**R**
1	64,15	0,359	0,179	0,821	0,918	6620,41	0,000
2	63,54	0,365	0,182	0,818	0,907	9351,89	0,004
3	56,4	0,436	0,218	0,782	0,779	5040,74	0,003
4	58,1	0,419	0,210	0,791	0,808	13627,92	0,000
5	51,7	0,483	0,242	0,759	0,701	11627,75	0,001
6	53,06	0,469	0,235	0,765	0,723	8642,61	0,000
7	60,96	0,390	0,195	0,805	0,859	11115,68	0,001
8	61,5	0,385	0,193	0,808	0,869	13745,50	0,080
9	65,52	0,345	0,172	0,828	0,945	5020,59	0,478
10	53,81	0,462	0,231	0,769	0,736	8281,52	0,027
11	61,52	0,385	0,192	0,808	0,869	29406,91	0,007
12	51,84	0,482	0,241	0,759	0,704	6144,94	0,001
13	57,75	0,423	0,211	0,789	0,802	9840,15	0,029
14	54,45	0,456	0,228	0,772	0,746	5944,74	0,004
15	50,3	0,497	0,249	0,752	0,679	35604,14	0,000
16	50,72	0,493	0,246	0,754	0,686	11087,51	0,006
17	51,17	0,488	0,244	0,756	0,693	7019,50	0,002
18	50,66	0,493	0,247	0,753	0,685	5659,10	0,005
19	52,72	0,473	0,236	0,764	0,718	11506,03	0,004
20	56,53	0,435	0,217	0,783	0,781	1417,91	0,206
21	50,94	0,491	0,245	0,755	0,689	1344,59	3,899
22	54,59	0,454	0,227	0,773	0,749	1601,66	0,931

Estimation of iterations number for "Substructure" – Output cell 3

ID	Confidence level (%)	α	α/2	1-(α/2)	Zα/2	St. Dev.	**R**
1	63,23	0,368	0,184	0,816	0,901	9031,61	0,002
2	60,83	0,392	0,196	0,804	0,857	2411,47	0,004
3	54	0,460	0,230	0,770	0,739	11470,59	0,002
4	55,91	0,441	0,220	0,780	0,771	7364,61	0,004
5	51,53	0,485	0,242	0,758	0,699	19878,09	0,005
6	53,08	0,469	0,235	0,765	0,724	5494,00	0,006
7	58,3	0,417	0,209	0,792	0,812	8792,57	0,004
8	72,14	0,279	0,139	0,861	1,083	31526,71	0,238
9	73,87	0,261	0,131	0,869	1,123	13408,92	0,142
10	83,65	0,164	0,082	0,918	1,393	26988,30	0,045
11	70,32	0,297	0,148	0,852	1,043	42875,14	0,028
12	54,49	0,455	0,228	0,772	0,747	7095,59	0,009
13	74,45	0,256	0,128	0,872	1,137	30961,11	0,044
14	83,33	0,167	0,083	0,917	1,383	14765,27	0,027
15	52,57	0,474	0,237	0,763	0,716	82999,21	0,010
16	84,07	0,159	0,080	0,920	1,407	632020,24	3,447
17	58,89	0,411	0,206	0,794	0,822	14000,74	0,013
18	52,2	0,478	0,239	0,761	0,710	22720,53	0,007
19	87,51	0,125	0,062	0,938	1,535	36510,22	0,135
20	65,94	0,341	0,170	0,830	0,953	1545,61	0,021
21	79,66	0,203	0,102	0,898	1,272	24779,40	0,043
22	85,54	0,145	0,072	0,928	1,459	5960,11	0,143

Estimation of iterations number for "Superstructure" – Output cell 4

ID	Confidence level (%)	α	α/2	1-(α/2)	Zα/2	St. Dev.	**R**
1	51,73	0,483	0,241	0,759	0,702	1285,98	0,000
2	48,74	0,513	0,256	0,744	0,655	11559,65	0,001
3	42,43	0,576	0,288	0,712	0,560	7144,15	0,000
4	50,48	0,495	0,248	0,752	0,682	3084,85	0,000
5	50,52	0,495	0,247	0,753	0,683	4096,37	0,000
6	50,95	0,491	0,245	0,755	0,690	1096,17	0,000
7	63,14	0,369	0,184	0,816	0,899	5863,78	0,001
8	55,86	0,441	0,221	0,779	0,770	8391,02	2,995
9	65,12	0,349	0,174	0,826	0,937	8529,35	0,262
10	79,3	0,207	0,104	0,897	1,262	15468,61	0,021
11	67,83	0,322	0,161	0,839	0,991	30464,11	0,008
12	51,64	0,484	0,242	0,758	0,701	3087,10	0,002
13	64,72	0,353	0,176	0,824	0,929	21923,61	0,014
14	74,75	0,253	0,126	0,874	1,144	5712,42	0,006
15	51,16	0,488	0,244	0,756	0,693	17436,69	0,001
16	70,28	0,297	0,149	0,851	1,042	14069,29	0,005
17	56,19	0,438	0,219	0,781	0,775	4334,34	0,002
18	51,56	0,484	0,242	0,758	0,699	12950,45	0,001
19	73,56	0,264	0,132	0,868	1,116	6662,19	0,014
20	65,94	0,341	0,170	0,830	0,953	8824,89	0,004
21	75,49	0,245	0,123	0,877	1,162	30178,24	0,013
22	73,46	0,265	0,133	0,867	1,114	15773,82	0,018

Estimation of iterations number for "Finishes" – Output cell 5

ID	Confidence level (%)	α	α/2	1-(α/2)	Zα/2	St. Dev.	**R**
1	59,14	0,409	0,204	0,796	0,826	8882,57	0,002
2	55,67	0,443	0,222	0,778	0,767	38727,64	0,004
3	49,12	0,509	0,254	0,746	0,661	13746,54	0,002
4	51,12	0,489	0,244	0,756	0,692	1504,70	0,002
5	51,12	0,489	0,244	0,756	0,692	5821,28	0,002
6	52,73	0,473	0,236	0,764	0,718	2091,93	0,004
7	62,53	0,375	0,187	0,813	0,888	4026,53	0,004
8	72,89	0,271	0,136	0,864	1,101	16746,26	0,278
9	68,59	0,314	0,157	0,843	1,007	1916,67	0,173
10	92,05	0,080	0,040	0,960	1,754	11705,26	0,091
11	81,41	0,186	0,093	0,907	1,323	29419,26	0,067
12	54,11	0,459	0,229	0,771	0,741	2278,18	0,009
13	70,56	0,294	0,147	0,853	1,049	4405,45	0,045
14	87,77	0,122	0,061	0,939	1,545	3050,97	0,045
15	53,35	0,467	0,233	0,767	0,728	18379,16	0,018
16	94,86	0,051	0,026	0,974	1,948	16950,52	0,084
17	61,97	0,380	0,190	0,810	0,877	1299,85	0,016
18	52,77	0,472	0,236	0,764	0,719	31589,12	0,013
19	95,24	0,048	0,024	0,976	1,981	16025,44	0,284
20	54,97	0,450	0,225	0,775	0,755	2203,69	0,023
21	86,39	0,136	0,068	0,932	1,490	138029,62	0,071
22	96,34	0,037	0,018	0,982	2,090	110564,26	0,427

Estimation of iterations number for "Project Final Cost" – Output cell 6

ID	Confidence level (%)	α	α/2	1-(α/2)	Zα/2	St. Dev.	**R**
1	61,4	0,386	0,193	0,807	0,867	15485,12	0,000
2	60,97	0,390	0,195	0,805	0,859	41728,45	0,002
3	63	0,370	0,185	0,815	0,896	20008,60	0,001
4	55,64	0,444	0,222	0,778	0,766	17022,44	0,001
5	51,43	0,486	0,243	0,757	0,697	24287,03	0,001
6	52,65	0,474	0,237	0,763	0,717	11711,96	0,001
7	59,44	0,406	0,203	0,797	0,832	17425,21	0,001
8	68,09	0,319	0,160	0,840	0,996	39653,36	0,099
9	68,56	0,314	0,157	0,843	1,006	16758,33	0,072
10	72,23	0,278	0,139	0,861	1,086	34505,09	0,005
11	61,56	0,384	0,192	0,808	0,870	68012,20	0,002
12	55,42	0,446	0,223	0,777	0,762	10225,22	0,001
13	66,71	0,333	0,166	0,834	0,968	39440,18	0,006
14	71,57	0,284	0,142	0,858	1,071	17239,85	0,003
15	51,49	0,485	0,243	0,757	0,698	93250,25	0,001
16	70,23	0,298	0,149	0,851	1,041	67981,52	0,004
17	55,82	0,442	0,221	0,779	0,769	16831,29	0,002
18	51,51	0,485	0,242	0,758	0,698	41353,86	0,001
19	74,76	0,252	0,126	0,874	1,145	42725,40	0,012
20	70	0,300	0,150	0,850	1,036	9358,70	0,003
21	68,8	0,312	0,156	0,844	1,011	143844,39	0,014
22	53,6	0,464	0,232	0,768	0,732	111633,21	0,020

Appendix 8 – Questionnaire booklet

CME
3TU.Federatie

"RISK SHARING IN TRADITIONAL CONSTRUCTION CONTRACTS FOR BUILDING PROJECTS. A CONTRACTOR'S PERSPECTIVE IN THE GREEK CONSTRUCTION INDUSTRY."

FACULTY: ENGINEERING TECHNOLOGY (CTW)
DEPARTMENT: CONSTRUCTION MANAGEMENT AND ENGINEERING (CME)
MASTER OF SCIENCE: CONSTRUCTION MANAGEMENT AND ENGINEERING
RESEARCH AREA: RISK MANAGEMENT

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EXAMINATION COMMITTEE
Prof. dr. J.IM. Halman (Chair)
Assoc. prof. dr. S.H. Al-Jibouri (Main supervisor)

UNIVERSITY OF TWENTE.

Survey specification

Dear colleagues,

I am a civil engineer coming from Greece and having studied Civil Engineering between 2004-2011 for the qualification of Master in Engineering at the University of Patras, Greece. After acquiring a 2 years working on-site experience, I decided to pursue my master studies in Construction Management and Engineering at the University of Twente, in the Netherlands. From December 2013 and so on I am working on my master thesis project for which I chose the Greek geographical area to examine the formation of risk-sharing schemes in traditional (Design-Bid-Build) contracts. Two reasons implied this focus: firstly the frequent used practice of competitive bidding for both private and public clients and secondly the high affinity of in Greece-operating construction practitioners with the traditional procurement system.

This introduction aims to briefly inform you regarding the purpose of the present questionnaire form in respect to its practical and scientific importance.

The questionnaire is serving as a survey research tool to gather all the required data for my research graduation project. The study has a twofold goal. Firstly it explores the risk-sharing practices of contractors in a traditional construction contract for building projects. Secondly it aims to map how profit-related decisions are taken and how these decisions could lead to optimal contingency setting, so to remain competitive in a bidding round. In addition to the above, potential hypotheses will be formulated so to explore contractors' perceptions in relation to contingency, riskiness of cost category, incentive profits, change in contingency levels and the probability meeting the base estimate.

In order to achieve the goal described above, the data that the respondents will be asked to fill are the following:

- Organizational characteristics (section A),
- Base estimates of the total project (section B),
- Percentages of the total estimate for each construction phase (section B),
- Range limits for each construction phase (section B),
- Risk ownership or cost risk-sharing rates for the identified construction risks (section B),
- The minimum change in the margin profit of each construction phase (section B),
- The probability and impact estimations of each individual risk factor and the cost risk drivers' importance rating (section C), and
- Details for personal communication (section D).

Scientifically the study will extend the knowledge in risk-sharing agreements by revealing *where* (cost category) and *why* (risk perception) contractors become more or less risk aversive and how risk contingencies are associated to the change of incentive profits. This will lead to the formulation of practical implications explaining how the risk-sharing decisions of contractors influence the total project cost performance.

I would like to thank you in advance for your participation and your valuable assistance for the implementation of this study.

All the data used and the derived results will remain in the possession of the respondents and only with their permission will be used in a possible scientific publication.

For any questions you may have and further needed elaborations, do not hesitate to contact me directly. If case of additional time required and anonymity to be kept, please contact the author.

Yours faithfully,

Kordas Dimitrios

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INTRODUCTION

The present study assists the author to complete the degree of Master of Science in Construction Management and Engineering and in the same time to expand the current knowledge in risk sharing practices between contractors and clients when they negotiate on traditional contracts.
This form serves as a tool to collect the organizational characteristics of the respondents participated and the project specific characteristics. The form is expected to take **30 minutes** to be filled in.

DEFINITIONS

- **Risk**: An uncertain event or condition that, if occurs, has a positive or negative impact on at least one project objective.
- **Risk sharing**: In respect of contractors' controllable and uncontrollable risks, risk sharing is the arrangement on which the two contractual parties (contractor – client) agree on the way they bear or own the construction risks. A similar notion is risk ownership. Both terms are expressed in this study by the risk sharing rate, denoted with *b*.
- **Traditional contract**: Is the procurement basis under which a designer (architect) sometimes in collaboration with a project coordinator prepares a fully detailed design which is used by the client (project owner). The client procures this design in a tendering process and then selects the best bid price offered by candidate contractors. Once the contractor is awarded the contract he is solely responsible for the actual construction and if agreed for the project's maintenance too. This is the so called "Design-Bid-Build" project delivery system.
- **Fixed risks**: Are risks that either occur or don't (with probability each). When these risks occur, they have a range of effect which can be described with a probability density function. An example of a fixed risk is the additional costs due to delayed planning of legal permissions, in case that a client or his/her contractor wants to transfer sensitive equipment through a traffic circle at an intersection, this might have a 40% probability to happen and consequently a 60% probability of not happening.
- **Variable risks**: Are risks that will certainly occur but their impact is quantified over a range of values. For variable risks thus, the assignment of probability of occurrence is 100%. The impact of variable risks in the cost elements/activities of a project is introduced with a value of 100% (equal to 1). Errors or omissions in design specifications are risks that certainly will emerge due to human factor decisions and relevant mistakes.

SECTION A: ORGANISATION PROFILE

1. What is your position in your organization?

☐ Director or Executive

☐ Project manager

☐ In-house/Site engineer

☐ Risk manager

☐ Procurement officer / Tender manager

2. Description of company in relation to the building project delivered:

☐ Owner

☐ Contractor

☐ Subcontractor

☐ Supplier

☐ Construction manager

☐ Designer

3. Average construction volume (in Euros: €) of building projects procured with the traditional (Design-Bid-Build) project delivery system, the last three (3) years:

☐ < 500,000 (0.5 mil. or less)

☐ 500,000 – 1,000,000

☐ 1,000,000 – 5,000,000

☐ 5,000,000 – 10,000,000

☐ > 10,000,000 (10 mil. or more)

4. Number of building projects executed the last three (3) years:

☐ < 10 (less than 10)

☐ 10 – 19

☐ 20 – 29

☐ ≥ 30 (30 or more)

5. Experience of your company (in years) in procuring and constructing building projects:

☐ < 5 (less than 5)

☐ 5 – 9

☐ 10 – 14

☐ 15 – 19

☐ ≥ 20 (20 or more)

6. How many traditional bidding packages do you prepare every year on average, for building projects?

☐ < 25 (less than 25)

☐ 25 – 49

☐ 50 – 74

☐ 75 – 99

☐ ≥ 100 (100 or more)

7. In the company who performs risk management processes?

☐ A specialized personnel team (e.g. procurement officers)

☐ A senior (internal/external) consultant

☐ Informal system

☐ No use of risk management staff

8. Type of client

☐ Private

☐ Public

SECTION B: PROJECT PROFILE

1. Specify the payment mechanism applied in the specific building project for which you reply this section:

☐ Fixed fee

☐ Cost reimbursable

☐ Lump-sum

☐ Unit-price

☐ Performance-based

2. Specify the **initial** cost estimate (*E*) for the entire project. Fill in with a monetary value in Euros (€) the space in Table A 1.

Table A 1. Initial total project cost estimate

E = € . . .

3. Specify the percentages (0-100%) of the **initial** estimate of each construction phase. According to your experience specify the variation of the estimates you gave. Fill in the columns of Table A 2.

Table A 2. Percentage cost estimates of construction phases

Phases	**Part of the initial total cost estimate (% of E)**	**Range limits**	
		- (%)	**+ (%)**
Land Preparation			
Foundations			
Substructure			
Superstructure			
Finishes			

4. Please consider the **minimum percentage (0 – 100%) change: increase (+) or decrease (-)** on your **Margin profit** (denoted as *ΔM*) for the specific building project in order your bid offer to be the winning one again. Assign a value to *ΔM*, for each construction phase, followed with a **plus** (+) or **minus** (-) mathematical sign. Fill in the column of the Table A3.

5. Specify the **new** cost estimate (*E'*) for the entire project considering your **profit related decisions**. Fill in with a monetary value in Euros (€) the space in Table A 4.

Table A 3. Decision on the "profitability percentage change"

Phases	ΔM (± %)
Land Preparation	
Foundations	
Substructure	
Superstructure	
Finishes	

Table A 4. New (Revised) total project cost estimate

E' = € . . .

6. Specify the percentages (0-100%) of the **new** estimate of each construction phase. According to your experience specify the variation of the estimates you gave. Fill in the columns of Table A 5.

Table A 5. Percentage cost estimates of construction phases

Phases	Part of the initial total cost estimate (% of E')	Range limits	
		- (%)	+ (%)
Land Preparation			
Foundations			
Substructure			
Superstructure			
Finishes			

7. For each of the five phases, please rate the **risk sharing** for **each construction risk** provided in the specific phase for both the **initial** and **new** cost estimate. Fill in the columns of the following tables (Table A 6, Table A 7, Table A 8, Table A 9, Table A 10). Use the scale between 0 – 100 % to fill in the values of risk sharing rates (denoted as b_i).

"The construction risks provided assessed in this survey are used as examples. It is not implied that these risks are they only ones involved in the specific construction phases. For any additional construction-related risks that you may have been dealing with during the execution of building projects please leave a comment in the blank space."

Table A 6. Cost risk sharing in "Land preparation"-related activities

Phase I: Land preparation			
Risks		Risk-sharing b_i (0-100 %)	
		For E	For E'
R1	Removal of obstructions and existed structures	b_1=…	b'_1=…
R2	Additional costs for inspection and removal of buried contaminants (e.g. asbestos)	b_2=…	b'_2=…
R3	Costs of stabilizing sloped or landslide ground parts	b_3=…	b'_3=…
R4	Costs of damages due to ground subsidence in existing projects	b_4=…	b'_4=…
R5	Rework costs due to incomplete dewatering	b_5=…	b'_5=…

Table A 7. Cost risk sharing in "Foundations"-related activities

Phase II: Foundations			
Risks		Risk-sharing b_i (0-100 %)	
		For E	For E'
R6	Deflection of earth retaining walls in deep excavations	b_6=…	b'_6=…
R7	Protection costs due to unsafe access to excavation site	b_7=…	b'_7=…
R8	Additional costs of permits related to safety and health issues	b_8=…	b'_8=…
R9	Rework costs of permits due to water inrush	b_9=…	b'_9=…
R10	Underestimated stiffness of support systems	b_{10}=…	b'_{10}=…
R11	Settlements in the surrounding due to vibration during pit-wall construction or due to deformation of the pit-wall	b_{11}=…	b'_{11}=…
R12	Additional costs (e.g. legal penalties, extra rework) due to finding of cultural buried heritages	b_{12}=…	b'_{12}=…

Table A 8. Cost risk sharing in "Substructure"-related activities

Phase III: Substructure			
Risks		Risk-sharing b_i (0-100 %)	
		For E	For E'
R13	Rework costs due to wrongly connected formwork and inappropriate scaffolding	b_{13}=…	b'$_{13}$=…
R14	Fixing costs of deflected earth retaining walls	b_{14}=…	b'$_{14}$=…
R15	Additional costs of waterproofing box type basements	b_{15}=…	b'$_{15}$=…
R16	Additional costs of waterproofing box type basements	b_{16}=…	b'$_{16}$=…
R17	Leaking substructure due to insufficient inspection	b_{17}=…	b'$_{17}$=…
R18	Costs of reinforcing under-designed diaphragm walls	b_{18}=…	b'$_{18}$=…

Table A 9. Cost risk sharing in "Superstructure"-related activities

Phase IV: Superstructure			
Risks		Risk-sharing b_i (0-100 %)	
		For E	For E'
R19	Costs of installation delays of prefabricated or in-situ elements	b_{22}=…	b'$_{22}$=…
R20	Costs of transportation delays of prefabricated or in-situ elements	b_{23}=…	b'$_{23}$=…
R21	Additional transportation costs due to unavailability of "purpose-built" plant	b_{24}=…	b'$_{24}$=…
R22	Costs of re-planning waste management practices and determining proper locations	b_{25}=…	b'$_{25}$=…
R23	Accident costs due to incorrect lifting practices or lack of handling equipment	b_{26}=…	b'$_{26}$=…

Table A 10. Cost risk sharing in "Finishes"-related activities

Phase V: Finishes			
Risks		Risk-sharing b_i (0-100 %)	
		For E	For E'
R24	Rework costs due to inaccurate installation of insulations	b_{24}=…	b'_{24}=…
R25	Rework costs due to faulty adjustments of electrical components	b_{25}=…	b'_{25}=…
R26	Incomplete surface treatment (e.g. flooring, plastering, painting)	b_{26}=…	b'_{26}=…
R27	Inefficient tightness test (e.g. gas, air leakage, acoustics, heating system, drainage water)	b_{27}=…	b'_{27}=…

SECTION C: DIRECT RATING OF RISK DRIVERS & RISK FACTORS

1. Please fill in Table A 11 and Table A 12, which contain the risk drivers by assigning an indicator of *importance* and of *impact,* respectively. Please use the <u>check symbol</u> √ for filling Table A 11. Please assign a percentage value (0 – 100%) in <u>all three columns</u> of Table A 12

Level of importance				
Low (L)	Slight (S)	Moderate (M)	High (H)	Extreme (E)

Table A 11. Direct rating of the importance of the four cost risk drivers

Risk importance					
Risk drivers	**L**	**S**	**M**	**H**	**E**
Quantity					
Unit cost					
Schedule					
Global					

Table A 12. Direct rating of the cost impact of the four cost risk drivers

Risk impact (0-100%)			
Risk drivers	Best scenario (-)	Most likely (- or +)	Worst scenario (+)
Quantity			
Unit cost			
Schedule			
Global			

Please consider carefully Table A 13, in which every risk factor is categorized as **Fixed** or **Variable** based on the risk source. After reviewing Table A 13, please fill in the values required in Table A 14.

In the <u>4th column</u> (*Personal judgment on risk type and risk driver*), note **F** for **F**ixed risks or **V** for **V**ariables risk types, and **Q**/**UC**/**S**/**G** for **Q**uantity/**U**nit **C**ost/**S**chedule/**G**lobal risk drivers if you do not agree with the provided categorization, if you agree leave the column's cells blank.

In the <u>5th column</u> (*likelihood of occurrence*) note a percentage value (0 – 100%): for variable risks (as explained in definitions) this value is always 100% and for fixed risks this value has to be determined by using your personal experience.

Table A 13. Risk list with presentation of the risk source and risk type

Risk factor	Risk name	Risk source	Risk type
R1	Removal of obstructions and existed structures	Requirements change	Fixed
R2	Additional costs for inspection and removal of buried contaminants	Requirements change	Fixed
R3	Costs of stabilizing sloped or landslide ground parts	Unexpected ground conditions	Variable
R4	Costs of damages due to ground subsidence in existing projects	Unexpected ground conditions	Variable
R5	Rework costs due to incomplete dewatering	Requirements change	Fixed
R6	Deflection of earth retaining walls in deep excavations	Incomplete design specifications	Variable
R7	Protection costs due to unsafe access to excavation site	Site and security management	Variable
R8	Additional costs of permits related to safety and health issues	Site and security management	Variable
R9	Rework costs of permits due to water inrush	Legal permits	Fixed
R10	Underestimated stiffness of support systems	Incomplete design specifications	Variable
R11	Settlements in the surrounding due to vibration during pit-wall construction or due to deformation of the pit-wall	Inexperienced labor	Variable
R12	Additional costs due to finding of cultural buried heritages	Legal permits	Fixed
R13	Rework costs due to wrongly connected formwork and inappropriate scaffolding	Inexperienced labor	Variable
R14	Fixing costs of deflected earth retaining walls	Requirements changes	Fixed
R15	Additional costs of waterproofing box type basements	Project scope changes	Fixed
R16	Liability costs of damages after the excavation to existing third party structures	Legal permits	Fixed
R17	Leaking substructure due to insufficient inspection	Incomplete design specifications	Variable
R18	Costs of reinforcing under-designed diaphragm walls	Incomplete design specifications	Variable
R19	Costs of installation delays of prefabricated or in-situ elements	Ineffective time planning	Fixed
R20	Costs of transportation delays of prefabricated or in-situ elements	Ineffective time planning	Fixed
R21	Additional transportation costs due to unavailability of "purpose-built" plant	Requirements changes	Fixed
R22	Costs of re-planning waste management practices and determining proper locations	Site and security management	Variable
R23	Accident costs due to incorrect lifting practices or lack of handling equipment	Site and security management	Variable

R24	Rework costs due to inaccurate installation of insulations	Lack of labor independence and/or instructions	Variable
R25	Rework costs due to faulty adjustments of electrical components	Lack of labor independence and/or instructions	Variable
R26	Incomplete surface treatment (e.g. flooring, plastering, painting)	Lack of labor independence and/or instructions	Variable
R27	Inefficient tightness test (e.g. gas, air leakage, acoustics, heating system, drainage water)	Lack of labor independence and/or instructions	Variable

Table A 14. Probability estimation for each risk factor

Risk drivers	**Risk factors**	**Type of risk** Fixed (F) or Variable (V)	**Judgment on**		**Likelihood of occurrence (%)**
			Risk Type	Risk Driver	
Quantity					
	R1	F			
	R2	F			
	R3	V			100
	R4	V			100
	R10	V			100
	R11	V			100
	R12	F			
	R18	V			100
Unit cost					
	R5	F			
	R6	V			100
	R13	V			100
	R14	F			
	R15	F			
	R26	V			100
	R27	V			
Schedule					
	R16	F			
	R17	V			100
	R19	F			
	R20	F			
	R21	F			
	R24	V			100
	R25	V			100
Global					
	R7	V			100
	R8	V			100
	R9	F			
	R22	V			100
	R23	V			100

SECTION D: CONTACT INFORMATION

Think about your past experience within traditional tender processes for building projects. Consider how and why you share the risks enlisted and re-consider how slight changes in your margin profits could affect your risk-sharing arrangements with the client. If you would be willing to discuss in detail past projects experience and share successful or unsuccessful decisions in risk-sharing arrangements, please identify how you would like to be contacted.

☐ Telephone:____

☐ Email:____

☐ Visited by the researcher:____

☐ Other:____

Date:____

Personal full name:____

Organization name:____

THANK YOU FOR PARTICIPARING IN MY SURVEY!

Corporate stamp / Personal signature

____

____

~ This page was left intentionally blank for any further comments that participants may leave. ~

Comment: ____

Domain: ____

Advice on the questionnaire format: ____

Appendix 9 – Professional profile of survey participants

	Full name	Position hold	Activities involved	Company name	Corporate Experience (years)
1	xxx	xxx	xxx	xxx	≥ 20
2	xxx	xxx	xxx	xxx	≥ 20
3	xxx	xxx	xxx	xxx	15 – 19
4	xxx	xxx	xxx	xxx	10 – 14
5	xxx	xxx	xxx	xxx	< 5
6	xxx	xxx	xxx	xxx	≥ 20
7	xxx	xxx	xxx	xxx	n/a
8	xxx	xxx	xxx	xxx	n/a
9	xxx	xxx	xxx	xxx	≥ 20
10	xxx	xxx	xxx	xxx	< 5
11	xxx	xxx	xxx	xxx	n/a
12	xxx	xxx	xxx	xxx	10 – 14
13	xxx	xxx	xxx	xxx	5 – 9
14	xxx	xxx	xxx	xxx	10 – 14
15	xxx	xxx	xxx	xxx	≥ 20
16	xxx	xxx	xxx	xxx	≥ 20
17	xxx	xxx	xxx	xxx	≥ 20
18	xxx	xxx	xxx	xxx	5 – 9
19	xxx	xxx	xxx	xxx	5 – 9
20	xxx	xxx	xxx	xxx	n/a
21	xxx	xxx	xxx	xxx	≥20
22	xxx	xxx	xxx	xxx	15 – 19
23	xxx	xxx	xxx	xxx	≥ 20
24	xxx	xxx	xxx	xxx	< 5
25	xxx	xxx	xxx	xxx	15 – 19
26	xxx	xxx	xxx	xxx	n/a
27	xxx	xxx	xxx	xxx	10 – 14
28	xxx	xxx	xxx	xxx	n/a
29	xxx	xxx	xxx	xxx	n/a
30	xxx	xxx	xxx	xxx	< 5
31	xxx	xxx	xxx	xxx	≥ 20
32	xxx	xxx	xxx	xxx	Less than 5
33	xxx	xxx	xxx	xxx	≥ 20
34	xxx	xxx	xxx	xxx	≥ 20
35	xxx	xxx	xxx	xxx	10 – 14

*n/a: not available, no feedback was received
*T.S.A.: Technical Société Anonyme

Appendix 10 – Feedback status form

	Full name	Questionnaire delivered	Questionnaire received	Valid form	Geographical location
1	xxx	YES	YES	YES	Patras, GR
2	xxx	YES	YES	YES	Patras, GR
3	xxx	YES	YES	YES	Evia, GR
4	xxx	YES	YES	YES	Patras, GR
5	xxx	YES	YES	YES	Patras, GR
6	xxx	YES	YES	YES	Patras, GR
7	xxx	YES	NO	×	×
8	xxx	YES	NO	×	×
9	xxx	YES	YES	YES	Patras, GR
10	xxx	YES	YES	NO	Amfissa, GR
11	xxx	YES	NO	×	×
12	xxx	YES	YES	YES	Patras, GR
13	xxx	YES	YES	YES	Patras, GR
14	xxx	YES	YES	YES	Messenia, GR
15	xxx	YES	YES	NO	Patras, GR
16	xxx	YES	YES	YES	Patras, GR
17	xxx	YES	YES	YES	Patras, GR
18	xxx	YES	YES	NO	Corfu, GR
19	xxx	YES	YES	YES	Lamia, GR
20	xxx	YES	NO	×	×
21	xxx	YES	YES	YES	Patras, GR
22	xxx	YES	YES	YES	Patras, GR
23	xxx	YES	YES	YES	Patras, GR
24	xxx	YES	YES	NO	Patras, GR
25	xxx	YES	YES	YES	Patras, GR
26	xxx	YES	NO	×	×
27	xxx	YES	YES	YES	Komotini, GR
28	xxx	YES	NO	×	×
29	xxx	YES	NO	×	×
30	xxx	YES	YES	YES	Thessaloníki,GR
31	xxx	YES	YES	NO	Patras, GR
32	xxx	YES	YES	NO	Nafplio, GR
33	xxx	YES	YES	YES	Patras, GR
34	xxx	YES	YES	YES	Araxos, GR
35	xxx	YES	YES	YES	Patras, GR

(green)	**Valid** questionnaire
(orange)	**Invalid** questionnaire

Appendix 11 – SPSS Inputs & Results

"Variables view" tab

	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure	Role
1	Position	String	8	0		{1, Director ...	None	8	Left	Ordinal	Input
2	Company	String	8	0	Role	{1, Owner}...	None	8	Left	Nominal	Input
3	Volume	Numeric	8	3	Average	{1,000, Low}...	None	8	Left	Scale	Input
4	Projects	Numeric	8	2	Buildings comp...	{1,00, Low}...	None	8	Left	Scale	Input
5	Experience	Numeric	8	2	Company related	{1,00, Low}...	None	8	Left	Scale	Input
6	Packages	Numeric	8	2	Traditional bids	{1,00, Low}...	None	8	Left	Scale	Input
7	RMpersonnel	String	8	0	Performing RM	{1, A specia...	None	8	Left	Nominal	Input
8	Client_type	String	8	0		{1, Private}...	None	8	Left	Nominal	Input
9	Payment	String	8	0	Compensation ...	{1, Fixed fe...	None	8	Left	Nominal	Input
10	Participant_ID	Numeric	8	2	Contractors	None	None	8	Left	Nominal	Input

Frequency tables for each variable

Respondent's position

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Director or Executive	9	40,9	40,9	40,9
	Project manager	4	18,2	18,2	59,1
	In-house/Site engineer	8	36,4	36,4	95,5
	Procurement officer/Tender manager	1	4,5	4,5	100,0
	Total	22	100,0	100,0	

Company-related role

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Owner	1	4,5	4,5	4,5
	Contractor	12	54,5	54,5	59,1
	Subcontractor	3	13,6	13,6	72,7
	Construction manager	3	13,6	13,6	86,4
	Designer	3	13,6	13,6	100,0
	Total	22	100,0	100,0	

Average construction volume (in past 3 years)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Low	5	22,7	22,7	22,7
	Relative Low	8	36,4	36,4	59,1
	Medium	6	27,3	27,3	86,4
	Relative High	3	13,6	13,6	100,0
	Total	22	100,0	100,0	

Buildigs completed (in past 3 years)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Low	11	50,0	50,0	50,0
	Relative low	7	31,8	31,8	81,8
	Relative High	3	13,6	13,6	95,5
	High	1	4,5	4,5	100,0
	Total	22	100,0	100,0	

Company-related experience

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Low	3	13,6	13,6	13,6
	Relative Low	1	4,5	4,5	18,2
	Medium	6	27,3	27,3	45,5
	Relative High	2	9,1	9,1	54,5
	High	10	45,5	45,5	100,0
	Total	22	100,0	100,0	

Traditional bid packages (per year)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Low	13	59,1	59,1	59,1
	Relative Low	7	31,8	31,8	90,9
	Medium	2	9,1	9,1	100,0
	Total	22	100,0	100,0	

RM personnel

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	A specialized personnel team	3	13,6	13,6	13,6
	A senior (external/internal) consultant	2	9,1	9,1	22,7
	Informal system	11	50,0	50,0	72,7
	No use of RM staff	6	27,3	27,3	100,0
	Total	22	100,0	100,0	

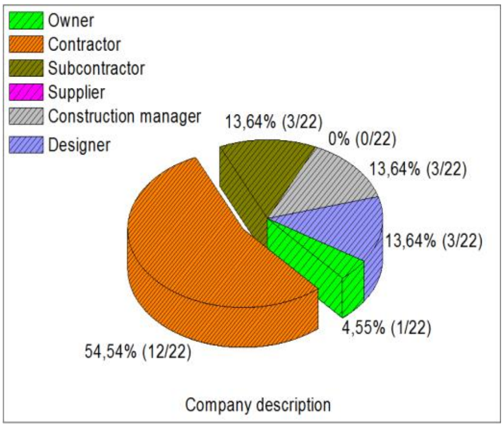
Client_type

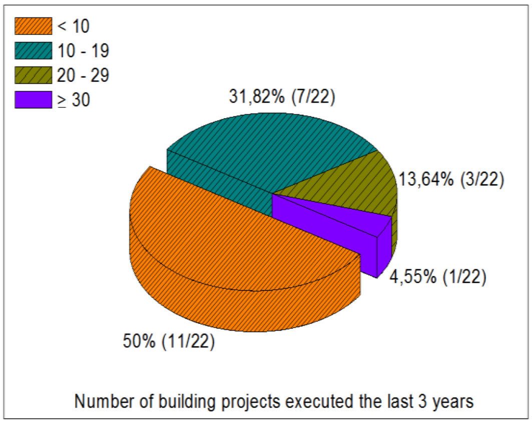
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Private	16	72,7	72,7	72,7
	Public	6	27,3	27,3	100,0
	Total	22	100,0	100,0	

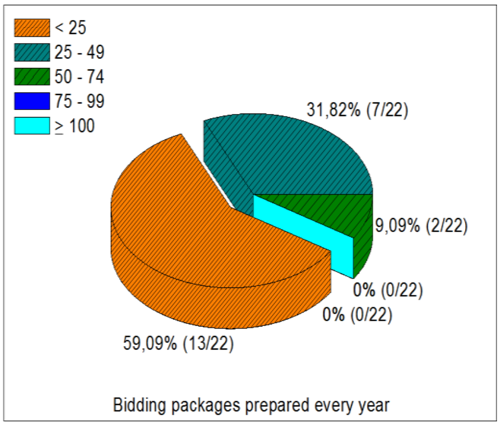
Compensation mechanism

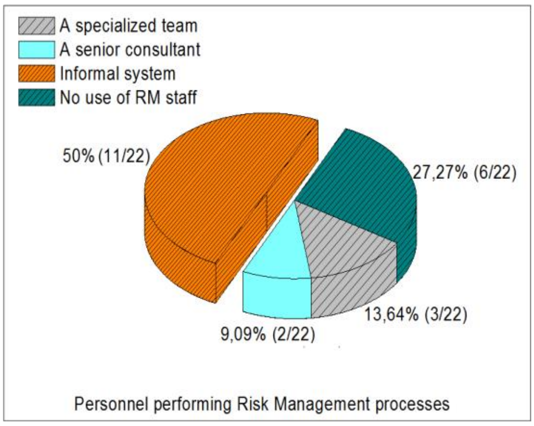
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Fixed fee	8	36,4	36,4	36,4
	Cost reimbursable	6	27,3	27,3	63,6
	Lump-sum	1	4,5	4,5	68,2
	Unit-price	6	27,3	27,3	95,5
	Performance-bssed	1	4,5	4,5	100,0
	Total	22	100,0	100,0	

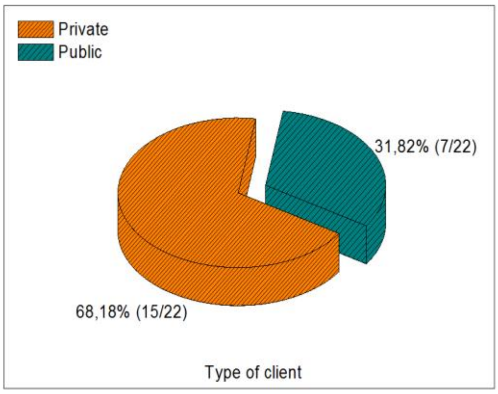
Appendix 12 – Organizational characteristics

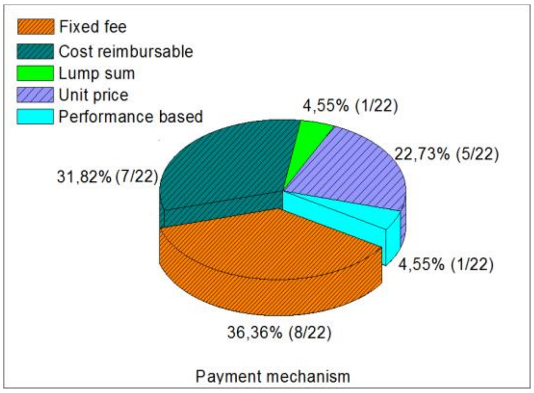












Appendix 13 – Experts validation form & panel

Please consider the following questions. All these questions aim to evaluate the extent to which the survey instrument designed is compatible with both researcher's and potential participants' abilities to fully present and support the particular problem. For every item, **please check (√) only one score ranging from 1 to 4**, in the table provided below.

Researcher (Information source)

Item 1: Communication
"Does the researcher minimize the information transfer gaps and assist participants in understanding risk sharing and risk management concepts?"

Item 2: Self-efficacy
"Does the researcher possess the required knowledge and confidence to clearly present on paper, by providing elaborations and examples, the qualitative and quantitative context of the questionnaire?"

Problem (Task)

Item 3: Complexity
"Do you consider the steps of the delivered questionnaire demanding in terms of time-effort relation?"

Item 4: Importance

4.1 "Do you consider valuable the final outcome of the research to your organization?"
4.2 "Did it help you in understanding past or present decisions in traditional cost estimation practices and risk-sharing decisions?"
4.3 If the method proposed was tailored to your company-specific strategy, would you adopt it?

Participant (Information seeker)

Item 5: Comprehension
"Do you consider the structuring of the form logical and compatible to your personal thinking capabilities?"

Questionnaire design

Item 6: Ambiguity

6.1 "Do you think the mathematical terms and managerial concepts selected make sense in the study?"
6.2 "In case of any improvements required, what would you change?"
6.3 "Do you think that the writing style was eliminating repeated notions?"

Item 7: Clarity

7.1 "Do you consider the description language of relationships, viewpoints and activities intuitive enough?
7.2 "In case of any improvements required, what would you change?"

Scoring (from 1 to 4) the seven validation items

	Not relevant	Somewhat relevant	Quite relevant	Highly relevant
Scale / **Items**	1	2	3	4
Communication				
Self-efficacy				
Complexity				
Importance				
Comprehension				
Ambiguity				
Clarity				

Profiles of external validation panel's members

Full name (Anonymity was required)	**Organization**	**Role**	**Educational background**	**Professional experience** (years)
Rater 1	Public Urban Planning Department (Patras, GR)	Chief tender manager	BSc in Economics MSc in Infrastructure Management	18
Rater 2	G. Moschonas T.S.A. (Patras, GR)	CEO & Principal design engineer	MEng in Civil Engineering	28
Rater 3	TRIAINA S.A. (Patras, GR)	Architect	MEng in Architecture	21
Rater 4	Public Urban Planning Department (Zakynthos, GR)	Building energy inspector	BSc in Civil Engineering	22
Rater 5	DOSSEK T.S.A. (Patras, GR)	CEO & Principal design engineer	BSc in Civil Engineering MSc in Design & Analysis of Earthquake Structures	20

Appendix 14 – Reliability statistics

Pearson Product-Moment correlation test results

		Var.3	Var.4	Var.5	Var.6
Var.3: Average volume	Pearson Correlation	1	,646**	,630**	,534*
	Sig. (2-tailed)		,001	,002	,010
	N	22	22	22	22
Var.4: Buildings completed	Pearson Correlation	,646**	1	,299	,642**
	Sig. (2-tailed)	,001		,177	,001
	N	22	22	22	22
Var.5: Company experience	Pearson Correlation	,630**	,299	1	,267
	Sig. (2-tailed)	,002	,177		,230
	N	22	22	22	22
Var.6: Traditional bid packages	Pearson Correlation	,534*	,642**	,267	1
	Sig. (2-tailed)	,010	,001	,230	
	N	22	22	22	22

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Spearman rank correlation test results

		Var.3	Var.4	Var.5	Var.6
Var.3: Average volume	Spearman Correlation	1	,603**	,648**	,439*
	Sig. (2-tailed)		,003	,001	,041
	N	22	22	22	22
Var.4: Buildings completed	Spearman Correlation	,603**	1	,277	,550**
	Sig. (2-tailed)	,003		,211	,008
	N	22	22	22	22
Var.5: Company experience	Spearman Correlation	,648**	,277	1	,219
	Sig. (2-tailed)	,001	,211		,328
	N	22	22	22	22
Var.6: Traditional bid packages	Spearman Correlation	,439*	,550**	,219	1
	Sig. (2-tailed)	,041	,008	,328	
	N	22	22	22	22

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Internal consistency test results – Cronbach's alpha

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Item	N of Items
,75	,80	

Inter-item correlation matrix

	Var.3	Var.4	Var.5	Var.6
Var.3: Average volume	1,000	,646	,630	,534
Var.4: Buildings completed	,646	1,000	,299	,642
Var.5: Company experience	,630	,299	1,000	,267
Var.6: Traditional bid packages	,534	,642	,267	1,000

Item-total correlation test

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation	Cronbach's Alpha if Item Deleted
Average	6,9090	5,42	,79	,63	,56
Buildings completed	7,5000	6,64	,58	,55	,69
Company related	5,5454	4,83	,48	,41	,81
Traditional bids	7,7272	7,63	,53	,43	,73

Intra-class coefficient values

	Intraclass Correlation[b]	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Sig
Single Measures	,439	,22	,66	4,13	2	6	,00
Average Measures	,758	,53	,88	4,13	2	6	,00

Two-way mixed effects model where people effects are random and measures effects are fixed.

a. The estimator is the same, whether the interaction effect is present or not.

b. Type C intraclass correlation coefficients using a consistency definition-the between-measure variance is excluded from the denominator variance.

c. This estimate is computed assuming the interaction effect is absent, because it is not estimable otherwise.

Appendix 15 – Simulation results

Participant 1

	Pre-ΔM condition			Post- ΔM decision			
ΔM (%)	**b (%)**	**E (€)**	**C (€)**	**b' (%)**	**E' (€)**	**C' (€)**	**Δb (%)**
-15	8.75	52500	62755	13	46500	53705.68	4.25
-1	8.6	70000	77562.70	13,6	62000	68858.87	5
-1	10	87500	98098.98	18,3	77500	86936.80	8.3
-1	16	52500	52792.41	27	46500	46750.86	11
-10	5	87500	94467.05	12.5	77500	84512.90	7.5

Probability density function

Condition: Pre-ΔM decision	**Base (E) estimate (€)**	**Probability distribution fitted**	**Probability (%) meeting/under-running the E: P(X≤E)**	**Expected cost (C): mean from PDF simulated (€)**	**Higher estimation on base estimate (%)**
Land preparation	54250	Beta Gen.	13.50	62755	15.67
Earthworks	70000	Beta Gen.	20.36	77562.70	10.80
Substructure	87500	Normal	11.91	98098.98	12.11
Superstructure	52500	Normal	41	52792.41	0.55
Finishes	86625	Normal	18.86	94467.05	9.05
Final Project	350875	Normal	77	385676.13	9.92

Cumulative distribution

Condition: Pre-ΔM decision	**Expected confidence level (50%+Overall risks effect%)**	**Expected estimation at this confidence level (€)**	**Contingency set (€) = Exp. Estimation - Base estimate**	**Contingency on the base estimate (%)**
Land preparation	50+18.74=68.74	65702.95	11452.95	21.11
Earthworks	50+14.15=64.15	79949.68	9949.68	14.21
Substructure	50+13.23=63.23	101568	14068	16.08
Superstructure	50+1.73=51.73	52817.85	317.85	0.605
Finishes	50+9.14=59.14	96590.04	9965.04	11.5
Final Project	50+11.4=61.4	390378.4	39503.4	11.26

Probability density function

Condition: Post-ΔM decision	**Base (E) estimate (€)**	**Probability distribution fitted**	**Probability (%) meeting/under-running the E: P(X≤E)**	**Expected cost (C): mean from PDF simulated (€)**	**Higher estimation on base estimate (%)**
Land preparation	46500	Beta Gen.	11.9	53705.68	15.5
Earthworks	62000	Beta Gen.	21.23	68858.87	11.06
Substructure	77500	Beta Gen.	21.53	86936.80	12.17
Superstructure	46500	Normal	41.23	46750.86	0.54
Finishes	77500	Beta Gen.	52.42	84512.90	9.05
Final Project	310000	Normal	50.27	340765.11	9.92

Cumulative distribution

Condition: Post-ΔM decision	**Expected confidence level (50%+Overall risks effect%)**	**Expected estimation at this confidence level (€)**	**Contingency set (€) = Exp. Estimation - Base estimate**	**Contingency on the base estimate (%)**
Land preparation	50+18.74=68.74	55907	9407	20.23
Earthworks	50+14.15=64.15	71006.5	9006	14.53
Substructure	50+13.23=63.23	89753.1	12253.1	15.81
Superstructure	50+1.73=51.73	46772.2	272.2	0.58
Finishes	50+9.14=59.14	86333.2	8833.2	11.39
Final Project	50+11.4=61.4	344779.2	34779.2	11.22

Participant 2

	Pre-ΔM condition			Post- ΔM decision			
ΔM (%)	**b (%)**	**E (€)**	**C (€)**	**b' (%)**	**E' (€)**	**C' (€)**	**Δb (%)**
-55	32.5	25000	30904.68	19	20000	24735.97	-13.5
-32	73.6	60000	66311.95	65.7	56000	61855.81	-7.9
-50	46.7	18000	19817.06	34	48000	52875.73	-12.7
-37	69	130000	126249.81	58	120000	116842.10	-11
-52	85	267000	525257.74	81.25	216000	227786,96	-3.75

Probability density function

Condition: Pre-ΔM decision	**Base (E) estimate (€)**	**Probability distribution fitted**	**Probability (%) meeting/under-running the E: P(X≤E)**	**Expected cost (C): mean from PDF simulated (€)**	**Higher estimation on base estimate (%)**
Land preparation	25000	Beta Gen.	23.27	30904.68	23.616
Earthworks	60000	Beta Gen.	30.34	66311.95	10.52
Substructure	18000	Beta Gen.	38.44	19817.06	10.09
Superstructure	130000	Weibull	62.72	126249.24	×
Finishes	267000	Normal	34.95	281974.81	5.61
Final Project	500000	Normal	27.25	525257.74	5.05

Cumulative distribution

Condition: Pre-ΔM decision	**Expected confidence level (50%+Overall risks effect%)**	**Expected estimation at this confidence level (€)**	**Contingency set (€) = Exp. Estimation - Base estimate**	**Contingency on the base estimate (%)**
Land preparation	50+26.09=76.09	34028.02	9028.02	36.11
Earthworks	50+13.54=63.54	69585.93	9585.93	15.97
Substructure	50+10.83=60.83	20502.21	2502.21	13.9
Superstructure	50-1.30=48.70	126010.90	-3989	×
Finishes	50+5.67=55.67	292607.20	25607.20	9.6
Final Project	50+10.97=60.97	537358.42	37358.42	7.47

Probability density function

Condition: Post-ΔM decision	Base (E) estimate (€)	Probability distribution fitted	Probability (%) meeting/under-running the E: P(X≤E)	Expected cost (C): mean from PDF simulated (€)	Higher estimation on base estimate (%)
Land preparation	20000	Gamma	52.19	24735.97	23.68
Earthworks	56000	Normal	25.82	61855.81	10.45
Substructure	48000	Beta Gen.	32.94	52875.73	10.16
Superstructure	120000	Weibull	61.52	116842.10	×
Finishes	216000	Normal	35.51	227786.96	5.45
Final Project	460000	Normal	25.2	483751.30	5.16

Cumulative distribution

Condition: Post-ΔM decision	Expected confidence level (50%+Overall risks effect%)	Expected estimation at this confidence level (€)	Contingency set (€) = Exp. Estimation - Base estimate	Contingency on the base estimate (%)
Land preparation	50+26.09=76.09	27608.022	7608	38.04
Earthworks	50+13.54=63.54	64908.58	8908.6	15.91
Substructure	50+10.83=60.83	54800.23	6800.23	14.17
Superstructure	50-1.30=48.70	116444.3	-3555.7	×
Finishes	50+5.67=55.67	231939.74	15939.74	7.12
Final Project	50+10.97=60.97	497290.02	37290.02	8.11

Participant 3

	Pre-ΔM condition			Post- ΔM decision			
ΔM (%)	**b (%)**	**E (€)**	**C (€)**	**b' (%)**	**E' (€)**	**C' (€)**	**Δb (%)**
-5	58.75	19000	21346.60	58	21210	23573.90	-0.75
-20	22.14	38000	39766.27	17.14	36000	37564.05	-5
-20	15	95000	98956.98	9.2	75000	77952.99	-5.8
-25	20	114000	104974.27	11	84000	77512.33	-9
-30	25	114000	113256.76	6.3	84000	83082.33	-18.7

Probability density function

Condition: Pre-ΔM decision	**Base (E) estimate (€)**	**Probability distribution fitted**	**Probability (%) meeting/under-running the E: P(X≤E)**	**Expected cost (C): mean from PDF simulated (€)**	**Higher estimation on base estimate (%)**
Land preparation	19190	Beta Gen.	23.41	21346.3	11.24
Earthworks	38000	Beta Gen.	45.57	39766.27	4.6
Substructure	95000	Normal	36.50	98956.98	4.16
Superstructure	114000	Beta Gen.	88.08	104974.27	×
Finishes	114000	Weibull	52.15	113256.76	×
Final Project	380000	Normal	57.64	376140.73	×

Cumulative distribution

Condition: Pre-ΔM decision	**Expected confidence level (50%+Overall risks effect%)**	**Expected estimation at this confidence level (€)**	**Contingency set (€) = Exp. Estimation - Base estimate**	**Contingency on the base estimate (%)**
Land preparation	50+13.25=63.25	21997.75	2807.75	14.63
Earthworks	50+6.4=56.4	40541.8	2541.8	6.68
Substructure	50+3.99=54	99945.5	4946.5	5.21
Superstructure	50-7.77=42.23	103881.04	×	×
Finishes	50-0.88=49.12	113394.94	×	×
Final Project	50+12.99=63	383134.93	3134.93	0.825

Probability density function

<u>Condition:</u> Post-ΔM decision	**Base (E) estimate (€)**	**Probability distribution fitted**	**Probability (%) meeting/under-running the E: P(X≤E)**	**Expected cost: mean PDF from simulated (€)**	**Higher estimation on base estimate (%)**
Land preparation	21210	Beta Gen.	20.21	23573.9	11.14
Earthworks	36000	Normal	37.33	37564.05	4.34
Substructure	75000	Beta Gen.	43.97	77952.99	3.94
Superstructure	84000	Beta Gen.	85.78	77512.33	×
Finishes	84000	Weibull	53.60	83082.33	×
Final Project	300000	Normal	50.80	299685.28	×

Cumulative distribution

<u>Condition:</u> Post-ΔM decision	**Expected confidence level (50 % + Overall risks effect %)**	**Expected estimation at this confidence level (€)**	**Contingency set (€) = Exp. Estimation - Base estimate**	**Contingency on the base estimate (%)**
Land preparation	50+13.25=63.25	24370.36	3160	14.9
Earthworks	50+6.4=56.4	38229.34	2229.34	6.2
Substructure	50+3.99=54	78785.95	3785	5.05
Superstructure	50-7.7742.23	76709.47	×	×
Finishes	50-0.88=49.12	83141.84	×	×
Final Project	50+12.998=63	305439.93	5439.93	1.81

Participant 4

	Pre-ΔM condition			Post- ΔM decision			
ΔM (%)	b (%)	E (€)	C (€)	b' (%)	E' (€)	C' (€)	Δb (%)
-15	73.5	38250	42489.12	24	31950	35428.15	-13.5
-15	14.3	89250	94807.58	7.14	85200	90542.24	-7.14
-10	13	51000	53793.03	8.33	42600	45178.49	-4.7
-6	27	63750	63865.38	22	42600	42710.98	-5
-25	65	12750	12893.45	56.25	10650	10765.05	-8.75

Probability density function

Condition: Pre-ΔM decision	**Base (E) estimate (€)**	**Probability distribution fitted**	**Probability (%) meeting/under-running the E: P(X≤E)**	**Expected cost (C): mean from PDF simulated (€)**	**Higher estimation on base estimate (%)**
Land preparation	38250	Beta Gen.	35.08	42489.12	11.08
Earthworks	89250	Weibull	34.17	94807.58	6.22
Substructure	51000	Weibull	35.22	53793.03	5.47
Superstructure	63750	Normal	48.51	63865.38	0.18
Finishes	12750	Beta Gen.	51.48	12893.45	1.12
Final Project	255000	Normal	22.51	267848.55	5.03

Cumulative distribution

Condition: Pre-ΔM decision	**Expected confidence level (50%+Overall risks effect%)**	**Expected estimation at this confidence level (€)**	**Contingency set (€) = Exp. Estimation - Base estimate**	**Contingency on the base estimate (%)**
Land preparation	50+12.59=62.59	44442.57	6192.57	16.19
Earthworks	50+8.1=58.10	97413.78	8163.78	9.15
Substructure	50+5.91=54	55012.77	4012.77	7.87
Superstructure	50+0.48=50.48	63892.02	142.02	0.22
Finishes	50+1.12=51.12	12940.5	190.50	1.49
Final Project	50+12.99=63	270057.82	15057.82	5.9

Probability density function

Condition: Post-ΔM decision	**Base (E) estimate (€)**	**Probability distribution fitted**	**Probability (%) meeting/under-running the E: P(X≤E)**	**Expected cost: mean from PDF simulated (€)**	**Higher estimation on base estimate (%)**
Land preparation	31950	Beta Gen.	34.12	35428.15	10.88
Earthworks	85200	Weibull	33.12	90542.24	6.27
Substructure	42600	Beta Gen.	41.21	45178.49	6.05
Superstructure	42600	Normal	47.66	42710.98	0.26
Finishes	10650	Beta Gen.	52.83	10765.05	1.08
Final Project	213000	Normal	21.61	224624.91	5.46

Cumulative distribution

Condition: Post-ΔM decision	**Expected confidence level (50 % + Overall risks effect %)**	**Expected estimation at this confidence level (€)**	**Contingency set (€) = Exp. Estimation - Base estimate**	**Contingency on the base estimate (%)**
Land preparation	50+12.59=62.59	37088.54	5138.54	16.08
Earthworks	50+8.1=58.10	93010.97	7810.97	9.17
Substructure	50+5.91=54	46175.14	3575.14	8.39
Superstructure	50+0.48=50.48	42709.83	109.83	0.26
Finishes	50+1.12=51.12	10812.88	162.88	1.53
Final Project	50+12.99=63	226607.94	13607.94	6.39

Participant 5

	Pre-ΔM condition			Post- ΔM decision			
ΔM (%)	**b (%)**	**E (€)**	**C (€)**	**b' (%)**	**E' (€)**	**C' (€)**	**Δb (%)**
-5	18.75	16500	16755.52	7	15290	15563.34	-11.75
-18	29.3	66000	66749.55	17.9	61160	61912.86	-11.4
-10	60	115500	117125.26	41.3	107030	108804.21	-18.7
-3	14	82500	82825.04	8	76450	76741	-6
-1	10	49500	49991.90	2.5	45870	46391.31	-7.5

Probability density function

Condition: Pre-ΔM decision	**Base (E) estimate (€)**	**Probability distribution fitted**	**Probability (%) meeting/under-running the E: P(X≤E)**	**Expected cost (C): mean from PDF simulated (€)**	**Higher estimation on base estimate (%)**
Land preparation	16500	Beta Gen.	47.37	16775.52	1.67
Earthworks	66000	Weibull	47.43	66749.55	1.13
Substructure	115500	Weibull	46.74	117125.26	1.41
Superstructure	82500	Beta Gen.	45.92	82825.04	0.394
Finishes	49500	Beta Gen.	53.92	49991.90	0.993
Final Project	330000	Weibull	44.32	333467.27	1.05

Cumulative distribution

Condition: Pre-ΔM decision	**Expected confidence level (50%+Overall risks effect%)**	**Expected estimation at this confidence level (€)**	**Contingency set (€) = Exp. Estimation - Base estimate**	**Contingency on the base estimate (%)**
Land preparation	50+2.29=52.29	17054.34	554.34	3.36
Earthworks	50+1.70=51.70	67499.38	1499.38	2.27
Substructure	50+1.53=51.53	118374.72	2874.72	2.48
Superstructure	50+0.52=50.52	82845.58	345.58	0.42
Finishes	50+1.12=51.12	50264.50	764.50	1.54
Final Project	50+1.43=51.43	334601.73	4601.73	1.39

Probability density function

Condition: **Post-ΔM decision**	**Base (E) estimate (€)**	**Probability distribution fitted**	**Probability (%) meeting/under-running the E: P(X≤E)**	**Expected cost (C): mean from PDF simulated (€)**	**Higher estimation on base estimate (%)**
Land preparation	15290	Beta Gen.	51.19	15563.54	1.79
Earthworks	61160	Weibull	47.19	61912.86	1.23
Substructure	107030	Beta Gen.	46.15	108804.21	1.66
Superstructure	76450	Normal	46.67	76741	0.38
Finishes	45870	Beta Gen.	46.16	46391.31	1.13
Final Project	305800	Normal	43.65	309412.91	1.18

Cumulative distribution

Condition: **Post-ΔM decision**	**Expected confidence level (50 % + Overall risks effect %)**	**Expected estimation at this confidence level (€)**	**Contingency set (€) = Exp. Estimation - Base estimate**	**Contingency on the base estimate (%)**
Land preparation	50+2.29=52.29	15518.05	228.05	1.49
Earthworks	50+1.70=51.70	62755.96	1595.96	2.61
Substructure	50+1.53=51.53	110249.94	3219.94	3.01
Superstructure	50+0.52=50.52	76832.35	382.35	0.5
Finishes	50+1.12=51.12	46621.38	751.38	1.64
Final Project	50+1.43=51.43	310922.38	5122.38	1.67

Participant 6

	Pre-ΔM condition			Post- ΔM decision			
ΔM (%)	b (%)	E (€)	C (€)	b' (%)	E' (€)	C' (€)	Δb (%)
-15	4.25	18750	19269.59	9.4	15000	15309.26	5.15
-25	7.14	37500	38380.12	2.14	25000	25625.94	-5
-25	38.33	28125	28783.16	15.83	25000	25628.28	-22.50
-25	34	28125	28333.24	13	25000	25171.75	-21
-10	40	12500	12840.56	53.75	10000	10264.44	+13.75

Probability density function

Condition: Pre-ΔM decision	**Base (E) estimate (€)**	**Probability distribution fitted**	**Probability (%) meeting/under-running the E: P(X≤E)**	**Expected cost (C): mean from PDF simulated (€)**	**Higher estimation on base estimate (%)**
Land preparation	18750	Beta Gen.	54.81	19269.59	2.77
Earthworks	37500	Weibull	68.32	38380.12	2.35
Substructure	28125	Beta Gen.	58.33	28783.16	2.34
Superstructure	28125	Beta Gen.	54.25	28333.24	0.74
Finishes	12500	Beta Gen.	54.78	12840.56	2.72
Final Project	125000	Normal	41.19	127607.27	2.085

Cumulative distribution

Condition: Pre-ΔM decision	**Expected confidence level (50%+Overall risks effect%)**	**Expected estimation at this confidence level (€)**	**Contingency set (€) = Exp. Estimation - Base estimate**	**Contingency on the base estimate (%)**
Land preparation	50+3.41=53.41	19905.48	1155.48	6.16
Earthworks	50+3.06=53.06	39374.15	1874.15	4.99
Substructure	50+3.08=53.08	29409.47	1284.47	4.56
Superstructure	50+0.95=50.95	28506.50	381.5	1.35
Finishes	50+2.73=52.73	13096.79	596.79	4.77
Final Project	50+2.65=52.65	128548.68	3548.68	2.83

Probability density function

<u>Condition:</u> **Post-ΔM decision**	**Base (E) estimate (€)**	**Probability distribution fitted**	**Probability (%) meeting/under-running the E: P(X≤E)**	**Expected cost (C): mean from PDF simulated (€)**	**Higher estimation on base estimate (%)**
Land preparation	15000	Beta Gen.	51.95	15309.26	2.06
Earthworks	25000	Beta Gen.	52.42	25625.94	2.50
Substructure	25000	Beta Gen.	56.53	25628.28	2.51
Superstructure	25000	Beta Gen.	49.97	25171.75	0.68
Finishes	10000	Weibull	43.67	10264.44	2.64
Final Project	100000	Normal	40.88	101999.68	1.99

Cumulative distribution

<u>Condition:</u> **Post-ΔM decision**	**Expected confidence level (50 % + Overall risks effect %)**	**Expected estimation at this confidence level (€)**	**Contingency set (€) = Exp. Estimation - Base estimate**	**Contingency on the base estimate (%)**
Land preparation	50+3.41=53.41	15817.67	817.67	5.45
Earthworks	50+3.06=53.06	26252.36	1252.36	5.01
Substructure	50+3.08=53.08	26140.12	1140.12	4.56
Superstructure	50+0.95=50.95	25222.14	222.14	0.89
Finishes	50+2.73=52.73	10456.48	456.48	4.56
Final Project	50+2.65=52.65	102748.53	2748.53	2.75

Participant 7

	Pre-ΔM condition			Post- ΔM decision			
ΔM (%)	**b (%)**	**E (€)**	**C (€)**	**b' (%)**	**E' (€)**	**C' (€)**	**Δb (%)**
-15	14	42750	43481.28	28	47067	48472.29	14
-25	10	71250	78265.60	25	78445	86265.20	15
-25	25.8	57000	61278.27	38.8	62756	67343.05	13
-25	22	85500	93954.73	29	94134	103508.10	7
-10	7.5	28500	32081.30	11.25	31378	35271.85	3.75

Probability density function

Condition: Pre-ΔM decision	**Base (E) estimate (€)**	**Probability distribution fitted**	**Probability (%) meeting/under-running the E: P(X≤E)**	**Expected cost (C): mean from PDF simulated (€)**	**Higher estimation on base estimate (%)**
Land preparation	42750	Weibull	45.89	43481.28	1.71
Earthworks	71250	Weibull	25.35	78265.60	9.84
Substructure	57000	Beta Gen.	42.08	61278.27	7.50
Superstructure	85500	Beta Gen.	8.90	93954.73	9.88
Finishes	28500	Beta Gen.	26.86	32081.30	12.56
Final Project	285000	Normal	8.36	309061.18	8.44

Cumulative distribution

Condition: Pre-ΔM decision	**Expected confidence level (50%+Overall risks effect%)**	**Expected estimation at this confidence level (€)**	**Contingency set (€) = Exp. Estimation - Base estimate**	**Contingency on the base estimate (%)**
Land preparation	50+2.28=52.28	44147.37	1397.37	3.27
Earthworks	50+10.96=60.96	81743.11	10493.11	14.73
Substructure	50+8.30=58.30	63338.53	6338.53	11.12
Superstructure	50+13.14=63.14	95710.70	10210.7	11.94
Finishes	50+12.53=62.53	33434.86	4934.86	17.31
Final Project	50+9.44=59.44	313139.81	28139.81	9.87

Probability density function

Condition: Post-ΔM decision	**Base (E) estimate (€)**	**Probability distribution fitted**	**Probability (%) meeting/under-running the E: P(X≤E)**	**Expected cost (C): mean from PDF simulated (€)**	**Higher estimation on base estimate (%)**
Land preparation	47067	Laplace	49.22	48472.29	2.98
Earthworks	78445	Weibull	25.83	86265.20	9.97
Substructure	62756	Beta Gen.	42.05	67343.05	7.31
Superstructure	94134	Beta Gen.	8.36	103508.10	9.96
Finishes	31378	Beta Gen.	30.18	35271.85	12.41
Final Project	313780	Logistic	17.51	340860.49	8.63

Cumulative distribution

Condition: Post-ΔM decision	**Expected confidence level (50 % + Overall risks effect %)**	**Expected estimation at this confidence level (€)**	**Contingency set (€) = Exp. Estimation - Base estimate**	**Contingency on the base estimate (%)**
Land preparation	50+2.28=52.28	49729.84	2662.84	5.66
Earthworks	50+10.96=60.96	89870.63	1142.63	14.56
Substructure	50+8.30=58.30	69663.92	6907.92	11.01
Superstructure	50+13.14=63.14	105391	11257.01	11.96
Finishes	50+12.53=62.53	36789.62	5411.62	17.24
Final Project	50+9.44=59.44	347600.8	33820.82	10.78

Participant 21

	Pre-ΔM condition			Post- ΔM decision			
ΔM (%)	**b (%)**	**E (€)**	**C (€)**	**b' (%)**	**E' (€)**	**C' (€)**	**Δb (%)**
-2	48	277.5	280.30	54	271.95	271.90	6
-2	58.6	9990	10083.58	63.6	9790.20	9870.88	5
-2	76.7	68820	86130.84	77.5	67443.60	84420.95	0.8
-2	100	155400	174536.50	100	152292	171698.43	0
-2	100	320512.50	437732.50	100	314102.3	429427.34	0

Probability density function

Condition: **Pre-ΔM decision**	**Base (E) estimate (€)**	**Probability distribution fitted**	**Probability (%) meeting/under-running the E: P(X≤E)**	**Expected cost (C): mean from PDF simulated (€)**	**Higher estimation on base estimate (%)**
Land preparation	277.5	Beta Gen.	47	280.3	2.03
Earthworks	9990	Weibull	46.3	10083.58	1.44
Substructure	68820	Gamma	24.9	86130.84	26.42
Superstructure	155400	Pearson5	28	174536.5	14.61
Finishes	320512.5	Weibull	20.9	437732.5	42.26
Final Project	555000	Weibull	32.4	708703.8	28.86

Cumulative distribution

Condition: **Pre-ΔM decision**	**Expected confidence level (50%+Overall risks effect%)**	**Expected estimation at this confidence level (€)**	**Contingency set (€) = Exp. Estimation - Base estimate**	**Contingency on the base estimate (%)**
Land preparation	50+1.55=51.55	283.11	8.38	3.05
Earthworks	50+0.94=50.94	10151.16	211.11	2.12
Substructure	50+29.66=79.66	107206.3	39074.48	57.35
Superstructure	50+25.49=75.49	194110.97	41818.97	27.46
Finishes	50+36.39=86.39	593318.6	2377.85	47.56
Final Project	50+18.80=68.80	778178	228178.03	41.49

Probability density function

Condition: Post-ΔM decision	**Base (E) estimate (€)**	**Probability distribution fitted**	**Probability (%) meeting/under-running the E: P(X≤E)**	**Expected cost (C): mean from PDF simulated (€)**	**Higher estimation on base estimate (%)**
Land preparation	271.95	Beta Gen.	46.9	274.90	1.08
Earthworks	9790.2	Beta Gen.	47.2	9870.88	0.82
Substructure	67443.6	Gamma	24.5	84420.95	25.17
Superstructure	152292	Pearson5	27.8	171698.43	12.74
Finishes	314102.3	Gamma	20.2	429427.34	36.72
Final Project	543900	Weibull	15.2	695692.61	27.91

Cumulative distribution

Condition: Post-ΔM decision	**Expected confidence level (50 % + Overall risks effect %)**	**Expected estimation at this confidence level (€)**	**Contingency set (€) = Exp. Estimation - Base estimate**	**Contingency on the base estimate (%)**
Land preparation	50+1.55=51.55	277.71	5.76	2.12
Earthworks	50+0.94=50.94	9925.41	135.21	1.38
Substructure	50+29.66=79.66	105005.15	37561.55	55.69
Superstructure	50+25.49=75.49	191125.82	38833.82	25.50
Finishes	50+36.39=86.39	583464.08	269361.8	85.76
Final Project	50+18.80=68.80	762669.20	218769.2	40.22

Participant 22

	Pre-ΔM condition			Post- ΔM decision			
ΔM (%)	b (%)	E (€)	C (€)	b' (%)	E' (€)	C' (€)	Δb (%)
+2	20	25000	26634.82	20	21440	22862.06	0
-5	14.3	10000	10338.15	14.3	24120	24965.93	0
-5	16.7	10000	13046.42	16.7	24120	31127.76	0
-5	20	67500	75353.14	20	91120	99059.67	0
+15	25	137500	200853.98	25	107200	154773.51	0

Probability density function

Condition: Pre-ΔM decision	**Base (E) estimate (€)**	**Probability distribution fitted**	**Probability (%) meeting/under-running the E: P(X≤E)**	**Expected cost (C): mean from PDF simulated (€)**	**Higher estimation on base estimate (%)**
Land preparation	25000	Beta Gen.	22.3	26634.82	6.54
Earthworks	10000	Beta Gen.	41.7	10338.15	3.38
Substructure	10000	Beta Gen.	32.2	13046.42	30.46
Superstructure	67500	Laplace	42.7	75353.14	11.63
Finishes	137500	Weibull	29.2	200853.98	46.08
Final Project	250000	Weibull	26.4	324226.62	29.69

Cumulative distribution

Condition: Pre-ΔM decision	**Expected confidence level (50%+Overall risks effect%)**	**Expected estimation at this confidence level (€)**	**Contingency set (€) = Exp. Estimation - Base estimate**	**Contingency on the base estimate (%)**
Land preparation	50+8.07=58.07	27131.22	2131.22	8.52
Earthworks	50+4.59=54.59	10558.77	558.77	5.59
Substructure	50+35.54=85.54	19740.22	9740.22	97.40
Superstructure	50+23.46=73.46	79952.49	12452.49	18.45
Finishes	50+46.344=96.344	410264.6	272764.55	198.37
Final Project	50+23.6=73.6	395178.4	145178.44	58.07

Probability density function

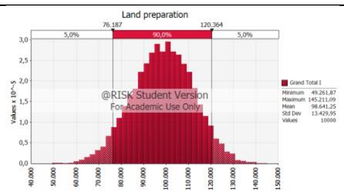
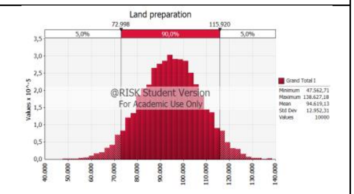
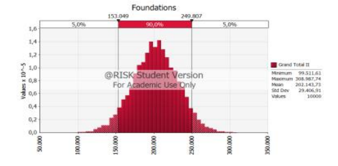
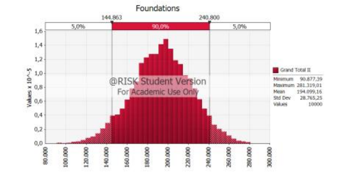
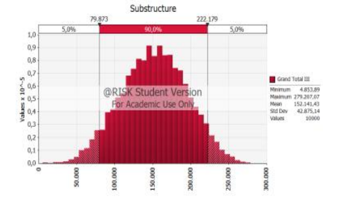
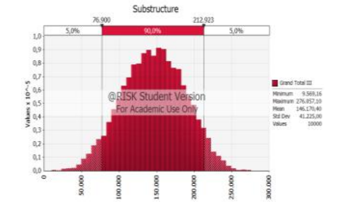
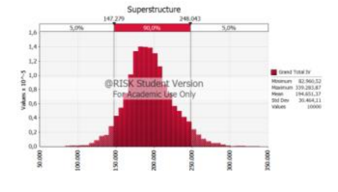
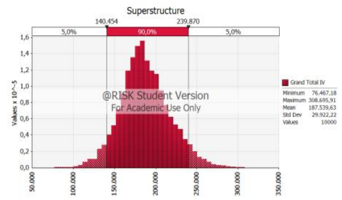
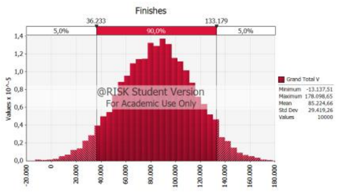
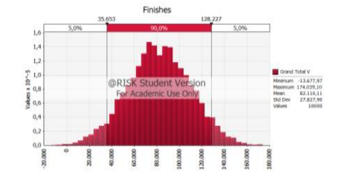
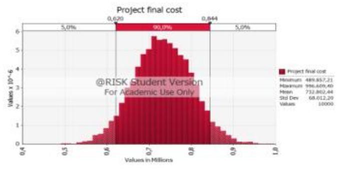
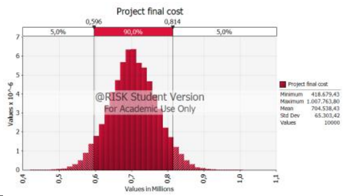
Condition: **Post-ΔM decision**	**Base (E) estimate (€)**	**Probability distribution fitted**	**Probability (%) meeting/under-running the E: P(X≤E)**	**Expected cost (C): mean from PDF simulated (€)**	**Higher estimation on base estimate (%)**
Land preparation	21440	Weibull	21.1	22862.06	6.63
Earthworks	24120	Beta Gen.	41.6	24965.93	3.51
Substructure	24120	Beta Gen.	33.1	31127.76	29.05
Superstructure	91120	Laplace	43.5	99059.67	8.71
Finishes	107200	Weibull	30.3	154773.51	44.38
Final Project	268000	Weibull	25.1	332788.93	24.17

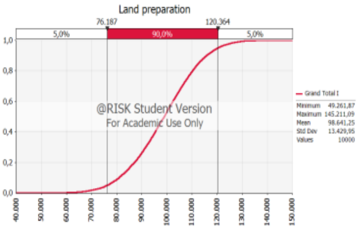
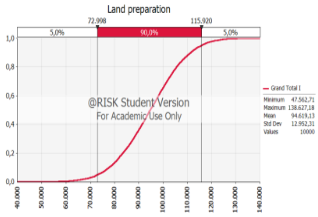
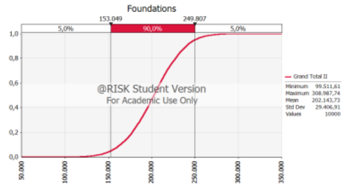
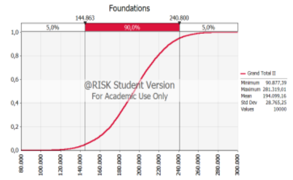
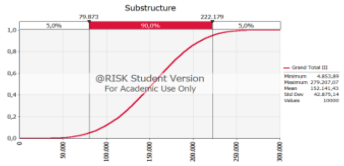
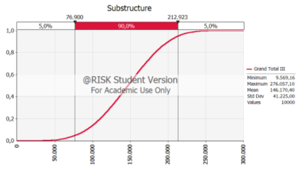
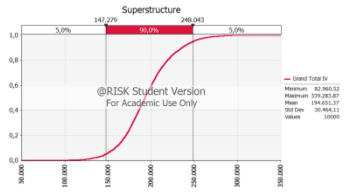
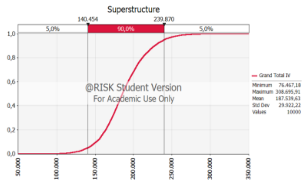
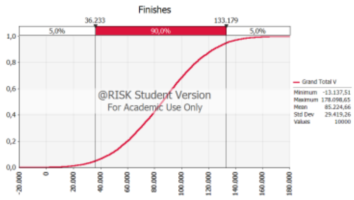
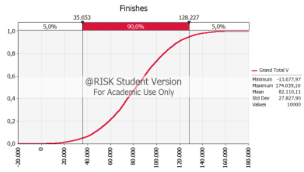
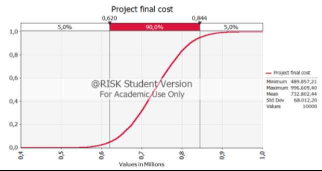
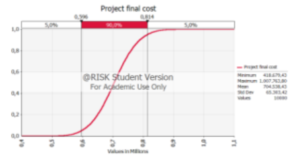
Cumulative distribution

Condition: **Post-ΔM decision**	**Expected confidence level (50%+Overall risks effect%)**	**Expected estimation at this confidence level (€)**	**Contingency set (€) = Exp. Estimation - Base estimate**	**Contingency on the base estimate (%)**
Land preparation	50+8.07=58.07	23287.00	1847.00	8.61
Earthworks	50+4.59=54.59	25485.51	1365.51	5.66
Substructure	50+35.54=85.54	47346.70	23226.70	96.30
Superstructure	50+23.46=73.46	108383.73	17263.73	18.95
Finishes	50+46.344=96.344	322634.48	215434.48	200.97
Final Project	50+23.6=73.6	389776.82	121776.82	45.44

Appendix 16 – Simulated output for each construction phase

The tabulated figures below are an example of the probability density function (PDF) and cumulative distribution produced after the end of the simulation performed for the 17th survey's participant. The PDF assists in reading the probability of meeting the initial estimate (E) provided by the survey participant. The ascending cumulative graph serves to observe the expected estimate at the desired confidence level and then specify the level of contingency set for each cost element.

Project ID 17		Pre-ΔM decision		Post-ΔM decision
Probability Density Function	Land preparation		Land preparation	
	Foundations		Foundations	
	Substructure		Substructure	
	Superstructure		Superstructure	
	Finishes		Finishes	
	Project final cost		Project final cost	

Cumulative Density Function	Land preparation		Land preparation	
	Foundations		Foundations	
	Substructure		Substructure	
	Superstructure		Superstructure	
	Finishes		Finishes	
	Project final cos		Project final cos	

Appendix 17 – Marginal distributions fitted

ID	Land preparatior	Foundations	Substructure	Superstructure	Finishes	Final Project
1	Beta General	Beta General	Normal	Normal	Normal	Normal
2	Beta General	Beta General	Beta General	Weibull	Normal	Normal
3	Beta General	Beta General	Normal	Beta General	Weibull	Normal
4	Beta General	Weibull	Weibull	Normal	Beta General	Normal
5	Beta General	Weibull	Weibull	Beta General	Beta General	Normal
6	Beta General	Weibull	Beta General	Beta General	Beta General	Normal
7	Weibull	Weibull	Beta General	Beta General	Beta General	Normal
8	Beta General	Normal	Weibull	Lognorm	Weibull	Normal
9	Beta General	Beta General	Weibull	InvGauss	Beta General	Normal
10	Beta General	Normal	Weibull	InvGauss	Beta General	Normal
11	Weibull	Weibull	Weibull	Logistic	Weibull	Normal
12	Beta General	Beta General	Beta General	Beta General	Weibull	Normal
13	Beta General	Weibull	Weibull	Gamma	Weibull	Normal
14	Weibull	Beta General	Weibull	Pearson5	Beta General	Normal
15	Beta General	Weibull	Weibull	Logistic	Weibull	Weibull
16	Normal	Normal	Weibull	ExtValue	Weibull	Gamma
17	Beta General	Beta General	Weibull	Normal	Beta General	Normal
18	Beta General	Beta General	Weibull	Logistic	Weibull	Weibull
19	Weibull	Beta General	Weibull	LogLogistic	Weibull	Weibull
20	Beta General	Beta General	Beta General	Normal	Beta General	Normal
21	Beta General	Weibull	Gamma	Pearson5	Weibull	Weibull
22	Beta General	Beta General	Beta General	Laplace	Weibull	Weibull

Note: It was observed that the *Weibull* distributions could simulated the same range of cost data as the *Normal* distributions. So a replacement of *Weibull* with *Normal* distributions could be possible in the specific case.

Appendix 18 – Overview of AHP process

Comparing the criteria to each other

	Propensity	Perception	Performance	Relative Priorities
Propensity	1	7	3	0.65
Perception	1/7	1	1/3	0.09
Performance	1/3	3	1	0.26
Sum (columns)	1.476	11	4.333	1.00

n	3
λ_{max}	3.049
CI	0.0245
CR	0.042<0.10

Comparing the 2 sub-criteria of "propensity" to each other

	Reasoning RA	Sharing agreements	Relative Priorities
Reasoning RA	1	7	0.88
Sharing agreements	1/7	1	0.12
Sum (columns)	1.142	8	1.00

Comparing the 3 sub-criteria of "perception" to each other

	Sensitivity	Attitude	Fear	Relative Priorities
Sensitivity	1	1/7	1/5	0.70
Attitude	7	1	3	0.08
Fear	5	1/3	1	0.22
Sum (columns)	13	1.476	4.20	1.00

Comparing the 2 sub-criteria of "performance" to each other

	Ability	Motivation	Relative Priorities
Ability	1	1/3	0.75
Motivation	3	1	0.25
Sum (columns)	4	1.33	1.00

Comparing the cost risk drivers to the "Reasoned risk assessment" sub-criterion

	Q	UC	S	G	Relative Priorities
Q	1	2	1/2	6	0.31
UC	1/2	1	1/4	3	0.15
S	2	4	1	8	0.49
G	1/6	1/3	1/8	1	0.05
Sum(columns)	3.67	7.33	1.88	18.00	1.00

n	4
λ_{max}	4.114
CI	0.0382
CR	0.042<0.10

Comparing the cost risk drivers to the "Sharing agreement" sub-criterion

	Q	UC	S	G	Relative Priorities
Q	1	1/2	1/7	1/5	0.06
UC	2	1	1/5	1/5	0.11
S	7	5	1	1	0.45
G	5	5	1	1	0.38
Sum(columns)	15.00	11.50	2.34	2.40	1.00

n	4
λ_{max}	4.107
CI	0.03597
CR	0.039<0.10

Comparing the cost risk drivers to the "Sensitivity" sub-criterion

	Q	UC	S	G	Relative Priorities
Q	1	2	5	7	0.46
UC	1/2	1	3	8	0.38
S	1/5	1/3	1	2	0.11
G	1/7	1/8	1/2	1	0.05
Sum(columns)	1.84	3.46	9.50	18.00	1.00

n	4
λ_{max}	4.154
CI	0.0513
CR	0.057<0.10

Comparing the cost risk drivers to the "Attitude" sub-criterion

	Q	UC	S	G	Relative Priorities
Q	1	4	1/2	6	0.35
UC	1/5	1	1/4	3	0.14
S	2	4	1	8	0.46
G	1/6	1/3	1/8	1	0.05
Sum(columns)	3.42	9.33	1.88	18.00	1.00

n	4
λ_{max}	4.250
CI	0.083
CR	0.093<0.10

Comparing the cost risk drivers to the "Specific fear" sub-criterion

	Q	UC	S	G	Relative Priorities
Q	1	1	1/7	1/3	0.08
UC	1	1	1/7	1/3	0.08
S	7	7	1	2	0.58
G	3	3	1/2	1	0.25
Sum(columns)	12.00	12.00	1.79	3.67	1.00

n	4
λ_{max}	3.982
CI	-0.0059
CR	-0.006<0.10

Comparing the cost risk drivers to the "Ability" sub-criterion

	Q	UC	S	G	Relative Priorities
Q	1	3	1/3	5	0.28
UC	1/3	1	1/5	3	0.14
S	3	5	1	9	0.54
G	1/5	1/3	1/9	1	0.05
Sum(columns)	4.53	9.33	1.64	18.00	1.00

n	4
λ_{max}	4.291
CI	0.097
CR	0.108≈0.10

Comparing the cost risk drivers to the "Motivation" sub-criterion

	Q	UC	S	G	Relative Priorities
Q	1	1	1/5	1/6	0.08
UC	1	1	1/4	1/5	0.09
S	5	4	1	1	0.38
G	6	5	1	1	0.45
Sum(columns)	13.00	11.00	2.45	2.37	1.00

n	4
λ_{max}	4.005
CI	0.0019
CR	0.002<0.10

Synthesis of all priority vectors as computed from the above 11 matrices

	Risk Propensity (0.65)		**Risk Perception (0.09)**			**Performance (0.26)**		**Overall Priority**	**Normalized Overall Priority**
	Reasoned RA (0.88)	Sharing agreements (0.12)	Sensitivity (0.70)	Attitude (0.08)	Specific fear (0.22)	Ability (0.75)	Motivation (0.25)		
Q	0.31	0.06	0.46	0.35	0.08	0.28	0.08	0.057	0.583
UC	0.15	0.11	0.38	0.14	0.08	0.14	0.09	0.033	0.328
S	0.49	0.45	0.11	0.46	0.58	0.54	0.38	0.130	1.00
G	0..05	0.38	0.05	0.05	0.25	0.05	0.45	0.039	0.226

Appendix 19 – Summary statistics of importance weights

ID	Total (€)	Cost Risk (€)				Impact of each driver			
		Q	UC	S	G	Q	UC	S	G
1	35033.06	20103.31	8234.98	6693.77	1	0.57	0.24	0.19	0.00
2	25439.37	13304	2589.04	14480.85	-4934.52	0.52	0.10	0.57	-0.19
3	2745.05	8579.19	-2142.44	5283.7	-8975.4	3.13	-0.78	1.92	-3.27
4	12818.94	11912.87	521.63	384.23	0.21	0.93	0.04	0.03	0.00
5	3580.93	1668.39	1248.52	424.03	239.99	0.47	0.35	0.12	0.07
6	2708.71	1237.18	1114.47	203.23	153.83	0.46	0.41	0.08	0.06
7	24127.21	1840.61	1542.13	7988.53	12755.94	0.08	0.06	0.33	0.53
8	51868.05	27957.31	5.41	23901.23	4.1	0.54	0.00	0.46	0.00
9	27761.34	10306.82	9.81	17444.62	0.09	0.37	0.00	0.63	0.00
10	47294.49	1596.11	6470.71	39227.6	0.07	0.03	0.14	0.83	0.00
11	83897.36	2193.87	22283.01	38998.74	20421.74	0.03	0.27	0.46	0.24
12	3650.59	1366.19	741.65	1138.04	404.71	0.37	0.20	0.31	0.11
13	34523.93	10349.94	529.13	23210.37	434.49	0.30	0.02	0.67	0.01
14	26185.54	4426.47	430.41	21044.45	284.21	0.17	0.02	0.80	0.01
15	10734.92	39.21	2348.65	8338.79	8.27	0.00	0.22	0.78	0.00
16	89797.92	1752.19	641.75	87403.56	0.42	0.02	0.01	0.97	0.00
17	6106.26	428.82	358.61	5102.41	216.42	0.07	0.06	0.84	0.04
18	6574.35	441.24	27.36	5421.9	683.85	0.07	0.00	0.82	0.10
19	38686.28	3350.36	773.44	34561.85	0.63	0.09	0.02	0.89	0.00
20	4068.26	1323.71	0.34	2018.28	725.93	0.33	0.00	0.50	0.18
21	153878.15	340.44	2048.08	151489	0.62	0.00	0.01	0.98	0.00
22	74730	2265.02	836.24	71628.72	0.02	0.03	0.01	0.96	0.00
Mean						**0.3894**	**0.0632**	**0.6433**	**-0.0961**
St.Dev						**0.6597**	**0.2253**	**0.4173**	**0.7213**

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