TOWARDS MORE EFFECTIVE COST MANAGEMENT IN CONSTRUCTION: AN INTEGRATED PROJECT MANAGEMENT HOLISTIC APPROACH

A thesis submitted in partial fulfilment of the requirement for the degree of
Doctor of Philosophy

by

Dimitrios D. Kantianis
Diploma in Civil Engineering, University of Patras, Greece
M.Sc. in Construction Management, University of Bath, United Kingdom

Department of Economic and Regional Development
Faculty of Sciences of Economy and Public Administration
Panteion University of Social and Political Sciences

June 2016

Statement of Original Authorship

DECLARATION

The work contained in this Ph.D. thesis has not been previously submitted for a degree or diploma at any other higher education institution. To the best of my knowledge and belief, this thesis contains no material previously published or written by another person except where due reference is made.

Signed: ________________________

Date: _______________________

To the memory of my beloved father
Damianos D. Kantianis
(1939-2014)

ACKNOWLEDGEMENTS

By far the largest debt incurred in writing this Ph.D. thesis is owed to my Supervising Professor Konstantinos Liapis for his dedicated guidance, assistance and support. I consider myself extremely fortunate to have collaborated with Dr. Liapis throughout this research project.

My profound gratitude goes to Professor Athanasios Papadaskalopoulos for believing in me in the first place and for realising my potential as a researcher.

I am truly grateful to the members of the Doctoral Committee: Professor Anastasios Tsamis, Professor Anastasios Tassopoulos, Associate Professor Ioannis Dimopoulos, Associate Professor Stelios Rozakis, Associate Professor Antonios Rovolis and Associate Professor Stella-Sofia Kyvelou-Chiotini.

I would also like to thank the friends/colleagues who kindly provided historical data for the research. I keep their names undisclosed for confidentiality reasons.

I feel immensely privileged to have such a wonderful family; without their love, patience and encouragement, this doctorate would not have been earned. I wish this accomplishment to become a benchmark for ‘always aiming high’ for my two precious little daughters.

ABSTRACT

Effective cost management is probably the most significant aspect of project management. Construction makes no exception and management of building projects deals with a broad range of cost engineering functions, such as estimating, budgeting, scheduling, resource costing, life-cycle costing, cost control and financial management, all within an *uncertain* and *complex* environment – an idiosyncratic characteristic of construction that demands an *integrative* approach for delivering successful built assets. Furthermore, the conventional project life-cycle context, as normally viewed by the contractor, only considers the project from conception to handover; however, the client's perspective entails a wider picture – what is often termed the product life-cycle – which considers the facility 'from the cradle to the grave'. Thus, a strong need has emerged to adopt a *holistic* attitude and to look more closely at the costs and revenues incurred over the product's whole-life, from conception to demolition.

This thesis introduces an integrated project management holistic methodology in order to originally contribute to the existing theory and practice on the topic of cost management for building construction projects. The value of the research lies in the provision of a 'front-end' strategic view of the constructed final product as a whole, from the start of the project construction production process to the end of the product whole-life cycle. This is achieved through the scientific analysis of the production and useful-life discrete time-sequential phases of the process, the derivation of relevant cost models (statistical, as well as mathematical – both *deterministic* and *probabilistic*), the verification and validation of the developed models based on historical data and empirical cases, and finally the synthesis of the models' outcomes in order to reach important conclusions concerning the critical variables involved. The research is expected to assist both researchers and practitioners in *decision-making* towards more effective project cost management in the built environment.

Keywords:

Construction management; project management; managerial accounting; finance; economics of building; operational research; statistics; decision-making.

LIST OF PUBLICATIONS

The following published research work is based upon this Ph.D. Thesis:

1. Liapis, K.J., Kantianis, D.D. and Galanos, C.L. (2014) Commercial property whole-life costing and the taxation environment, *Journal of Property Investment & Finance*, **32**(1), 56-77.

2. Liapis, K.J., Kantianis, D.D. and Galanos, C.L. (2015) Commercial Real Property Investments under Debt Crisis Economic Conditions, In *EU Crisis and the Role of the Periphery*, Springer International Publishing, 165-187.

3. Liapis, K.J. and Kantianis D.D. (2015) Depreciation Methods and Life-cycle Costing (LCC) Methodology, *Procedia Economics and Finance*, **19**, 314-324.

LIST OF FIGURES

LIST OF TABLES

TABLE OF CONTENTS

CHAPTER 1
PROLOGUE

CHAPTER 2
LITERATURE REVIEW – SCIENTIFIC FRAMEWORK

CHAPTER 3
RESEARCH METHODOLOGY

CHAPTER 4
CONSTRUCTION PROJECT PRODUCTION

CHAPTER 5
CONSTRUCTED PRODUCT USEFUL LIFE

CHAPTER 6
SYNTHESIS TO AN INTEGRATED PROJECT MANAGEMENT WHOLE-LIFE METHODOLOGY

CHAPTER 7
EPILOGUE

This page intentionally left blank

CHAPTER 1

PROLOGUE

1.1 Theoretical Background

The construction industry’s clients and professionals operate within a *complex* and *uncertain* environment with increasing demands in terms of: the performance of projects, both functionally and aesthetically, the capital and running costs and the time required from conception of the project to occupation (Walker, 2002). This unique construction process affects project management triangular parameters of *cost, time* and *performance* (Baccarini, 1996). Moreover, construction today is increasingly sophisticated with clients’ requirements focusing on principles based on ‘value for money’ rather than lowest costs (CIOB, 2010). Despite its engendered complex and uncertain characteristics, construction is one of the largest industries worldwide contributing to about 10% of the Gross National Product in industrialised countries and playing a significant role in the development and achievement of society’s goals (Allmon *et al.*, 2000). The construction industry occupies a fundamental position in many national economies. This large and pervasive industry is often regarded as the bellwether of economic growth. Periods of national prosperity usually are associated with high levels of construction activity. One seems to be the natural result of the other (Sears *et al.*, 2015). Constructed facilities cost to households, firms and other organisations significant proportions of their income or revenue whilst creating a substantial proportion of their wealth. The scale, quality and distribution of built products affect the level of efficiency with which producers of goods and services operate, as well as the quality and shape of the environment (Mulligan, 1993). However, the value delivering performance of the industry has often been criticised. The predictability of the costs of constructed facilities has proven to be difficult, particularly over their *whole life-cycle*. The special characteristics of construction, such as fragmented demand and supply chains, the uniqueness and complexity of projects and long lead times are basic causes, often leading to cost and time overruns, delivery of less value than agreed, and dissatisfied clients and users. In addition, it is difficult to assess all uncertainties and risks beforehand. Besides, fixed prices and predefined contractual specifications make it difficult to respond to changing demands and circumstances, and to deploy increasing knowledge of parties and people involved during the design and construction processes (De Ridder and Vrijhoef, 2004). The Global Financial Crisis in 2008 further exacerbated the problem and continues to have a significant impact on the financing of construction projects around the world, as financiers tighten lending controls and avoid lending for capital investments lacking sufficient risk controls (Smith, 2014).

The primary objective during construction is delivering the project on time and within the budget while meeting established quality requirements and other specifications. Hence, a substantial focus on managing the construction process is required. However, managing construction is impossible without a plan and a control system. The plan establishes goals for project's schedule (time), cost and resource use, as well as the tasks and methods for carrying out the work. It is usually developed based on historical databases together with *past experience* from similar projects. On the other hand, a control system collects actual data (feedback) on a project's schedule, cost and resource use; it compares existing progress to the planned schedule (performance analysis) to highlight potential problem areas that need closer attention; and it assists managers in decision-making emphasising on the results from this performance analysis (Rasdorf and Abudayyeh, 1991). However, divergences from the project plan occur and within construction such occurrences are common. Such divergences are nevertheless expected because of the nature of construction work and the uncertainties associated with it (Al-Jibouri, 2003). In general, according to Koushki *et al.* (2005), time delays and cost overruns are among the most common phenomena in the construction industry – from simple to complex projects. Morris and Hough (1987) examined the records of more than 4000 construction projects and found that projects were rarely finished within the allocated budget. Kaming *et al.* (1997); Assaf *et al.* (1995); Tah *et al.* (1993); Arditi *et al.* (1985); and Rad (1979) also observed that time and cost overruns were commonplace in the construction industry worldwide. A large-scale study of 900 construction projects by the World Bank (1996) has reported an average cost overrun of 40% over the original project cost and an average time overrun of 60% over the planned completion time. Leung *et al.* (2004) found that even in a sample of successful construction projects, cost and schedule overruns occurred. Woodward *et al.* (1994) believe that the problems of time and cost overruns are generally regarded as endemic in construction; indeed, they are so long established that, through the entire project chain from commissioning client to tradesman, they are accepted as the norm. Cost management problems start at the initial design stage with feasibility and elemental budgets that can be inaccurate; they continue at design development stage when specification changes that affect the final budget are not carried through to the relevant cost reports because of ineffective manual systems. It has been estimated that approximately 80% of projects are already over budget by the time construction commences on site, but ignorance of the fact has allowed the projects to go ahead (Woodward *et al.*, 1994). Olawale and Sun (2010) recently stated that despite the wide use of numerous project control methods and software packages in practice, many construction projects still suffer time and cost overruns. This poor cost performance of construction projects has been a major concern for both clients and contractors (Baloi and

Price, 2003). For the client, accurate cost estimates are vital for business decisions on strategies for asset development, potential project screening and resource commitments for existing and proposed project developments. Accurate estimates are critical to the initial decision-to-build process for the construction of capital projects (Flyvbjerg *et al.*, 2002). Furthermore, project cost accuracy is very important to clients as it enables them to have better cost control over projects. However, construction projects are notorious for running over budgets (Hester *et al.*, 1991). According to Mbachu and Nkado (2004), these cost overruns have obvious negative implications for the key stakeholders in particular, and the industry in general. To the client, high cost implies added costs over and above those initially agreed upon at the onset, resulting in less returns on investment. To the end user, the added costs are passed on as higher rental/lease costs or prices. To the consultants, it means inability to deliver value for money and could tarnish their reputation and result in loss of confidence reposed in them by clients. To the contractor, it implies loss of profit through penalties for non-completion, and negative word of mouth that could jeopardise their chances of winning further jobs, if at fault. Adrian (1979) found that inadequate project cost estimation is the second major cause of construction contractors' failures in the United States (US).

In today's time of rapid technological change, tough global and domestic competition, total cost management is central to sustained corporate profitability and competitiveness. However, cost management has to be an ongoing continuous improvement process in order to: a). meet clients' requirements for obtaining higher quality products on lower costs and b). satisfy the shareholders' demands for the required rate of return on their investment (Anand *et al.*, 2005). In this context, as Marchesan and Formoso (2001) believe, new cost management information providing better understanding and assisting in managing the increasingly turbulent and complex construction production process has become extremely important to drive improvement efforts to project success. Navon (2005) argued that success from the project management's viewpoint is when the project is completed with the lowest possible cost, as quickly as can be achieved and with the highest quality. In other words, success means bringing each of the project performance indicators – such as cost, schedule and performance – to an *optimum*. Therefore, a control system is an important element of any project management effort and control limits are set to assess the severity of deviations and to trigger corrective action. The role of the control system is to identify the discrepancies, by enabling the project management to identify the causes for the deviations and, accordingly, to decide about appropriate corrective measures. Navon (2005) further stressed the importance of accurate data collection in a timely fashion in order not only to control current projects but also to update the historical databases to enable better future planning of new projects. Traditional cost control methods are based on manual data collection, which is slow and inaccurate (Davidson and Skibniewski, 1995); this is probably why many project managers perform generic and infrequent control – if they want more accurate control, managers have to spend a disproportionate amount of time collecting data, causing them to be distracted from the more important task of supervising the project (McCullouch, 1997). The time-consuming and expensive current data collection methods is the reason why many construction companies do not collect extensive data and even less so in real-time. Even recent developments in automated data collection (Ciesielski, 2000) have not alleviated this situation. This is also supported by Saidi *et al.*'s (2003) study who pointed out that although construction measurement, sensing technologies and project information management software have advanced considerably in the past twenty years, accurate and up-to-date knowledge of the current status of construction projects remains elusive.

Betts (1992) argued that construction project management uses rudimentary forms of financial control. Compared to the more advanced forms of analysis and decision-making of other sectors, construction applies very simplistic techniques that have been fairly developed over a long period. Most of these techniques appear to follow one of two approaches: that of designing a building and then working out its cost, or that of setting a cost target for a building and then trying to design it within that constraint. In this regard, financial control is usually a support activity to the design and production process, based on a series of estimates that are seldom related back to initial plans or budgets. In practice, the adoption of cost strategies, satisficing or optimisation models, or the detailed evaluation of trade-offs between cost and design variables, are rarely approached. Ruan *et al.* (2001) believe that the conventional cost control systems are weak in dynamically controlling the cost in advance, due to the following two reasons: the first is that they only take cost into account, ignoring the other intimately interrelated project management concerns of progress and performance; the second is that they cannot estimate and predict the changing trend of the cost in order to provide effective measures to control or correct the cost differential. Hence, cost management models must be integrated and consider time, cost and performance in projects comprehensively. Nonetheless, as Perera and Imriyas (2004) point out, construction cost management has become more complicated with the introduction of new procurement methods and technologies, resources and various professionals' involvement. Furthermore, project cost management deals with a broad range of construction functions such as estimating, scheduling, cost control, resource costing and financial control with large quantity of data with many complex interrelationships; a characteristic that demands an *integrated system* for effective project cost management (Borland, 2001). The need for an integrated approach to construction cost management was also emphasized by many studies (Teicholz, 1987; Ibbs *et al.*, 1987; Rasdorf and Abudayyeh, 1991; Kodikara and McCaffer, 1993; Wong, 1993; Kang, 1998; Kim *et al.*, 1999; Froese, 1999; Syal and Kakakhel, 1999; Staub and Fischer, 1999; Sun and Aouad, 1999; Borland, 2001; Fayek, 2001; Isidore *et al.*, 2001; Ruan *et al.*, 2001; Perera and Imriyas, 2004; Aretoulis *et al.*, 2006; Hendrickson, 2008). Nonetheless, according to Doloi's (2011) study, while numerous methodologies and models have been published on the topic, traditional cost management principles are fundamentally inadequate for managing modern complex construction projects. The project development environment impacting cost performance still remains unexplored and all the underlying perceptive factors involved over the entire project life-cycle should be identified and examined in order to establish a benchmark for effective cost management of construction projects (Doloi, 2011). According to the *Construction Management Standards of Practice, effective* cost management involves the establishment of a realistic project budget, within the owner's cost limitations; further, the application of cost management skills and techniques to ensure the project is planned, designed, procured and constructed in the most economical way, ensuring conformance with the original project requirements (CMAA, 2008).

In construction, clients are frequently confronted with the problem of deciding on whether an *investment project* should be undertaken, or to select one out of several mutually exclusive investment projects from a given portfolio. For the assessment of investments, the *net present value* (NPV) rule has been well-established both in research and practice (Brealey and Myers, 2002). In classical investment theory, investments are specified by a stream of payments (a series of payments with associated payment times). For a stream of payments, the NPV is obtained by summing up all payments discounted to time zero (Zimmermann and Schwindt, 2002). In the case of *investment projects*, payment times are no longer given in advance but are subject to the *scheduling* process. An investment project consists of a set of events each of which is associated with a paying-in or paying-out. Moreover, there are prescribed time lags between the occurrences of these events. Thus, the stream of payments results from maximising the NPV of the project subject to the given time lags (Zimmermann and Schwindt, 2002). The formulation of this optimisation problem pre-supposes knowledge of the required rate of return (i.e. the proper discount rate) for discounting the payments and the specification of the project deadline. In practice, however, often neither the exact interest rate nor a project completion date is known. The proper interest rate is a theoretical value and can only be estimated; the project deadline is generally the result of negotiations between the investor and the contractor (Brealey *et al.*, 2014). The traditional investment calculations usually reflect the economic benefits. Disadvantages with traditional investment calculations include that they are *static*, and they are based on simplifying assumptions. The assumptions might not reflect the underlying production process in an appropriate manner (Artto *et al.*, 2001). Conventional investment appraisal is characterised by irreversibility and uncertainty about future rewards. Once money is spent, it cannot be recovered if the pay-offs hoped for do not materialise (Dixit and Pindyck, 1995). These decisions are typically made by using traditional project evaluation approaches, such as those based on *discounted cash-flow* (DCF) analysis. They assume implicitly that a project will be undertaken now and operated on continuously at a set time scale, until the end of its expected useful life, even though future is uncertain. Therefore, they underestimate the upside value of investment by assuming management's passive and inflexible commitment to a certain 'operating strategy'. In the real world, because of uncertainty and competitive interactions, the realisation of cash-flows will probably differ from what management originally expected (Kogut and Kulatilaka, 1994).

In general, a durable means of production loses value over its economic life span, i.e. as long as products are generated and, presumably, sold. Since the goal is to continue production as long as the market demands the products and production gives the entrepreneur a reasonable income, it must be possible to replace the capital goods. At each moment during the economic life span, the loss of value has to be compensated for by income. The annual loss of value is the *depreciation* and has to be estimated at the moment of investment decision-making (Tempelmans Plat, 2001). Economic analysis must, in most cases, include depreciation. Depreciation rates provide cash for asset replacement and to encourage new investment. The investor is allowed to recover the original investment over time from cash earnings as a deduction from taxable income (Westney, 1997).

During the useful life period, clients wish to know at any point in time the *value* of their constructed assets. *Fair value accounting* is an improvement to traditional accounting – the *historical cost accounting*. Under historical cost accounting, the initial price paid by the company during the purchase of the asset or incurrence of the liability is the one that matters. The price reflected on the balance sheet either is the purchase price or at a value reduced by obsolescence, depreciation or depletion (Nobes, 1997). For a financial asset, the price on the balance sheet does not change until the security is liquidated. Historical cost accounting is easy to understand because it relies on a fixed price that is always completely known, specifically the actual price that a company paid. Further, it is generally easier to follow since it is based on fixed and certain inputs. While this eliminates uncertainty from the initial valuation decision, it creates uncertainty in future periods about the *true value* of assets (Meunier, 2012).

Construction projects are subject to *uncertainty*, arising from both internal and external diverse sources, including technical, managerial and commercial issues. Project managers widely recognise that successful management of uncertainty is critically associated with project success, since proactive management constantly seeks to steer the project towards the achievement of the desired objectives (Hillson, 2002). Moreover, as new endeavours, projects require the implementation of previously untried designs and work processes, and must accomplish demanding requirements within strict time and cost boundaries. In other words, construction is prone to damage through uncertainties and risks and, it is not surprising, that many projects fail by wide margins to meet their targets (Harrison and Lock, 2004). Effective risk management of construction projects start at the initiation of the project, whereas risk management plans are developed, and continues throughout the project life-cycle. Moreover, in most projects, risk management is not a discrete stand-alone process, but is integrated with other project management functions, in that many of the steps are undertaken as part of normal project management (Cooper *et al.*, 2005). Any project risk analysis begins with an accurate PERT/CPM schedule, created with the use of best practices and checked for quality, reasonableness, and appropriateness of the network model. Without a well-designed and developed PERT/CPM baseline schedule, a risk analysis process will not be effective. The risk analysis depends upon accurate and consistent calculations of the network logic, the appropriateness of the sequencing and phasing, and a reasonable approach to estimating activity durations (Mubarak, 2015). Nevertheless, simple quantitative project risk modelling is unlikely to be sufficient for large scale construction projects, and it is often necessary to model financial structures and view the project on a business or enterprise basis. Therefore, *cash-flow planning*, *financial structuring* and risk analysis must be integrated carefully; further extensions to include *taxation* and *accounting* matters are common (Cooper *et al.*, 2005). In traditional project planning, the duration of each task is given a *single point estimate* and an analysis is performed to determine the *critical path*, i.e. the tasks that are directly determining the duration of the project. In a project schedule risk analysis, the critical path will not usually run through the same line of tasks in every iteration of the model (Vanhoucke, 2013). Hulett (2009) points out that the schedule activity durations are better understood as probabilistic statements of possible durations rather than a deterministic figure about how long the activity will last.

The aim of *systems theory* for business is to develop an objective, understandable environment for decision-making; that is, if the system within which managers make the decisions can be provided as an explicit framework, then such decision-making should be easier to handle (Johnson *et al.*, 1964). The antonym of *systematic* is *chaotic*. A 'chaotic' situation might be described as one where 'everything depends on everything else' (Simon, 1960). Since two major goals of science and research in any subject area are explanation and prediction, such a condition cannot be tolerated. Therefore, there is considerable incentive to develop *bodies of knowledge* that can be organized into a complex whole, within which subparts or subsystems can be interrelated (Johnson *et al.*, 1964). Construction managers need to convert disorganised resources of men, machines, and money into a useful, effective enterprise. Essentially, management is the process whereby these unrelated resources are integrated into a total *system for objective accomplishment*. *Systems analysis* and *systems engineering* correspond to the two main phases of a project production life-cycle, with the former dealing with pre-project economic analysis, and the latter with project engineering and management. Essentially, systems analysis determines 'what' is to be done, which is often a *strategic* decision-making process, while systems engineering focuses on 'how' to do it, which falls in the context of *operational* management. Both approaches strictly follow a hard-systems mental framework, and have been adapted and translated into policies in solving management problems (Yeo, 1993). *Systems thinking* is a process of understanding how things influence one another within a wider perspective; it is an approach to resolve any problems by understanding them as a part of the system, rather than responding to particular parts, results, or activities and, potentially, contributing to further developments (Sherwood, 2002). Thus, systems thinking allows engineers to take a *holistic view* of the project from conception to demolition (Flanagan, 2014).

1.2 Problem Statement

In this theoretical background, it could be argued that there is still a significant *knowledge gap* emerging *in establishing a reference (base-case) methodology for improving the cost management practices* across the construction industry. It is axiomatic of construction management that a project may be regarded as successful if the building is delivered at the right time, at the appropriate price and quality standards as well as achieving a high level of client satisfaction. To accomplish these goals within such a unique environment, construction professionals must be able to develop comprehensive and fully *integrated* information and management systems to plan, instruct, monitor, and control large amounts of data, as quickly and accurately as possible, in order to facilitate the problem solving and decision-making process (Burke, 2003).

However, there is no past research work that has developed an effective integrated system for construction project cost management, which encompasses cost estimating and scheduling, cost control, resource costing and financial control. Such an approach could result in an effective, transient and easy-to-use cost management system (Perera and Imriyas, 2004).

Clearly, a system is needed to structure all the key issues in balancing costs, performance, economic and financial aspects using: *systems thinking theory*, in order to provide a framework to manage the inherent *complexity* of construction and engineering today; and project *risk management* in order to deal with *uncertainty* and perceptions about the future (Flanagan, 2014). Furthermore, placing this framework in the context of *whole-life appraisal* highlights the important concept of *time*. Over the life of a facility, time will impact risk perceptions and it will add to the complexities within the system (Flanagan, 2014). This thesis attempts to fulfil the aforementioned gap by recommending a prototype integrated project management whole-life approach for construction projects.

1.3 Research Aim

This research project aims at developing an integrated project management holistic methodology towards more effective cost management in the construction industry.

1.4 Research Objectives

The main objectives of the research are stated as follows:

- ***to analyse the processes of the discrete phases of construction project production and built product useful life in order to synthesise them in an integrated cost management approach;***
- ***to establish the time, cost and value interdependencies over the whole-life cycle of constructed assets; and***
- ***to address cost and time uncertainty and risk engendered in construction project management.***

1.5 Methodology Outline

In order to achieve the research objectives, a comprehensive *literature review* is the starting point so that research focus can be determined. Subsequently, a *fieldwork* is conducted and records from *historical building projects* undertaken by construction contractors are accessed, in order to collect reliable *cost*, *time* and *resource consumption data*. The gathered data are analysed to form useful and valid datasets for each examined discrete phase. Then, a number of *deterministic* and *stochastic* theoretical models are constructed, verified and implemented to real-life building projects by means of *case studies*, in order to closely depict construction project management operations, to provide convincing explanations which justify practice choices and facilitate the development of a unique integrated and holistic project cost management methodology.

Model creation includes: pre-construction (early stage) cost and time forecasting models derived from simple and multiple linear regression statistical analyses; physical construction time and cost estimation and cost budgeting mathematical models; physical construction scheduling network analysis graphs; time and cost optimisation linear programming and simulation models; and useful life period simulation models. Lave and March (1975:3) defined a *model* as ‘a simplified picture of a part of the real world’. The findings from applying the aforementioned models to actual project cases are critically appraised to be able to draw conclusions and to find out whether these are aligned with the research aim and objectives. Lastly, recommendations for future research directions are suggested to both academics and practitioners in the field of construction management. Figure 1.1 (page 32) outlines the distinct steps required for executing the research project. The logic behind the selection of the research methodology followed in the thesis is extensively discussed in Chapter 3.

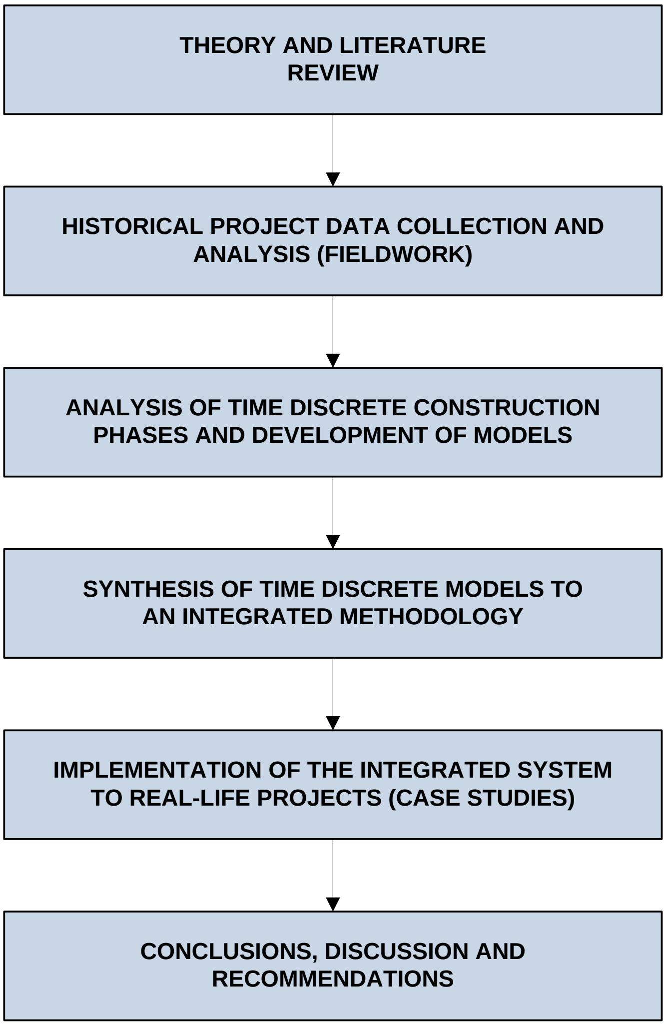


Fig. 1.1 Outline of the Research Process

1.6 Conceptual Framework

Miles and Huberman (1994:18) defined a *conceptual framework* as a visual or written product that ‘explains, either graphically or in narrative form, the main things to be studied – the key factors, concepts, or variables – and the presumed relationships among them’. A conceptual research framework is something that is *constructed*, not discovered. It incorporates pieces that are borrowed from elsewhere, but the structure, the overall coherence, is something that is being built, not something that exists ready-made (Miles and Huberman, 1994). The conceptual framework for this research project is visually explained in Figure 1.2 (page 33).

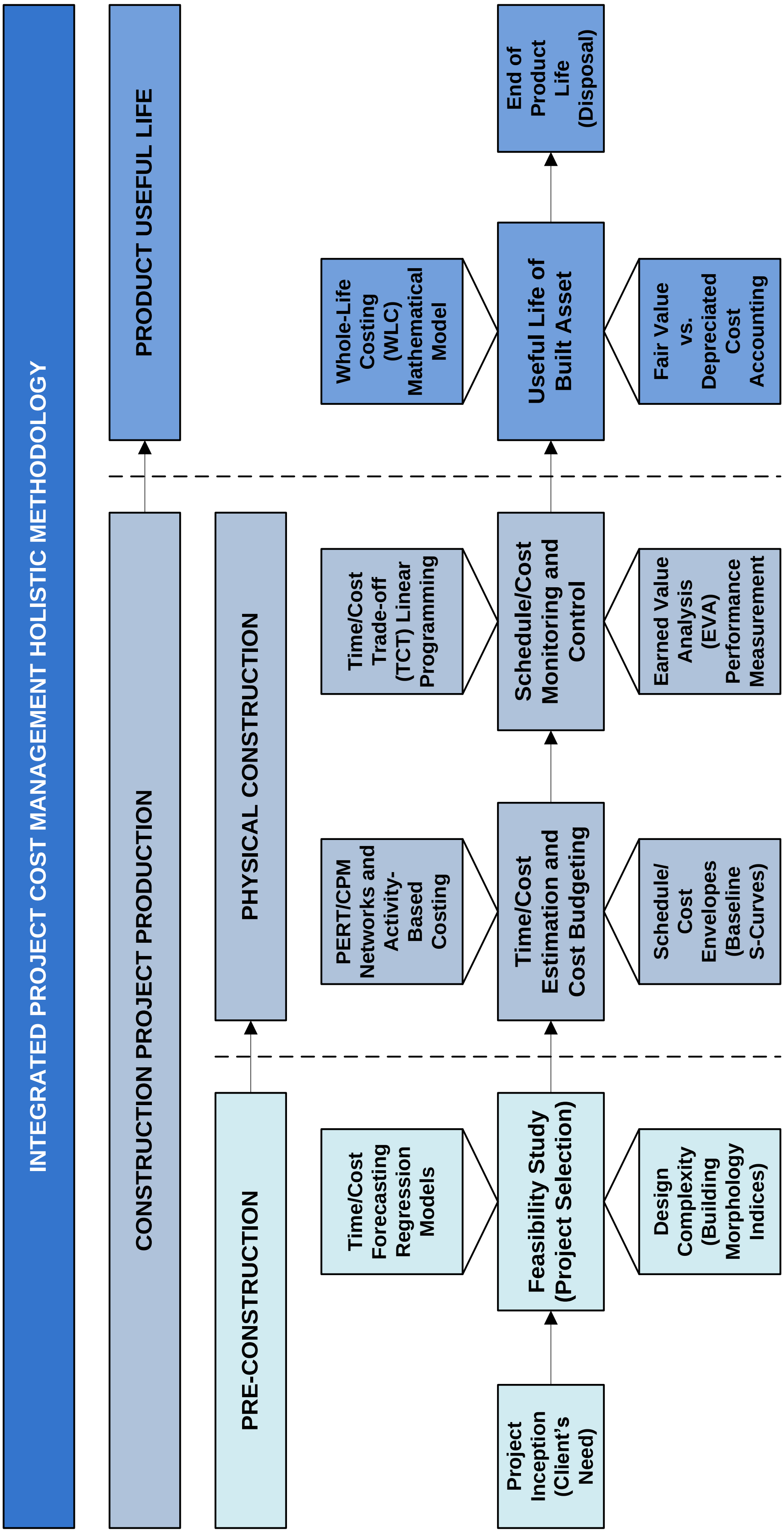


Fig. 1.2 The Conceptual Framework for the Research Project

1.7 Justification for the Research

The underlying philosophy of this thesis is to view the process of cost management for construction projects from a more *integrative*, *holistic* and *stochastic* perspective. The research is therefore expected to bring about an original contribution to the topic of construction project cost management and to assist construction clients, contractors and consultants in improving the effectiveness of managerial decision-making towards the delivery of more successful built products. The construction process is analysed in two time-discrete phases: a *construction project production* period which is further subdivided into *pre-construction* and *physical construction*; and a *product useful life* period whereas the constructed facility is occupied, operated and maintained by the owner. While there have been several attempts which deal with these discrete procedures separately, to the writer's knowledge there is no other research work which has tried to holistically and stochastically integrate them in a logical, theoretical and yet practical way.

The research is primarily motivated by the complex nature of the typical problems found in management science and engineering; in order to study such complicated systems, the development of mathematical models provides a practical tool to deal with complexity so that the problems are more transparent and the systems can be optimised. In general, engineers and managers in construction try to understand, create, and/or optimise *systems*. In this research, a *system* refers to the object of interest, which is the construction product and its processes; to understand and to tackle problems related to the complex construction systems, the construction project manager needs to apply appropriate simplified descriptions of the systems. The more appropriate models are the simplest models that still serve their purpose, that is, which are still complex enough to assist in understanding the system and to solve the problems under consideration at the same time.

In the framework of construction management as a discipline, there has been little emphasis on *theory development* (Koskela, 1999). A *theory* provides an *explanation* of observed behaviour; it contributes to understanding and can also provide a *prediction* of future behaviour. On the basis of the theory, tools for analysing, designing and controlling can be built. When shared, a theory provides a *common language* or *framework*, through which the co-operation of people in collective undertakings, like project, firm, etc., is facilitated and enabled. When explicit, it is possible to constantly test the theory in view of its validity. Innovative practices can be *transferred* to other settings by first abstracting a theory from that practice and then applying it in target conditions. From the point of view of practice of production management, the significance of the theory is crucial: the application of the theory should lead to improved performance. In reverse, the lack of the application of the theory should result in inferior performance. Here is the power and significance of a theory from a practical point of view: it provides an *ultimate benchmark for practice* (Koskela, 1999). 'It is not unreasonable to argue that conceptual models cannot be created in a vacuum and without any prior knowledge or appreciation of the reality of the problem situation. An intellectual model that is based on pure logic, and does not bear any resemblance to reality, is likely to be rejected as irrelevant or purely fantastic. However, of course, one must not forget that the conceptual model cannot be a mere mapping or description of the reality. Otherwise, there will be no problem to solve and no change to make if there is no difference between the conceptual model and the reality' (Yeo, 1993:114).

The goal of this study is to develop a conceptual comprehensive and integrative cost management methodology for construction projects in order to overcome the difficulties and limitations addressed above. The developed methodology is expected to be helpful to practitioners and researchers interested in construction management systems for the production of building projects and to clients evaluating and selecting projects to invest their capital to maximise their profit. Furthermore, in spite of the appearance of few studies which combine economic concepts with construction technology, most of them tend to be theoretical and directed towards broad analysis rather than solving practical management problems. Thus, the contribution of the building economist so far to the construction industry has been mainly in macro-economic aspects of the industry and its place in the economy and to a lesser extent in the environment of the construction project or the construction site. This research project attempts to fill this void with the development of a consistent and practical methodology derived from the basic theoretical approaches to the subject.

As Fellows (2010:11) suggested: ‘For the (hopefully, impending) future, ‘new paradigms’ should concern migration to stochastic perspectives and approaches from determinism; holism and the acceptance of complexity and its accommodation in investigations (of integrated processes and products); and, consequently, the rigorous use of methodological pluralism’.

This page intentionally left blank

CHAPTER 2

LITERATURE REVIEW – SCIENTIFIC FRAMEWORK

2.1 Introduction

The literature review (state-of-the-art) serves two purposes: first, it seeks systematic reading of previously published and unpublished information relating to the area of investigation in order to gather useful information and to develop issues and themes towards research design; second, it helps to improve the research study by looking into previous research which gives insights into more effective research design. In other words, a literature survey attempts to integrate what others have studied, to critically examine previous scholarly works, to build bridges between related topic areas, and/or to identify the central issues in the field (Naoum, 2007). Numerous research efforts have been published over the years concerning the *art* and *practice* of construction management, almost all of which have chapters on cost management. Primary sources of the literature include: academic refereed research journals (e.g. *Construction Management and Economics*; *International Journal of Project Management*; *Journal of Property Investment and Finance*; *Journal of Construction Engineering and Management*); refereed international conference proceedings related to the construction industry such as *Building Economics and Construction Management* (CIB W90) and *Association of Research in Construction Management* (ARCOM); PhD theses; and technical reports/ occasional papers published from, e.g. the Royal Institute of Chartered Surveyors (RICS) and the Chartered Institute of Building (CIOB). Secondary sources and reference guides contain: textbooks from Greek and worldwide Universities' libraries; dictionaries (*Concise Oxford Dictionary*; *Penguin Dictionary of Economics*); and handbooks.

2.2 The Economic Context of the Construction Industry

In this section, the construction industry is set in the general context of the national economy. To accomplish this, at first some basic definitions are provided, especially for the term construction itself, and then selective recently published extracts from the Greek official statistics are considered in order to identify the main features of the construction industry. Furthermore, reasons for the high rates of insolvency/bankruptcy of construction firms are suggested from an analysis of their financial structure.

2.2.1 The Significance of Construction

The construction sector is strategically important providing infrastructure and buildings on which all sectors of the economy depend. With almost 20 million operatives directly employed in the sector, it is Europe's largest industrial employer accounting for 7% of total employment and 28% of industrial employment in the European Union (EU). It is estimated that 44 million workers in the EU depend, in one way or another, on the construction sector. Construction contributes more than 10% of the gross domestic product (GDP) and more than 50% of the gross fixed capital formation of the EU, representing about €1,36 trillion in 2011 (Potts and Ankrah, 2013).

Being a subset of the wider EU market, the Greek construction industry similarly makes a considerable contribution to the national economy. According to the definitions provided by the Hellenic Statistical Authority (ELSTAT, 2016):

- *Building Construction* includes: demolition, site formation and clearance work, general construction work for buildings (new work, additions, alterations and renovation work), installation work of electrical wiring and fittings and other building installation work. Buildings include one- and two-dwelling buildings, multi-dwelling buildings, hotels, office buildings, industrial and retail trade buildings, public entertainment and education buildings, hospitals and other non-residential buildings.

- *Civil Engineering* includes: motorways, roads, streets, railways and airfields runways, sport facilities, bridges, tunnels, subways, long-distance pipelines, communication and power lines (oil and gas pipelines, electricity lines, tele-communication lines), water projects, etc.

The construction industry can be broken down into two very broad categories, general building construction and civil engineering construction. Most construction contractors concentrate on one of these categories, or even on a specialty within one of them. A third category of contractor is the specialty trade contractor, who usually works as a subcontractor for a general, or prime, contractor responsible for the construction of the entire project (Bennett, 2003). The construction industry includes building, civil engineering and process plant engineering, but the demarcation between these areas is blurred. It is concerned with the planning, regulation, design, manufacture, installation and maintenance of buildings and other structures. Construction work includes a wide variety of activities, depending on the size and type of projects undertaken and the professional and trade skills required. The construction industry has characteristics that separate it from all other industries (Ashworth, 2004):

- the physical nature of the product;
- the fact that the product is normally manufactured on the client's premises, i.e. the construction site;
- the fact that many of its projects are *one-off* designs, with no prototype model;
- the arrangement of the industry, where design is normally being separated from construction;

- the organisation of the construction process; and
- the methods used for price determination.

The final product is often large and expensive, and can represent a client's largest single capital outlay. Buildings and other structures are for the most part bespoke designed and manufactured to suit the individual needs of each customer, although there is provision for repetitive and speculative work, particularly in the case of housing. The nature of the work also means that an individual project can often represent a large proportion of the turnover of a single contractor in any year (Ashworth, 2004).

Construction has five distinguishing characteristics (Myers, 2008):

- each project is regarded as a unique *one-off* product;
- the industry is dominated by a large number of relatively small firms;
- the general state of the economy influences demand;
- prices are determined by tendering; and
- projects are characterised by their 'lumpiness' in terms of their scale and expense.

The final product of the industry is large, heavy and expensive. It is required over a wide geographical area and is, for the most part, made especially to the requirements of the individual customer. Most of the components of the industry are manufactured elsewhere by other industries. It is largely these product characteristics which determine the structure of the industry, including the large number of dispersed contracting firms and the usual separation of design from construction which has such important repercussions. The nature of the product, together with the structure of the industry it encourages, also means that each contract often represents a large proportion of the work of a contractor at any one time, causing substantial discontinuities in the flow of work. The work of the contracting part of the industry involves the assembly of a large variety of materials and components (Potts and Ankrah, 2013).

Tables 2.1 and 2.2 (pages 42-43) provide *broad* and *narrow* definitions of the construction industry according to the key stakeholders involved and to the areas and type of work performed.

Table 2.1 Construction Industry – *broadly* defined (Source: Manseau and Seaden, 2001)

The key stakeholders in the construction industry include:
- Suppliers of basic materials, e.g. cement and bricks; - Machinery manufacturers who provide equipment used on site, such as cranes and bulldozers; - Manufacturers of building components, e.g. windows and doors; - Site operatives who bring together components and materials; - Project managers and surveyors who co-ordinate the overall assembly; - Developers and architects who initiate and design new projects; - Facility managers who manage and maintain property; and - Providers of complementary goods and services such as transportation, distribution, demolition, disposal and clean-up.

More recently, the private sector has been given a greater role in the funding, building and maintenance of public facilities such as hospitals, schools, prisons and roads. In these *public private partnerships* (PPP), the private sector organises the funds and manages the risks, while the public sector specifies the level of service required and ultimately owns the assets, commonly returned to public ownership after 10, 15 or 25 years (Myers, 2008). At the core of any construction process are the *clients*. Some are well informed and know precisely what they want and how it can be technically achieved, but the majority seem to know little. The modern client in markets such as cars, steel and engineering products expects value for money, products that are free from defect, goods delivered on time, worthwhile guarantees and reasonable running costs. Unfortunately, the picture painted of construction in the late twentieth century was of an industry that ‘tends not to think about the customer (either the client or the consumer), but more about the next employer in the contractual chain’ (Egan, 1998:16). It is usual in the EU, and particularly in Greece, for the majority of work carried out on a construction site to be executed by *subcontractors*. Subcontractors often organise materials and maintain equipment. To the main contractor, labour-only subcontracting is a cheap and efficient option, as the self-employed worker is not entitled to the benefits of the permanent staff members. This tradition within the construction industry results in a high level of *fragmentation*, leading to many of the industry's recognised strengths and weaknesses (Briscoe, 1988).

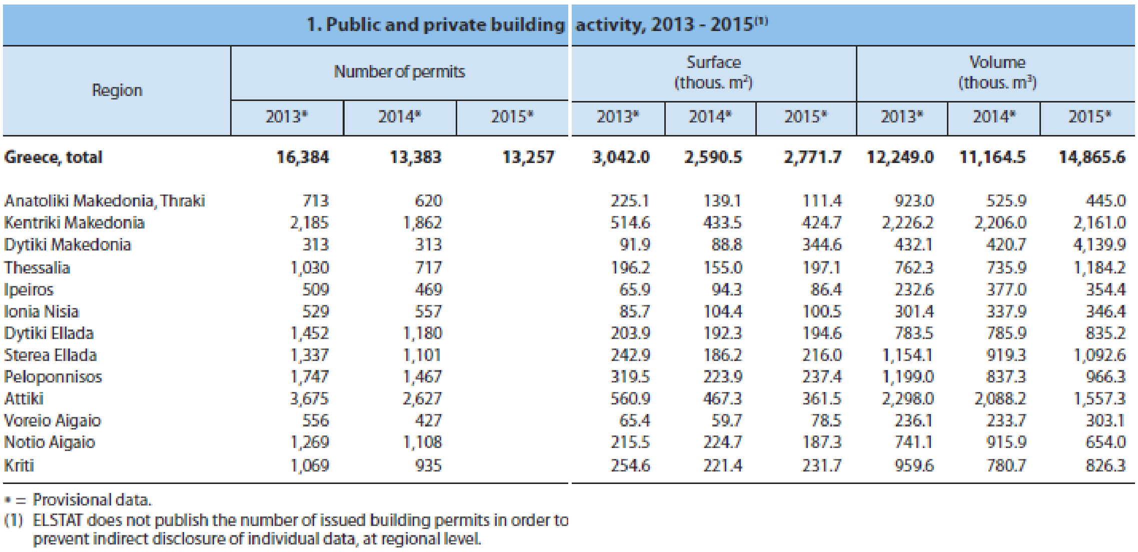
Table 2.2 Construction Industry – *narrowly* defined (Source: Myers, 2008)

Areas of Construction	***Examples of Type of Work***
Infrastructure	Water and Sewerage Energy Gas and Electricity Roads Airports, Harbours, Railways
Housing	Public Sector/Housing Associations Private Sector (New Estates)
Public Non-Residential	Schools, Colleges, Universities Health Facilities Sports and Leisure Facilities Services (Police, Fire, Prisons)
Private Industrial	Factories Warehouses Oil Refineries
Private Commercial	PFI (and similar PPP) Schools/Hospitals (where privately funded) Restaurants, Hotels, Bars Shops Garages Offices
Repair and Maintenance	Extensions and Conversions Renovations and Refurbishment Planned Maintenance

2.2.2 Construction Industry Statistics

Construction is sensitive to macroeconomic conditions, and today's poor state of the Greek economy means that there is little incentive for construction projects to begin. Tables 2.3, 2.4 and 2.5 (pages 44 and 45) provide recent relevant data published in 2016 by the Hellenic Statistical Authority for the Greek construction industry:

Table 2.3 Public and Private Building Activity, 2013-2015 (Source: ELSTAT, 2016:80-81)



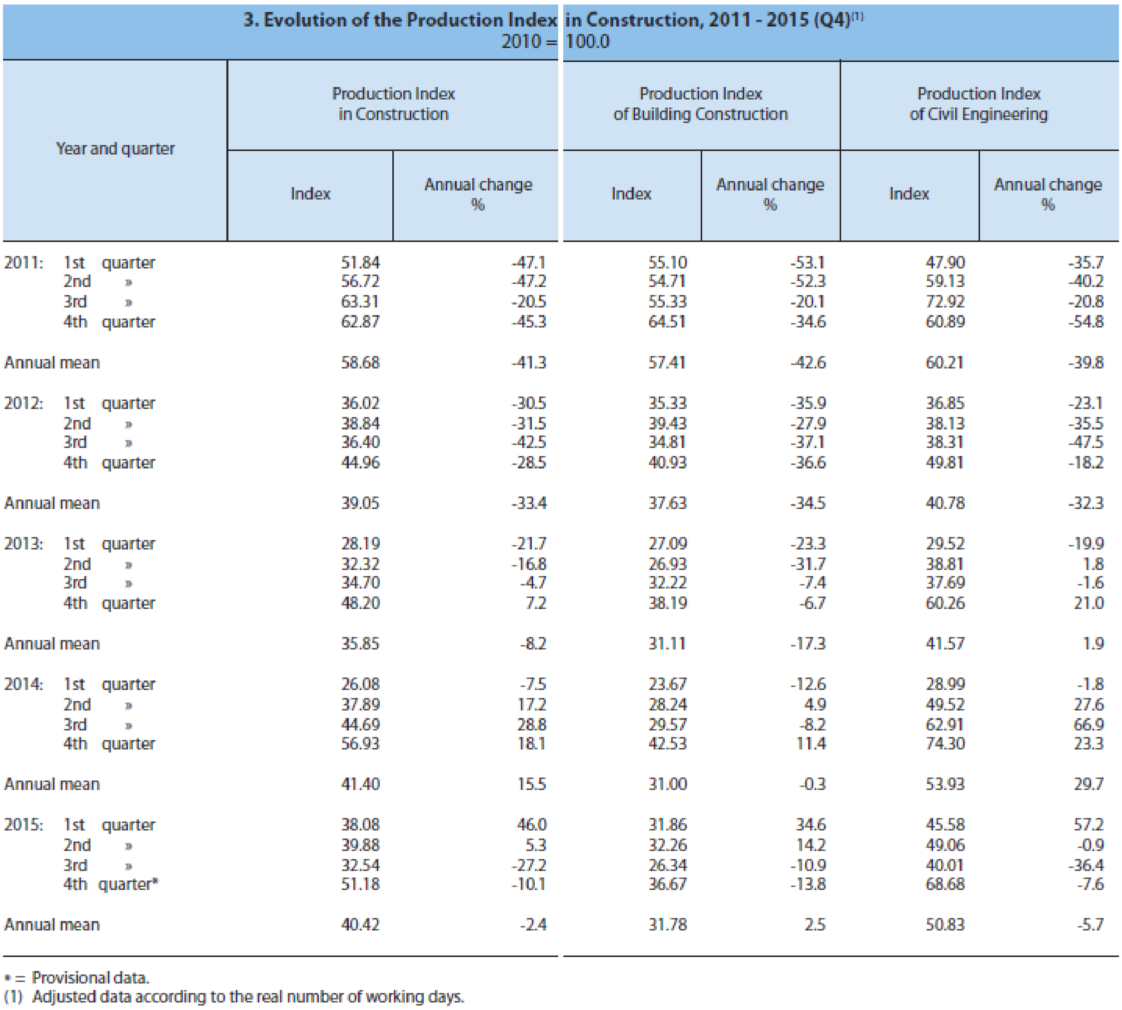
1. Public and private building activity, 2013 - 2015(1)

Region	Number of permits			Surface (thous. m²)			Volume (thous. m³)		
	2013*	2014*	2015*	2013*	2014*	2015*	2013*	2014*	2015*
Greece, total	**16,384**	**13,383**	**13,257**	**3,042.0**	**2,590.5**	**2,771.7**	**12,249.0**	**11,164.5**	**14,865.6**
Anatoliki Makedonia, Thraki	713	620		225.1	139.1	111.4	923.0	525.9	445.0
Kentriki Makedonia	2,185	1,862		514.6	433.5	424.7	2,226.2	2,206.0	2,161.0
Dytiki Makedonia	313	313		91.9	88.8	344.6	432.1	420.7	4,139.9
Thessalia	1,030	717		196.2	155.0	197.1	762.3	735.9	1,184.2
Ipeiros	509	469		65.9	94.3	86.4	232.6	377.0	354.4
Ionia Nisia	529	557		85.7	104.4	100.5	301.4	337.9	346.4
Dytiki Ellada	1,452	1,180		203.9	192.3	194.6	783.5	785.9	835.2
Sterea Ellada	1,337	1,101		242.9	186.2	216.0	1,154.1	919.3	1,092.6
Peloponnisos	1,747	1,467		319.5	223.9	237.4	1,199.0	837.3	966.3
Attiki	3,675	2,627		560.9	467.3	361.5	2,298.0	2,088.2	1,557.3
Voreio Aigaio	556	427		65.4	59.7	78.5	236.1	233.7	303.1
Notio Aigaio	1,269	1,108		215.5	224.7	187.3	741.1	915.9	654.0
Kriti	1,069	935		254.6	221.4	231.7	959.6	780.7	826.3

* = Provisional data.

(1) ELSTAT does not publish the number of issued building permits in order to prevent indirect disclosure of individual data, at regional level.

Table 2.4 Construction Production Index, 2011-2015 (Source: ELSTAT, 2016:82-83)



3. Evolution of the Production Index in Construction, 2011 - 2015 (Q4)(1)

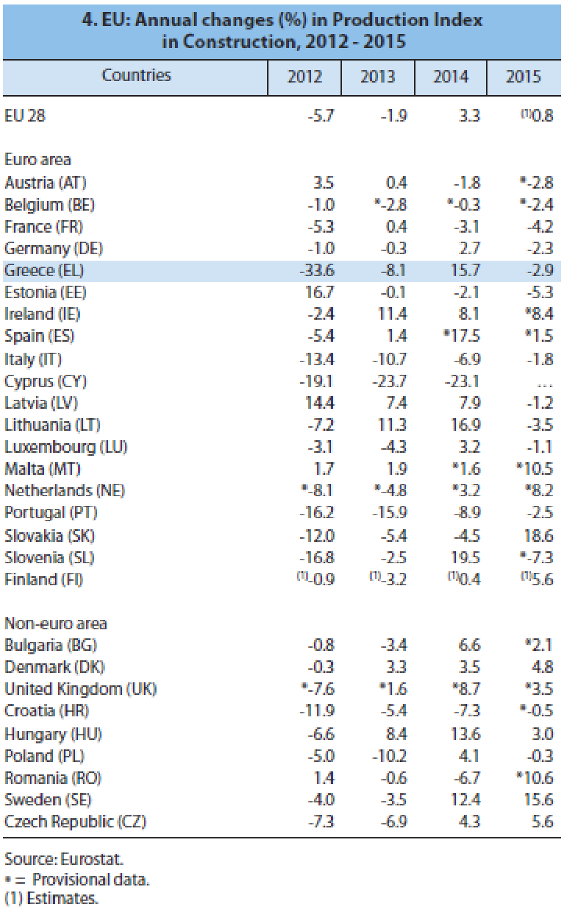
2010 = 100.0

Year and quarter	Production Index in Construction		Production Index of Building Construction		Production Index of Civil Engineering	
	Index	Annual change %	Index	Annual change %	Index	Annual change %
2011: 1st quarter	51.84	-47.1	55.10	-53.1	47.90	-35.7
2nd »	56.72	-47.2	54.71	-52.3	59.13	-40.2
3rd »	63.31	-20.5	55.33	-20.1	72.92	-20.8
4th quarter	62.87	-45.3	64.51	-34.6	60.89	-54.8
Annual mean	58.68	-41.3	57.41	-42.6	60.21	-39.8
2012: 1st quarter	36.02	-30.5	35.33	-35.9	36.85	-23.1
2nd »	38.84	-31.5	39.43	-27.9	38.13	-35.5
3rd »	36.40	-42.5	34.81	-37.1	38.31	-47.5
4th quarter	44.96	-28.5	40.93	-36.6	49.81	-18.2
Annual mean	39.05	-33.4	37.63	-34.5	40.78	-32.3
2013: 1st quarter	28.19	-21.7	27.09	-23.3	29.52	-19.9
2nd »	32.32	-16.8	26.93	-31.7	38.81	1.8
3rd »	34.70	-4.7	32.22	-7.4	37.69	-1.6
4th quarter	48.20	7.2	38.19	-6.7	60.26	21.0
Annual mean	35.85	-8.2	31.11	-17.3	41.57	1.9
2014: 1st quarter	26.08	-7.5	23.67	-12.6	28.99	-1.8
2nd »	37.89	17.2	28.24	4.9	49.52	27.6
3rd »	44.69	28.8	29.57	-8.2	62.91	66.9
4th quarter	56.93	18.1	42.53	11.4	74.30	23.3
Annual mean	41.40	15.5	31.00	-0.3	53.93	29.7
2015: 1st quarter	38.08	46.0	31.86	34.6	45.58	57.2
2nd »	39.88	5.3	32.26	14.2	49.06	-0.9
3rd »	32.54	-27.2	26.34	-10.9	40.01	-36.4
4th quarter*	51.18	-10.1	36.67	-13.8	68.68	-7.6
Annual mean	40.42	-2.4	31.78	2.5	50.83	-5.7

* = Provisional data.

(1) Adjusted data according to the real number of working days.

Table 2.5 EU Annual Construction Production Index, 2012-2015 (Source: ELSTAT, 2016:84)



4. EU: Annual changes (%) in Production Index in Construction, 2012 - 2015

Countries	2012	2013	2014	2015
EU 28	-5.7	-1.9	3.3	(1)0.8
Euro area				
Austria (AT)	3.5	0.4	-1.8	*-2.8
Belgium (BE)	-1.0	*-2.8	*-0.3	*-2.4
France (FR)	-5.3	0.4	-3.1	-4.2
Germany (DE)	-1.0	-0.3	2.7	-2.3
Greece (EL)	-33.6	-8.1	15.7	-2.9
Estonia (EE)	16.7	-0.1	-2.1	-5.3
Ireland (IE)	-2.4	11.4	8.1	*8.4
Spain (ES)	-5.4	1.4	*17.5	*1.5
Italy (IT)	-13.4	-10.7	-6.9	-1.8
Cyprus (CY)	-19.1	-23.7	-23.1	...
Latvia (LV)	14.4	7.4	7.9	-1.2
Lithuania (LT)	-7.2	11.3	16.9	-3.5
Luxembourg (LU)	-3.1	-4.3	3.2	-1.1
Malta (MT)	1.7	1.9	*1.6	*10.5
Netherlands (NE)	*-8.1	*-4.8	*3.2	*8.2
Portugal (PT)	-16.2	-15.9	-8.9	-2.5
Slovakia (SK)	-12.0	-5.4	-4.5	18.6
Slovenia (SL)	-16.8	-2.5	19.5	*-7.3
Finland (FI)	(1)-0.9	(1)-3.2	(1)0.4	(1)5.6
Non-euro area				
Bulgaria (BG)	-0.8	-3.4	6.6	*2.1
Denmark (DK)	-0.3	3.3	3.5	4.8
United Kingdom (UK)	*-7.6	*1.6	*8.7	*3.5
Croatia (HR)	-11.9	-5.4	-7.3	*-0.5
Hungary (HU)	-6.6	8.4	13.6	3.0
Poland (PL)	-5.0	-10.2	4.1	-0.3
Romania (RO)	1.4	-0.6	-6.7	*10.6
Sweden (SE)	-4.0	-3.5	12.4	15.6
Czech Republic (CZ)	-7.3	-6.9	4.3	5.6

Source: Eurostat.
* = Provisional data.
(1) Estimates.

2.2.3 Reasons for Construction Company Failure

According to the US census report, construction companies have a higher failure rate (14%) than most companies. According to Bashford (1996) only 26% of construction companies which started in 1976 were still in business in 1988 (Zayed and Liu, 2014). Al-Issa and Zayed (2007) emphasise on 2005 industry reports which showed that, out of the 853.372 construction specialty trade contractors operating in 2002, only 610.357 were still in business in 2004, with a 28,5% failure rate. A number of reasons have been suggested for the high rate of company mortality in construction: the ease of entry to construction, the fragmented structure of the industry, the high risky character of the construction process and the high proportion of subcontract work have all been identified as causes of failure.

Part of the problem seems to arise from the *ease of entry* to the industry which attracts inefficient contractors at a time of plentiful work. Construction firms have minimal capital requirements, arising from the system of *interim payments* during the execution of contracts, coupled with extensive credit concessions for materials purchasing and highly developed plant hiring facilities. This has encouraged an influx of hopeful entrepreneurs. Sadly, their demise often has been equally easy, though much more painful for their clients, creditors and staff who are left, respectively, with broken contracts, little redress and unemployment (Fellows *et al.*, 2002). Nonetheless, easy entry must logically be accompanied by ease of exit in a period of lower workload (Hillebrandt, 1977).

Another consideration is that very small contracting companies that dominate the construction industry are '… often vulnerable because they operate on a low level of invested capital or with only a small overdraft facility. If a client is slow to pay, or indeed fails to pay, they may not, therefore, have the financial resources to continue trading' (Upson, 1987:2-3). Furthermore, small firms often fail because of the financial failure of another company in the contractual chain. A significant number of insolvencies in construction occur as a direct result of the insolvency of another party – 'domino' or 'knock-on' effect (Davis, 1991). Thus, part of the insolvency problem is due to the industry's highly *fragmented structure*.

Hillebrandt (1977) argued that the reasons for the high rate of construction company failures are clear: the *high risks* involved, including that of pricing the product before it is produced; tendering as a method of pricing; the low fixed capital requirements; and a tendency to operate with too low a *working capital* (which can be done but requires a finely-balanced operation and can go wrong easily with a change in business conditions).

A construction project presents a unique problem to those involved in managing the construction production process. Each project is different from the others, carried out at a different location each time, and must be formulated and executed by integrating the efforts of a large number of organizations and individuals, all of whom have different (and often conflicting) priorities and objectives (Feiler, 1972). Frequently, each project constitutes a significant amount of a building contractor's annual turnover so that, if it goes wrong, it has a disproportionate affect on its overall financial position. This is especially so because the potential loss is a very high proportion of total turnover and, hence, of the total resources of the firm (Hillebrandt and Cannon, 1989).

It is largely these product characteristics, which determine the structure of the industry, including the large number of dispersed contracting companies and the separation of design in professional offices from physical construction production (Hillebrandt, 1985). This traditional separation of design and production within the industry may lead to consequent difficulties that can arise during the construction process. The shortfall between the architect's design and the contractor's requirements for information to construct may become the subject of a dispute which could lead to delays on site, under certification, or set-off as the works proceed (Davis, 1991).

The demand for constructed facilities is what the economists call *derived* demand. The structures produced by the industry are generally for investment rather than to be purchased for their own sake. As a result, construction is vulnerable to private-sector fluctuations in demand resulting from changes in expectations, a rise in the cost of borrowing, or induced changes related to the level of income (the *'accelerator'* effect) (Harvey, 1987).

The public-sector's demand for construction is affected, primarily, by the Government's use of monetary and fiscal measures to regulate the domestic economy. According to Briscoe (1988:42), the Government's monetary policy is a further cause of unstable construction demand '… as interest rates are important determinants of the willingness and ability to undertake investment in buildings and dwellings. Most construction work is financed by loan capital and, where monetary policy tightens the availability of loans and raises the cost of borrowing, demand for construction is likely to be significantly reduced'. The dependence of the construction industry on the state of the domestic economy and on the Government's policy, results in considerable *fluctuations* in demand for construction work and makes difficult the prediction of future trends in building contractors' download. Figure 2.1 shows the gross value added (in million €) by the Greek construction industry to the National economy's GDP for the period from 2000 to 2015 (ELSTAT, 2016).

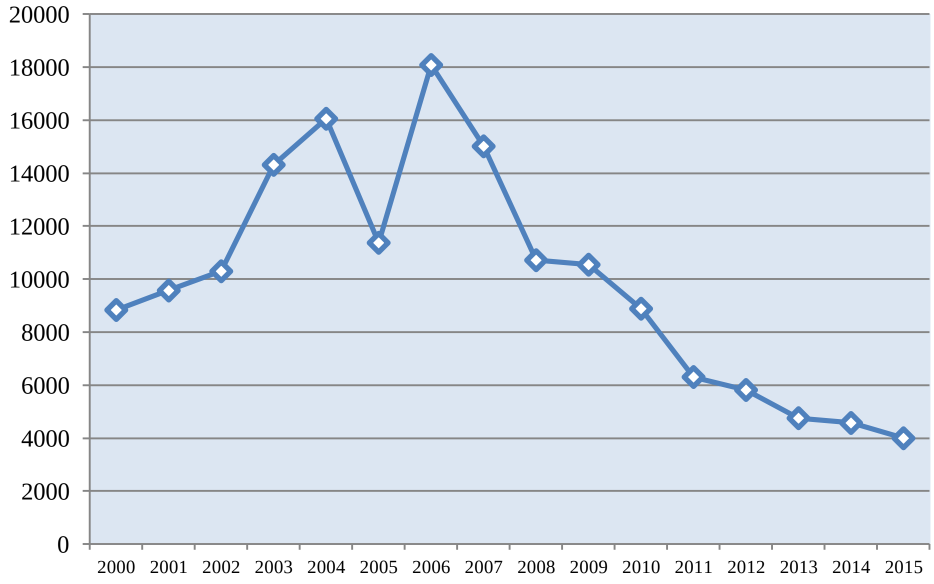


Fig. 2.1 Gross Value Added by Greek Construction Industry, 2000-2015 (Source: ELSTAT, 2016)

Obviously, the effect of these fluctuations is such that contracting firms, since they are not generally operating nationally or in all types of work, must remain very flexible in the type of work they mainly undertake and in their ability to survive in periods of low workload (Hillebrandt, 1985). Thus, the most common response of building contractors to shifts in demand for new construction work is *diversification* of activities. Such diversification permits the firm to divert resources more easily to the profitable areas of activity in the event of changes in the pattern of demand and provides a broader base for continuing existence since, although all industry sectors may be subject to recession, some sectors will be more adversely affected than others (Fellows *et al.*, 2002). Diversification, however, promotes the *use of subcontractors* as one of the major effects of the latter is '… greater flexibility of contractors to work anywhere in the country without having to transfer their labour force or recruit their own in the areas concerned' (Hillebrandt and Cannon, 1990:11). The high proportion of subcontract work has been suggested by Briscoe (1988) as another reason for construction enterprise failure. The majority of subcontractors are of small size, operating on a relatively narrow basic working capital, and their liquidity position is finely balanced. Thence, it is quite common for a subcontractor to go into liquidation or be declared bankrupt in the course of a contract with damaging consequences for the main contractor. Inevitably, *delays* result and significant *cost increases* are involved in securing another subcontractor to pick-up the pieces.

It could be argued that there exist several reasons for insolvencies of building firms, but *lack of liquidity*, cash or 'near cash', seems to be the major problem (Newcombe *et al.*, 1990). Nonetheless, as Woollett (1978) explained, shortage of cash need not lead to bankruptcy if building contractors could convince creditors and possible lenders of money that this inadequacy is only temporary. However, without convincing and accurate financial forecasts, contractors have little evidence to support the above contention. The need for the use of an effective system of financial management in construction is, therefore, vindicated.

2.3 The Unique Characteristics of Construction Projects

Construction projects have four distinct characteristics that make them unique: projects are generally very large in scale and complex, they are non-recurring, there are critical dates for completing portions of the project and a completion deadline for the entire project (Verma and Gross, 1978) and, finally, there are special professions like project planners and cost estimators (Zwikael, 2009). Each of these characteristics will now be discussed in some detail.

Construction is a multifaceted industry and construction projects are invariably not straightforward. They are generally unusually large in scale and extremely complex. The processes of tendering, contract award, work on site, completion and handover are often complicated and fraught with difficulties and sometimes disputes (Ross and Williams, 2013). Furthermore, construction projects are intricate, time-consuming undertakings. During the construction process itself, even a structure of modest proportions involves many skills, materials, and literally hundreds of different operations. The assembly process must follow a natural order of events that constitutes a complicated pattern of individual time requirements and restrictive sequential relationships among the structure's many segments (Sears *et al.*, 2015). Sometimes hundreds of contractors and suppliers are involved and their efforts must be co-ordinated. A delay in the supply of any one component or material could substantially delay the completion of the entire project. In some cases, the project may even come to a complete stop. The consequences in terms of costs of such delays could be disastrous especially in a recession period. Construction professionals are undoubtedly familiar of instances where a project was either started late or delayed during construction due to a labour dispute, non-availability of materials or downright inefficiency with the result that cost overruns have exceeded several hundred percent (Verma and Gross, 1978).

The second characteristic of construction projects is that they are generally of a *'one-shot'* nature. These projects are often too complex for a job shop type of operation and it is uneconomical to mass produce the item (Moder *et al.*, 1983). Some people may think of two construction projects as being identical just because they have the same design. In construction project management, there may be similar projects, but every project is unique. Differences may occur because of location (soil type, weather conditions, labour market, building codes, unforeseen conditions, etc.), labour skill level, management type and experience, or for other circumstances (and how much Murphy's Law was involved) (Mubarak, 2015). Firms in the construction industry undertake a range of discrete projects of relatively long duration, constructed outside and geographically dispersed and fixed. The majority of such projects are tailor-made to client's requirements, designed upon prescribed fee scales and built for a price established through the competitive tendering system which operates extensively in the industry. This system creates an unusual situation in which the product, i.e. a building, is sold before it is produced – a reversal of normal manufacturing practice. Individually, such projects frequently constitute a significant proportion of a firm's workload with serious consequences if things go wrong (Fellows *et al.*, 2002).

The third distinct feature of construction projects is that many critical dates exist by which certain portions of work must be completed in order to finish the entire project on schedule and that there is usually a deadline for completion of the entire project and some penalty for any delay beyond this deadline. In most contracts involving a large project, a completion date is part of the contract. This date, as agreed upon by both parties, specifies the time by which the project must be completed. If there is a delay, the contractor is charged a pre-set penalty in the form of a fixed amount per day or week late. Thus, the contractor is operating under a deadline unlike most other business ventures (Verma and Gross, 1978).

Another uniqueness of construction projects involves two specific positions which are not found in other sectors; these positions include *project planners* and *cost estimators* (Zwikael, 2009). Construction project planners add value to the contracting organisation by ensuring that estimating and tendering are based on a robust understanding of the methods, time and space required to carry out the tasks for each building contract and the corresponding risks involved (Winch and Kelsey, 2005). The second unique position in the construction industry is the ‘estimator’. The estimator’s main task is to predict the likely costs (Leung *et al.*, 2005) or resources involved in executing a future project (Tam and Tong, 2005). *Cost advice* and *cost planning* functions enable the QS to advise clients, architects, engineers and the other members of the design team of the probable costs of building schemes and on the costs of alternative designs before and during the design development phase of the project. This assists the design team to arrive jointly at practical designs for projects while staying within the owner’s budget. This advice enables design and construction to be controlled within predetermined expenditure limits at all stages of the project (Cunningham, 2014).

2.3.1 Construction Complexity

Construction projects are complicated entities, from the way they are designed to the way they are constructed, consisting of many materials put in place by workers, assisted by machines (Dell’Isola, 2002). In fact, the construction process may be considered the most complex undertaking in any industry (Bennett, 1991a). Moreover, the construction sector is highly fragmented and its firms co-operate in ever changing patterns. Almost all construction projects are divided into parts that are subcontracted to individual enterprises chosen mainly by lowest bid. As every firm, at the same time, participates in more than one project, utilizing the same production capacity, the industry as a whole is thereby also highly interwoven. Thus, due to its contracting practice, construction forms an interwoven network of high complexity and great dynamic (Bertelsen, 2003). Therefore, an understanding of project *complexity*, and how it might be managed, is of significant importance. However, the concept has received little detailed attention in the construction project management literature (Baccarini, 1996). Weaver (1948) defined complexity as a ‘sizeable number of factors, which are integrated into one organic whole’ and claimed that complexity is purely a gathering together of relevant variables, which are interrelated into a complicated fashion. Baccarini (1996), with emphasis towards the construction industry, defined project complexity as consisting of many varied interrelated parts and operationalised in terms of *differentiation* and *interdependency*. There are two types of complexity in projects, *organizational* and *technological*, and ‘it is important to state clearly the type of complexity being dealt with’. Baccarini (1996) also explained that technological complexity by differentiation refers to the variety or diversity of some aspect of a task involved on a project, such as the number and type of inputs and outputs, or the different tasks to produce the end product of a project, and by interdependency encompasses interdependencies between tasks within a network of tasks, or between different technologies.

Morris (1988) pointed out that differentiation and inter-dependencies can be managed through *integration*. Thompson (1967) asserted that the essential management function of project integration is especially important for construction projects as they are typified by strongly differentiated but largely interdependent components. As described by the Tavistock Institute (1966), the nature of *construction production*, which is the dominant *conversion process* performed by construction firms, is one of ‘interdependent autonomy’. This unique and temporary character of the (usually dispersed to a number of decentralised building sites) conversion process creates a high degree of technical and social complexity amongst the parties involved so that interdependency and *uncertainty* are key features of construction.

Williams (1999) stated that to support the construction project management function, in particular *planning*, *forecasting*, *monitoring* and *control*, analysts must be able to model complex projects:

- Classical *bottom-up* project decomposition models such as *network* models can be improved to include *stochastic* effects, or the effects of management decisions. Models of *time and cost risk* can be developed by modelling the combination of many risk elements. *Simulation* models can be built to mimic the behaviour of many project elements of different types in combination.
- Alternatively, *top-down holistic* models can be built. Such models usually fail to capture the detail desired by operational management, but they allow a strategic overview in the modelling of systemic effects that bottom-up methods miss out.
- Traditional methods capture only *'hard'* quantitative data. It has become clear that *'softer'* Operational Research methods must also be included in project models, if they are to be a useful representation of real projects.

Walker (2002) and Hughes (1989) have shown that there are complex interdependencies in construction projects and that differentiation in terms of skills or components (technology) is needed according to the complexity of the project's environment. Such diversity represents the amount of technological differentiation, and could be defined as the number of people of different trades or the number of 'work elements'. Such a measure would be well suited to the industry, which in terms of components is well suited to the methods of quantification. The literature shows that the measurement of complexity is very confused and diverse in nature. The main problem is that there is a lack of effective tools for measuring complexity (Gidado, 1996).

As a result, engineers are increasingly concerned with complex systems, in which parts interact with each other and with the outside world in many ways; the relationship between these parts determine how the system behaves (The Royal Academy of Engineering, 2007).

2.3.2 Uncertainty and Risk in Construction

Making a decision involves unknowns: risks and/or uncertainties. Risk may be defined as an unknown, the probability of the occurrence of which *can* be assessed by statistical means. Uncertainty, on the other hand, is an unknown, the probability of the occurrence of which *cannot* be assessed. As knowledge increases, and the wealth of statistical data regarding uncertain events increases, areas of uncertainty may be progressively transferred to areas of risk (Fellows and Langford, 1980). In order to make this transition, two important activities must take place: identifying the sources of uncertainty in the various stages of the process, and determining their probability distribution parameters. Thus, the inherent risk can be estimated and building developers can make a calculated decision concerning whether or not to undertake the project based on their acceptability of risk (Loizou and French, 2012). In essence, the usual distinction between risk and uncertainty is that measures of risk are based to some extent upon the existence of past evidence to support the level of risk attributed to the likelihood of similar future occurrences arising again. Uncertainty, on the other hand, is characterised by the distinct lack of supportive evidence or information about the different degrees of likelihood of a future event happening or not (Wright, 1996:86).

The duration of project activities, the amounts of various resources that will be required to complete a project, the estimates made of the value of accomplishing a project, all these and many other aspects of a project are uncertain. While a project manager may be able to reduce uncertainty, it cannot be eliminated. Decisions must be made in the face of the ambiguity that results from uncertain information. Risk analysis does not remove the ambiguity; it simply describes the uncertainties in a way that provides the decision maker with a useful insight into their nature (Meredith and Mantel, 2012).

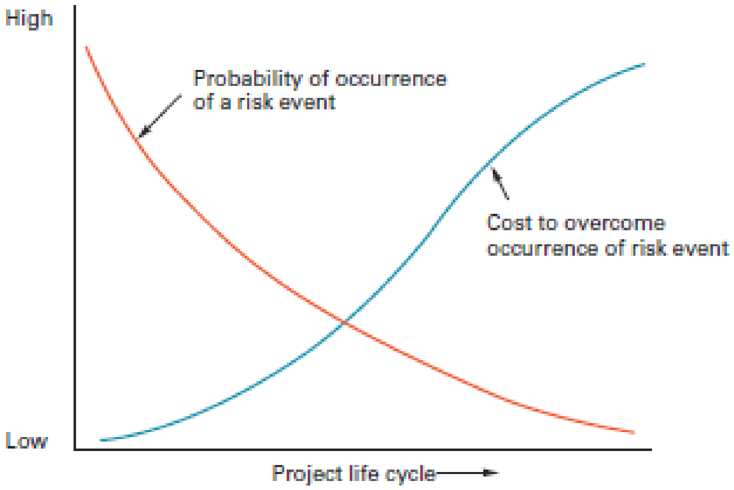


Fig. 2.2 The Relationship between Cost and Risk (Source: Gray and Larson, 2008)

Risk analysis starts with early planning in both budgetary cost estimating and preliminary scheduling in order to determine budgets and schedules with a comfortable level of confidence in the completion date and final cost. However, while there are entire volumes addressing risk in construction projects, it is important to note that the issue of time-related risk has not been universally incorporated into planning. Assessing cost risk is more intuitive and very often is done through the use of heuristics, so it has become more of a standard in the industry than time-related risk management (Mubarak, 2015). Figure 2.2 shows the relationship between the probability of occurrence of a risk event and the associated cost to overcome the occurrence of that risk event (Gray and Larson, 2008).

2.3.3 Systems Theory in Construction Project Management

Systems theory – originated from the articles of Ludwig von Bertalanffy (1951) in Biology and Kenneth Boulding (1956) which have provided the foundation for general systems theory – is essentially a *way of thinking* about *complex* processes so that the inter-relationships of the system parts and their influence upon the effectiveness of the total process can be better understood, analysed and improved (Walker, 2002). A *system* is ‘an organized or complex whole; an assemblage or combination of things or parts forming a complex or unitary whole (Johnson *et al.*, 1963)’. Nowadays, a ‘system’ is seen by business practitioners as a group of elements, either human or non-human, that is organised and arranged in such a way that the elements can act as a whole towards achieving some common goal or objective (Kerzner, 2009).

Project management is a systems approach to management. A project is a goal-oriented system of inter-related components – tasks and stakeholders – functioning in a larger environment; the purpose of project management is to unify or integrate the components – the interests, resources, work efforts of many stakeholders, as well as schedules, budgets, and plans – to accomplish the project goal (Nicholas and Steyn, 2008). The construction project is a good example of a system that can be studied over its full lifespan. The project can be viewed as a temporary system, set up for a specific purpose, with well-defined tasks and a set timescale (Miller and Rice, 1967).

In construction, there is a *technical* sub-system, the network of activities required for the physical erection of the building, and a *social* sub-system, the human resources who contribute their capital, energy and skills to the project. Both parts of the system are intertwined (Fryer, 1990). Early relevant studies conducted by Ireland (1985), Rowlinson (1988) and Hughes (1989) illustrated the potential for the application of systems theory to the building process. The fundamental premise of systems theory stresses the inter-relationships and is concerned not only with the links between the parts of the system but also with the parts themselves. The problem of how to make the links work effectively is essentially the problem of project management. In order to apply these ideas to the construction process to the greatest benefit, it is necessary to take as broad a perspective of the process as possible from conception of the project to completion and even beyond (Walker, 2002).

Moreover, construction is an *open system* and the success of a building project depends not only on effective *internal* management but on the activities of various *external* factors affecting the construction business, many of which are beyond management control (Fryer, 1990). These external and internal influences are referred to as the *project context* or *environment*. The external factors include: the client, various external consultants, contractors, suppliers, competitors, politicians, national and local government agencies, public utilities, the end users, and even the general public. Internal influences are the organization's management, the project team, technical and financial departments, and possibly the shareholders (Lester, 2014). Cleland and King (1983) stressed the strong influence of general systems theory on the development of *network-based* project management methodology. A systems-oriented manager realises that the overall organisational goals can be achieved only by viewing the entire system. To succeed this, increasing use of objective *scientific analysis* is required in solving decision problems. These methods rely on *models*, i.e. formal abstractions of real world systems, to predict the outcomes of various alternatives in complex situations. As explained by Moder *et al.* (1983), by using network-based techniques, the systems approach may be viewed as a logically consistent method of reducing a large part of a complex problem to a simple output. This output can then assist decision-makers, in conjunction with other considerations, to arrive at a best decision. It permits them to put aside those aspects which are best handled by systems analysis, and to focus on the parts of the problem that are most deserving of their individual attention. In this way, managers are able to get the 'big picture' in its proper perspective, rather than requiring them to devote attention to a myriad of minor, seemingly unrelated aspects of the total system.

Newcombe *et al.* (1990) pointed-out that systems thinking can be a powerful tool for studying the construction process by using inter-related sub-systems to pursue project goals (Figure 2.3); the analysis involves the use of the following procedures:

- Define the system: (a) by describing its *primary task* – what the system is and what it does; and (b) by establishing its *boundaries* – what is inside and what is outside of the system.
- Identify the component parts of the system: (a) the *inputs* to the system; (b) the *outputs* of the system, both tangible and intangible; (c) the *conversion processes* which the system uses to transform the inputs into outputs; and (d) the *feedback* loops which complete the *input-conversion-output* cycle.
- Define the environment of the system: what is outside the system in terms of the external elements which impact on the system and *vice versa*.

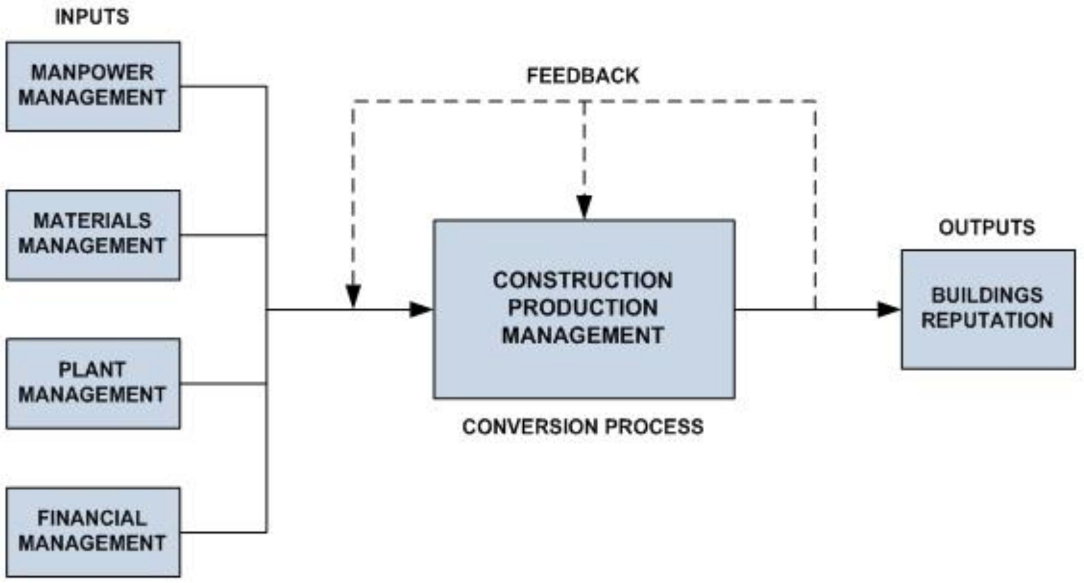


Fig. 2.3 Construction Management Systems Model (Source: Newcombe *et al*., 1990)

In the *PMBOK*$^{©}$ *Guide* (PMI, 2013), this systematic view of analysing and managing each of the totally nine project management *knowledge areas* is also obvious through the use of an *inputs-tools and techniques-outputs* process. Furthermore, a number of standard textbooks in the field (Nicholas and Steyn, 2008; Kerzner, 2009) have also adopted a systems approach to the management of projects.

To be systematic is to do things correctly or efficiently with clear objective(s) in mind. However, firm and clear objectives and courses of action are not always feasible, especially when dealing with large projects that utilize new and unfamiliar technology. There is also the tough question of whether the right things are being done in the first place when working under pressure in a rapidly changing project environment. In strategic decision-making, or in pre-project planning, it does pay to take a little longer to concentrate and think through all the related issues from different perspectives to create the rich picture of the reality, and subsequently to construct an enriched mental model that will lead to satisfactory problem solving (Yeo, 1993).

2.4 The Building Product Development Process

The components of every commercial transaction are a customer who wants a product, the product itself and a firm which designs, makes and/or sells the product. The construction industry is no exception. The principal components in any construction situation are the client, the project and the firm. The client may be defined as the sponsor of the construction product or service. The client may come from the private or public sector of industry, commerce or government. It may be a private individual or a large corporation. It may have a continuing building programme or build only once in its lifetime. Most clients are outside the construction industry and, therefore, are not familiar with common practices in the industry. The project is the design and production of the construction product. That product may, for example, be a building, or a bridge, or a motorway. The construction project is complex, discrete, and often bespoke. It is a distinctive undertaking, drawing on the skills of a variety of people operating within a well-defined financial and contractual framework. The firm is the design and production unit in the construction industry. The firm is the permanent and continuing component and the base for the long-term development of resources. The firms directly involved in design and/or production are firms offering a design or design-related service to the client, building contractors and firms offering a design and production service to the client (including speculative developers) (Fellows *et al.*, 2002). Buildings are constructed, altered, upgraded, restored or demolished for a variety of reasons. Whether the purpose is simply to create more space or to earn a financial gain from speculative development, all building projects need to fulfil a specific function and meet set performance criteria, no matter how fundamental or sophisticated the client's requirements may be (Emmitt and Gorse, 2014). Since the commitment of resources for such an investment is motivated by market demands or perceived needs, the facility is expected to satisfy certain objectives within the constraints specified by the owner and relevant regulations. With the exception of the speculative housing market, where the residential units may be sold as built by the real estate developer, most constructed facilities are custom made in consultation with the owners (Hendrickson, 2008). The development process applied to a construction project commences at inception and ends with demolition, when redevelopment of the site may occur. Table 2.6 (page 62) indicates the different stages of development, although in practice these are not discrete activities. The traditional view considers the project from inception through to the handing-over stage to the client. This might more correctly be termed the *capital development* process. However, this is an outmoded view; greater emphasis is now being placed on whole-life project analysis, designers or developers thus taking a longer term interest, and often advising the client on maintenance planning and facilities management throughout the entire project life. This links the design to use, makes the designer more accountable and should result in a feedback loop of problems not being repeated on future schemes (Ashworth, 2004). In progressing from initial planning to completion, the typical job passes through successive and distinct stages that demand inputs from such disparate areas as financial companies, governmental agencies, engineers, architects, lawyers, contractors, insurance firms, material manufacturers, suppliers, and building tradesmen (Sears *et al.*, 2015).

Table 2.6 The Construction Development Process (Source: Ashworth, 2004)

Stage	Phase	Typical time duration (years)
Inception	Brief Feasibility Viability	1
Design	Outline proposals Sketch design Detail design Contractual documentation Procurement	1
Construction	Project planning Installation Commissioning	3
In use	Maintenance Repair Modification	80
Demolition	Replacement	-

One of the goals for the majority of project owners is to deliver the completed project within the budget established for that project. This requires that the project team develop, implement and operate procedures intended to establish realistic costs at the outset of the project and monitor those costs throughout the pre-design, design, procurement, construction and the post-construction phases of the project. Some of the procedures developed should relate to controlling cost, or stemming cost growth, through these five project phases (CMAA, 2008). Construction is a major capital expenditure which clients do not commence until they are certain that there is a benefit. This benefit may be social in the case of public projects, with justification based normally on a cost-benefit analysis, or purely based on financial considerations in the case of private projects. Most clients are working within tight, predefined budgets, which are often part of a larger overall scheme, and if they are exceeded, the scheme could fail. *Pre-contract estimating* sets the likely expenditure to the client and assists in ensuring that the design stays within the scope of the original scheme. When developing an estimate the factors need to be considered are:

- land acquisition, including legal fees;
- client's own organization costs allocated to the project (this obviously varies but can be as much as 10% of the overall project budget);
- site investigation (frequently under rated and under budgeted, resulting in unnecessary extra costs and time – this could be as much as 1% of budget);
- enabling works, de-contamination;
- insurances (many major clients prefer to insure against the risks and take out a project insurance policy covering both themselves and the contractor – this may be up to 1% of the budget);
- consultants' fees, including design (on large transportation and infrastructure projects this can be as much as 15-20% of the budget);
- construction costs (these typically account for between 70% and 80% of the project sum, excluding land);
- value added tax (currently charged at 24% in Greece);
- contingency and risks (this covers for the unknown and may be between 20% and 25% or, if the project is of long duration, the contingency factor could be double or triple these amounts);
- financing and legal costs (financing costs can be substantial, depending on the financing method chosen and typical bank rate – these could amount to anything between 7% and 20%; lawyers are expensive, at anything up to £500 per hour and more) (Potts and Ankrah, 2013).

Estimates of the cost and time are prepared and revised at many stages throughout the project cycle. These are all predictions and should not be considered 100% accurate. The degree of realism and confidence achieved will depend on the level of definition of the work and the extent of the risk and uncertainty. Consequently, as the design develops, the accuracy of the estimate should improve (Potts and Ankrah, 2013).

2.5 Construction Project Economics

Hillebrandt (2000) and Ashworth (2004) broadly defined *building economics* as a special branch of general economics which consists of the application of the principles associated with general economic theories to the particular needs and requirements of the construction industry. It is concerned with the study of the building industry and its place within the economy, the construction firm, the roles of the designers and constructors, the processes employed and the final product of buildings and other structures.

Tempelmans Plat (2001) stated that building economics is the field that covers all research and educational activities in which the built environment in its various phases and levels of aggregation is viewed through ‘economic glasses’. According to Bon’s (1989) project-oriented definition, ‘Building Economics is about economising the use of scarce resources throughout the life-cycle of a building. The most ‘Economic’ building is the one that provides the values required at the lowest cost’. The three keywords in the above definition are *life-cycle*, *value* and *cost*. The relationship between these three concepts distinguishes building economics from related disciplines (Mulligan, 1993).

Generally, building owners wish to lower costs or increase revenues. To accomplish this, buildings must be located, designed, engineered, constructed, managed, and operated with an eye to the economic consequences of these decisions:

- Owners need to select locations which enhance income opportunities, or lower costs, or both;
- Architects need to consider the owning and operating costs of alternative designs;
- Mechanical and structural engineers need to take into account the economy of alternative designs and sizes of building systems and components;
- Architects and engineers need to work together to make economic trade-offs between the building envelope and mechanical systems;
- Construction companies and builders need to select cost-effective materials, equipment, and construction techniques;
- Building managers and operators need to establish cost-effective maintenance, repair, and replacement policies, and to decide when and what to renovate.

In short, those who design, engineer, construct, manage, operate, and own buildings are faced with decisions affecting the *economics of buildings* (Ruegg and Marshall, 1990).

The building site and the structures constructed on the land are *economic assets*. In addition to the cost of the land there are three interrelated costs to consider. The first is the initial cost, the cost of designing and erecting the building. This is usually the primary and sometimes the only concern of clients and developers. It covers professional fees and associated costs involved in land acquisition and permissions, the capital cost of materials and components and the labour costs associated with carrying out the work. The second cost to consider is the cost of the building in use, i.e. the costs associated with routine maintenance and replacement and the costs associated with heating and servicing the building over its life. These costs can be reduced by sensitive design and detailing, for example designing a building to use zero energy and to be easy to maintain will carry significant cost benefits over the longer term (not to mention benefits to the environment). All materials and components have a specified design life and should also have a specified service life. Designers and contractors need to be aware of these factors before starting work, thus helping to reduce defects and maintenance requirements before construction commences. The third cost is the cost of materials recovery at the end of the life of the building, i.e. the cost of demolition, recycling and disposal. All three areas of cost associated with building should be considered within a whole-life cost model, from which decisions can be made about the type of materials and components to be used and the manner in which they are to be assembled (and subsequently disassembled). This links with issues concerning maintenance, repair renovation and recycling (Emmitt and Gorse, 2014).

2.5.1 Cost Engineering/Quantity Surveying

The engineering practice devoted to building economics, involving the application of scientific principles and management techniques in such fields as estimating, cost control, cost forecasting, investment appraisal and risk analysis, is *cost engineering* – this is a definition derived from the publication *Provoc – Glossary of Common Project Control Terms* of the Association of Cost Engineers (ACostE). Ahuja and Walsh (1983) defined cost engineering as '… an active approach in the design, construction and commissioning phases of a project, aimed at extracting the best possible value for money throughout each activity that has cost implications'. As Greves and Joumier (2003) explained, the discipline of cost engineering essentially attempts to capture practical experience in a systematic way, to analyse that past experience in order to develop tools and models which, together with *expert judgement*, can be applied under different circumstances and the information available, to make predictions of likely cost, to assess whether a proposed budget is feasible and to address risks and opportunities.

According to *Wikipedia*, the skills and knowledge areas of cost engineering are similar to those of *quantity surveying*. The Australian Institute of Quantity Surveyors (AIQS, 2016) defines the *quantity surveyor* (QS), also known as *construction economist* or *cost manager*, as the professional adviser to estimate and monitor construction costs, from the project feasibility study through to the completion of the construction production phase. QS use techniques such as cost planning, estimating, cost analysis, cost-in-use studies and value management to advise the owners on the most economical way of achieving their requirements, to establish the project budget, and to ensure that the execution of the project remains on budget through cost management.

In a 1971 Report on *'The future role of the Quantity Surveyor'*, the Royal Institution of Chartered Surveyors (RICS) explained that the QS role is to ensure that the resources of the construction industry are utilized to the best advantage of society by providing, *inter alia*, the financial management for projects and a cost consultancy service to the client and designer during the whole construction process (Ashworth *et al.*, 2013). Quantity surveying is therefore concerned with controlling and managing the costs of construction projects from feasibility, design and construction, through to extension, refurbishment, maintenance and even demolition. Therefore, an understanding of the technical aspects of construction over the *whole life-cycle* of a building or facility is required (RICS, 2015). Cunningham (2013) pointed out that the cost of constructing a building project is a primary concern for the vast majority of construction clients and indeed providing answers to initial questions such as *'what is going to cost me?'* or *'can we do it any cheaper?'* is a key objective of quantity surveyors whose task is to predict the likely cost of building work and to manage the evolving project design to ensure that the client's approved budget is not exceeded. This is a challenging task, which frequently involves *one-off*, unique, purpose made buildings, and the QS typically operates within a design team brought together specifically for that particular project.

The main professional disciplines providing specialist project cost management services around the world are *cost engineers*, *quantity surveyors*, *construction economists* and *project managers*. Quantity Surveying is a profession with origins in the UK and is a professional title recognised mainly in Commonwealth countries. Cost Engineering is the term mainly used in North and South America, China and some parts of Europe. Construction Economist is used in some European countries and in other parts of the world as an alternate descriptor for the service. In other regions, particularly in Europe, these three professional titles are not recognised with cost management services largely carried out by Project Managers as part of their suite of services. A relatively new professional discipline of Project Controls has also emerged as a more encompassing descriptor of the role of the cost manager. The fundamental cost management principles and practices of these professions are the same (Smith, 2014).

2.5.2 Cost Management Fundamentals

Potts and Ankrah (2013) define *cost management* as ‘the process that is necessary to ensure that the planned development of a design and procurement of a project is such that the price for its construction provides value for money and is within the limits anticipated by the client’. Cost management’s objective is to control all those processes necessary to deliver the project within the approved owner’s budget (CMAA, 2008). According to the *PMBOK*© *Guide* (PMI, 2013) cost management includes three interactive processes required to ensure that projects are completed within the approved budget (Figure 2.4, page 69):

- *cost estimating*: developing an approximation (cost estimate) of the costs of the resources (including, but not limited to, labour, equipment, materials, services, facilities, and/or contingency allowances) needed to complete schedule activities;

- *cost budgeting:* aggregating the estimated costs of individual schedule activities (or work packages), in accordance with the work breakdown structure (WBS) which subdivides the entire project into its component elements and establishes the relationships among all the above components, in order to establish a total *cost baseline* for measuring project performance; and
- *cost control:* influencing the factors that create *cost variances* (positive/negative changes to the cost baseline) and controlling changes to the project budget in order to prevent quality or schedule problems or unacceptable levels of risk later in the project.

Cost management has, therefore, two distinct stages: in the pre-construction stage, the QS collects cost information from various sources; participate in providing cost estimates at the planning and design phases; have an active role in value analysis; and guard against cost growth; in the construction stage, the QS plays an active role in progress payment, change order (to limit scope creep), and claims processes (CMAA, 2008).

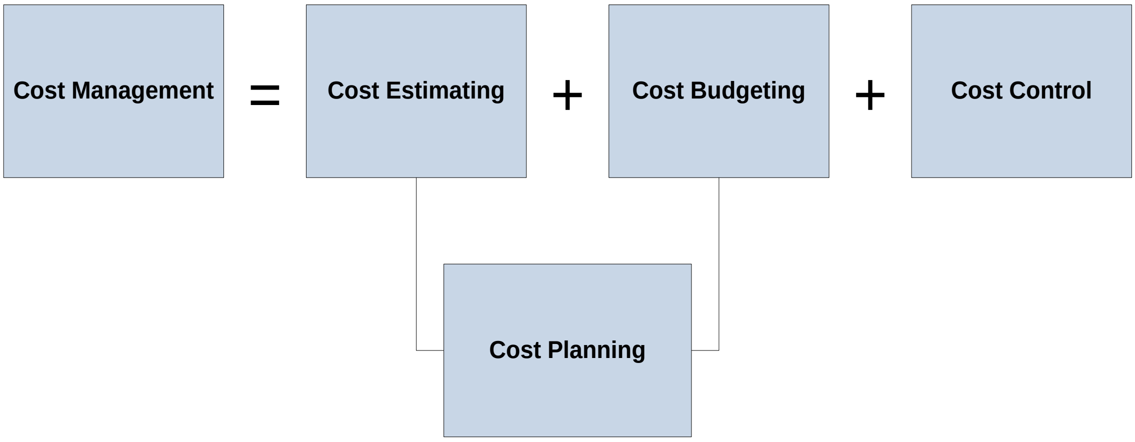


Fig. 2.4 The Cost Management Process (Source: Newcombe *et al.*, 1990)

Cost management begins at *project inception*. Virtually as soon as the project owner conceives of a project concept someone needs to start considering costs. Few project owners ever have unlimited funds. One of the biggest challenges during the *pre-design* phase of the project is gaining a thorough understanding of the project definition. Project stakeholders need to arrive at a rough agreement concerning the scope of the project before a conceptual estimate can be made and a preliminary budget established. A conceptual *budget* is, therefore, based upon an estimate of the cost of the project's concept (CMAA, 2008). Conceptual project cost can be estimated by using one of the following methods (Doloi, 2011):

- *analogous estimating (top-down estimating)*: uses actual costs of similar *previously performed* projects as a basis for estimating the cost of *this* project;
- *parametric modelling*: this form of estimating uses known project characteristics (parameters) in a mathematical equation to arrive at current project costs; square footage cost, per bed cost, megawatt cost, etc. may all be used in parametric modelling to arrive at a conceptual estimate;
- *bottom-up estimating*: the technique involves estimating the cost of individual project components and then summing the total of the project component estimates; and
- *computerised estimating:* more common today than ever, there are a number of computer software systems on the market that have *national cost databases* embedded within them; the estimator can start by inserting conceptual project information into these computer models and arrive at a conceptual estimate based on the data contained within the software.

Budget control is a critical aspect of a construction project. Costs can exceed budget for a number of reasons, and unless corrective action is taken, serious cost overruns can occur, possibly putting the project in jeopardy. Cost overruns can occur for various reasons. One possibility is that initial estimates might have been overly optimistic. Another is that unforeseen events such as weather or supplier issues, work or parts that were substandard and had to be remedied or some other event added costs (Stevenson, 2012).

2.5.2.1 The Difference between Cost, Price, Value and Profit

In the construction industry, the terms *cost, price, value* and *profit* represent different interpretations depending on the individual. Their particular meaning generally lies in the context in which they are being used.

The primal ambiguity is the distinction between cost and price. Cost is a quantitative measurement of the resources needed to produce an item; or rephrased, it is the amount of money needed to actually produce that item (Cunningham, 2014). Cost, to the building contractor, represents all those items included under the heading of his expenditure and it relates largely to manufacture, whereas price relates to selling (Ashworth, 2004).

The money paid by the client to the contractor is the contractor's price for providing the project and represent revenue for the contractor. The price of a building project is assumed to cover the contractor's direct costs of executing the work, the company's head-office overheads, the profit considered to be possible in the existing market conditions and the risk if the probability of making a *loss* is assessed as being greater than that of *breaking-even* (Harris and McCaffer, 2001).

Profit, the excess of income over expenditure, is probably the most important criterion for an economic decision, particularly in the construction industry. If a firm wishes to remain in business, conventional economic theory dictates that it must make a profit in the long term. Normal profit, i.e. the net earnings necessary to retain the entrepreneurs in business, is thus regarded as a long term 'cost', in addition to the traditional (and more easily appreciated and accepted) costs. Over a shorter period, a firm may continue to operate provided it covers only its variable costs, any excess earnings over this assisting with the payment of fixed costs. This theory assists in the explanation of why and how firms survive in recessions by ‘buying work’. Whilst ‘buying in’ work is automatically seen as unattractive, it may still give positive utility value to a firm (Fellows and Langford, 1980).

Value is a much more subjective term than either price or cost. In the economic theory of value, an object must be scarce relative to demand to have a value. Where there is an abundance of a particular object and only a limited demand for it, then, using the economic criteria, it has little or no value attributed to it. Value constitutes a measure, therefore, of the relationship between supply and demand. An increase in the value of an object can therefore be obtained either through an increase in demand or a decrease in supply. Maximum value is assumed to be found when a required service or function is attained and when the cost of providing that service or function is at a minimum. Value in this context can be measured objectively, but any solution found through such a procedure risks sub-optimisation. Any increase above the required level of either service or function, for a small extra cost, would often be perceived by clients as better value (Ashworth, 2004). A more meaningful approach when applied to the built environment considers the following four components that when aggregated combine to provide a clearer picture of value:

- *use value* – this is the benefit attached to the function for which the item is designed.
- *esteem valu*e – this attribute measures the attractiveness or aesthetics of the item.
- *cost value* – this represents the costs to produce or manufacture the item and to maintain it over its period of possession or life (whole-life costing).
- *exchange value* – this is the worth of an item as perceived by others who are primarily interested in its acquisition (Ashworth, 2004).

2.5.2.2 Cost Estimating

A key fundamental in the profession of *cost estimating* is that the focus is on costs, not price (Cunningham, 2014). Conceptual cost estimating is strategically important because it is an essential part of project planning (Doloi, 2011). Cost estimating is the predictive process used to quantify, cost, and price the resources required by the scope of an investment option, activity, or project. Cost estimating is a process used to predict uncertain future costs. In that regard, a goal of cost estimating is to minimise the uncertainty of the estimate given the level and quality of scope definition. The outcome of cost estimating ideally includes both an expected cost and a probabilistic cost distribution. As a predictive process, historical reference cost data (where applicable) improve the reliability of cost estimating. Cost estimating, by providing the basis for budgets, also shares a goal with cost control of maximizing the probability of the actual cost outcome being the same as predicted (Cartlidge, 2015). During the first half of the twentieth century six methods of estimating were used (Figure 2.5, page 74). The methods are much the same today; the main difference is the current popularity of elemental cost models, which are used by QS and contractors alike, in advising clients on their likely building costs, and helping designers to work within a budget (Brook, 2008). Methods of estimating, used in the early stages of cost planning, depend on reliable historical cost data whereas an analytical approach to estimating is based on applying current prices for resources to a well-developed design. A contractor may use a combination of estimating methods in developing a cost for a design and build project (Brook, 2008). Conceptual cost estimating is synonymous with approximate cost estimation and is the method of forecasting project cost with insignificant design information and incomplete scope definition and using the result to determine feasibility, screen project alternatives and make important project decision go/no go and the appropriation of funds. Usually the evolved estimate must be adjusted for dissimilarity with proposed project specification, time, location and size (Ajator *et al.*, 2015). Carr (1989) explained that *cost estimating* is to produce a statement of the approximate quantity of material, time and cost to perform construction and its purpose is to provide information to typical construction decisions such as procurement and pricing of construction, establishing contractual amounts for payment and controlling actual quantities by project management. Carr (1989) also suggested seven general estimating principles that guide good estimating practice: an estimate must be an *accurate* reflection of reality; an estimate should show only the *level of detail* that is relevant to decisions; *completeness* requires the estimate to include all items that will be in the facility, yet to add nothing extra; *documentation* must be in a form that can be easily understood, checked, verified and corrected; attention should be given to the distinction between *direct and indirect costs* as well as between *variable and fixed costs*; and *contingency* allowances must cover possible or unforeseen occurrences.

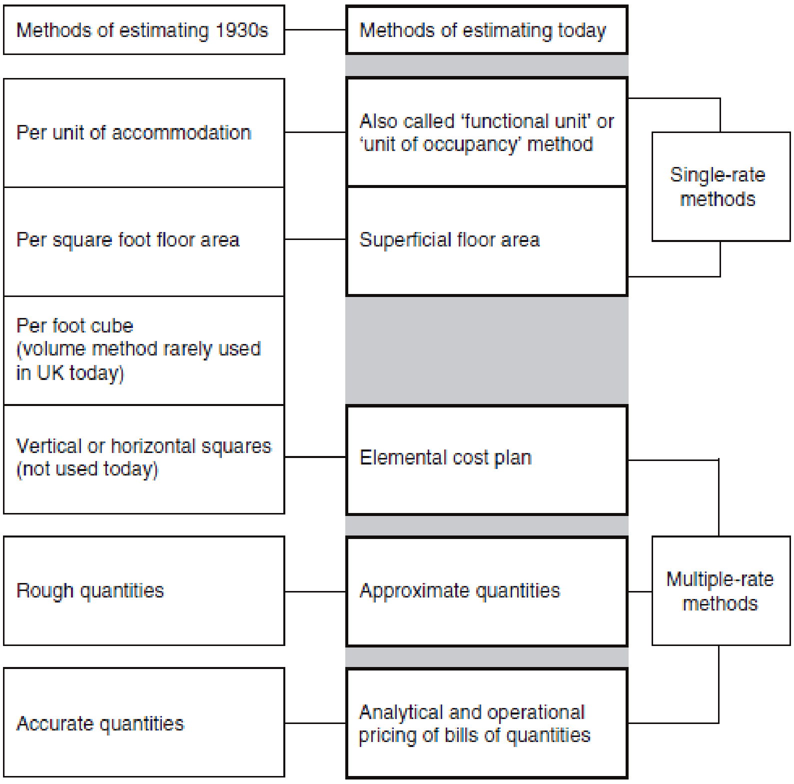


Fig. 2.5 Cost Estimating Methods (Source: Brook, 2008)

2.5.2.3 Cost Budgeting

The total project cost must, therefore, include the following in addition to the estimated construction cost.

- land acquisition cost;
- architectural, engineering and other design related costs;
- design contingency costs;
- construction management cost;
- financing cost;
- owner's management cost; and
- other costs depending on the nature, type and location of the project.

The total sum of all these costs then forms the *project budget*. It is this initial budget which forms the basis of the cost control plan. That is, all costs are compared to this initial budget. Conceptual cost budgets are based on conceptual cost estimates. Conceptual estimates are, by their very nature, based only on the most general project information (CMAA, 2008).

Authors generally agree that all estimates should be accompanied by some indication of accuracy (i.e. $^{+}/_{-}$ some percent) but there is no agreement on the percentage variances. For example, when considering conceptual estimates, Ritz and Levy (2013) suggest a level of accuracy of $^{+}/_{-}$ 25% to 30% for what is referred to as *feasibility* estimates.

The Association for the Advancement of Cost Engineering International (AACEI, 2006) refers to this estimate as an *order of magnitude* estimate and defines the accuracy at +50% to -30%. Analysis of project 'failures' all too often leads to the conclusion that an inadequate project budget was established at the outset, thus dooming the project (CMAA, 2008).

2.5.2.4 Cost Monitoring and Control

Planning (estimating and budgeting) is the process of preparing for the commitment of resources in the most effective fashion. *Controlling* is the process of making events conform to schedules by coordinating the action of all parts of the organisation according to the plan established for attaining the objective (Moder *et al.*, 1983). An effective cost monitoring and control system should contain the following characteristics:

- a budget for the project should be set with a contingency figure to be used at the discretion of the responsible manager;
- costs should be forecast before decisions are made to allow for the consideration of all possible courses of action;
- the cost-recording system should be cost effective to operate;
- contractors' cost control and monitoring;
- actual costs should be compared with forecasted costs at appropriate periods to ensure conformity with the budget and to allow for corrective action if necessary and if possible;
- actual costs should be subject to variance analysis to determine reasons for any deviation from the budget; and
- the cost implications of time and quality should be incorporated into the decision-making process (CMAA, 2008).

The purpose of cost control can be generally identified as follows (Ashworth, 2004):

- to limit the client's expenditure to within the amount agreed. In simple terms this means that the tender sum and final account should approximately equate with the budget estimate;
- to achieve a balanced design expenditure between the various elements of the buildings; and

- to provide the client with a *value for money* project. This will probably necessitate the consideration of a total-cost approach.

2.5.2.5 Cost Modelling

In the context of the economics of building design, two approaches to modelling may be distinguished: a). *deductive models* which use the techniques of statistical inference to deduce relationships between building features or design decisions (such as floor area) and cost; and b). *inductive models* which, on the other hand, are causal in nature, i.e. the resource implications of design decisions are calculated and aggregated to give the measure of economic performance (Raftery, 1984). *Linear regression* (LR) analysis as a cost modelling tool is a technique which enables the project cost to be expressed in very few items (McCaffer, 1975). According to Ashworth (2004), the idea of using regression analysis for estimating construction costs, both at the design stage and by the contractor, was developed by Professor Geoffrey Trimble at Loughborough University (UK) in the 1970's. Several research projects were undertaken to examine the practicalities of its use (McCaffer, 1975; McCaffer *et al.*, 1984). The method was considered to be appropriate for construction forecasts and is founded on the assumption that reliable estimating can be based on a sound knowledge of previously achieved project performance (Ashworth, 2004). Forecasting construction cost is mostly associated with forecasting an estimate (Raftery, 1991). Thus, by definition alone, it is impossible for a cost estimator to predict the costs of a building project accurately in advance. Both clients and contractors are unable to determine with any degree of accuracy the likely cost of a one-off project designed by others (Ashworth and Skitmore, 1983). Therefore, it has to be accepted that building cost forecasting can only be based on predictions and that these are subject to errors. Past trends are not always a sound basis for future predictions and estimators will frequently need to apply considerable intuition and skill in forecasting future costs. Moreover, the use of sophisticated formulae and mathematical models will not necessarily provide the correct solutions (Seeley, 1996). As Cusack (1984) explained, the majority of the mathematical cost models suffer from difficulties and inaccuracies inherent in the complex analysis necessary to derive a set of constraints from the project plan and the consequent need for high-powered computing facilities.

Brandon and Newton (1986), in a description of *knowledge-based* (expert) systems to building cost modelling, stated that in order to be effective and implemented in practice, the mathematical ('black box') models need to allow human judgment to be exercised over their processes. Brandon and Newton (1986) added that: 'The models should be seen merely as reference points and not an end in themselves.' Furthermore, it is clear that risk and uncertainty is endemic in construction and, hence, building cost forecasting has a probabilistic nature. 'Models which take account of risk and uncertainty capture the essence of the real world much more realistically than static pseudo-deterministic representations (Raftery, 1991:5).' The need, therefore, to 'shift' from a deterministic stance, where cost models are based upon 'single-figure' presentations, to a more realistic modelling representation by using methods which are more explanatory and logically transparent (Bowen and Edwards, 1985), is justified.

As a result, several techniques and models have been developed to support better project cost estimating; cost estimates can be provided as *probabilistic* or *deterministic* values. As each cost item is a *random variable* representing an unknown future cost, a deterministic value should be applied only when detailed or specific cost estimates are available from a reliable source. Deterministic values can be achieved through definitive formulation, linear programming, and optimisation approaches. On the other hand, probabilistic cost estimating should be utilised during the early project development stages, especially when the reliability of information is questionable. Probabilistic models treat the future final cost of a project as a random variable and use formal probability methods to quantify its uncertainty (Khodakarami and Abdi, 2014). Regression analysis, Monte Carlo simulation (MCS), artificial neural networks (ANN), fuzzy logic, and case-based reasoning (CBR) are commonly used to provide conceptual estimates of construction project costs (Kim *et al.*, 2012).

2.5.2.6 Studies on the Accuracy of Cost Estimating Models

There is an increasing awareness of the need for better accuracy in forecasting for construction projects (Skitmore, 1991). Morrison (1984) examined the accuracy of cost estimating models by measuring the deviation from the lowest acceptable tender in the project. Factors that affect the accuracy were identified as the variability of lowest tenders, the source of cost data used in estimating, the inherent error attached to the estimating technique and the suitability of cost data, in the order of importance; it was suggested that using previous cost data from projects where QS have had experiences and using single source of cost data is likely to improve the accuracy of cost estimates. Raftery (1984) proposed that the new generation of cost models developed since the 1970s were produced mainly as a reaction to the dissatisfaction that existed with traditional forecasting methods. Aibinu and Pasco (2008) examined the accuracy of pre-tender building cost estimates by investigating 56 Australian projects and surveying 102 firms. Their study revealed that cost estimation is largely affected by the size of the projects; in small projects, the cost is normally over-estimated by a large amount rather than under-estimated. Moreover, the accuracy of estimation has not improved over time, which implies that lack of experience plays a trivial role in biased cost estimation. Aibinu and Pasco (2008) suggested better estimation practice by ‘probability estimation and simulation of past estimates, reducing quantity surveying and cost engineering skill turnover, incorporating market sentiments into estimates, early involvement of the quantity surveyor at the brief stage, and proper documentation of experience gained in the estimation of projects' (Doloi, 2011). Jaskowski and Biruk (2011) pointed out that project activities' durations are directly affected by different risk factors independently. Existing risk analysis models, e.g. simple analytical and neural networks developed by Kog *et al.* (1999); Chua *et al.* (1997), Zayed and Halpin (2005), Shi (1999), AbouRizk *et al.* (2001); and Sonmez and Rowings (1998); fuzzy set model developed by Lee and Halpin (2003) and regression model developed by Hanna and Gunduz (2005) and Jaselskis and Ashley (1991) failed to provide more reliable solutions for predicting activity and whole project durations.

2.5.3 Technological Parameters Affecting Construction Cost

According to the *Concise Oxford Dictionary*, a *parameter* is *'a quantity which is constant in a particular case considered, but which varies in different cases'*. In any case, the parameters of *building morphology* are normally dictated by the plot area size and boundaries, topographical conditions and orientation, compulsory regulatory restrictions such as the built surface co-efficient and site coverage ratio, and as a result, the degree of choice of plan shape is rather limited. Moreover, the facility's *functional requirements* and *constructional methods* adopted are expected to play a significant role in the build-up of its cost.

Dell'Isola (2002) believes that developing an understanding of building economics is an important element in applying cost management: to gain an understanding of how to *estimate* and *manage* costs, so that a satisfying final product is delivered to clients, it is necessary not only to decipher and classify the major components that make-up project cost but also to identify the various direct or indirect determinants of that cost. According to Chan and Park (2005), construction project cost depends not only on a single factor but a cluster of variables related to the characteristics of the project and the construction team: technological and design requirements preset by the client and the consultants; contractor's expertise and management ability; and the client's desired level of construction sophistication. Skitmore and Marston (1999) explained that *design factors* range from *macro-level* variables such as gross and net floor area, number of storeys, and plan shape, to *micro-level* variables such as type of floor or wall finishes. Seeley (1996) identified the cost implications of *functional requirements* for different types of building (residential, commercial, industrial, educational) and of alternative *constructional techniques* of building elements (foundations, structural frame, walling, etc.) together with the effect of *site and market conditions* and the way in which they account for variations in the cost of similar type buildings erected in different locations.

There is a general view in the industry that the accuracy of cost estimates is crucial to all parties involved with the construction project. As a result, an analysis of the factors involved in cost estimating becomes imperative. An initial analysis of the factors shows that the main factors relevant to the cost estimating practice are: complexity of the project; scale and scope of construction; market condition; method of construction; site constraints; client's financial position; buildability; and location of the project (Akintoye, 2000). Despite the practical importance of the subject, there is surprisingly little research on the relationship between the *morphology* factors, which influence the components of a building, and construction costs (Chau, 1999). Ashworth (2004) argued that further research is required to achieve a better understanding of the determinants of building cost – at the moment only a small amount of analytical work has been carried out, and therefore advice to clients is often based on opinion and assumption, albeit of an expert nature. Kirkham (2015) recently stated that unfortunately insufficient research has been undertaken to date to give clear indications of the degree to which changes in the building parameters will affect the cost of that building. However, there is a great depth of knowledge gained by practitioners, which provide us with some general *'rules of thumb'*.

2.5.3.1 Building Design Economics

The study of economics applied to building projects has resulted in the development of a number of building *design* economic theories which can provide an initial broad indication of the cost implications of early design decisions. These *indices* are usually expressed in a mathematical equation form, based on the *geometrical* characteristics of buildings. The practical motive for investigating the relationship between design factors and construction cost is to assist designers to arrive at early stage design decisions from sketch plans development. The important design variables which give rise to principles for the achievement of economy in buildings are *plan shape*, *building size*, *building height*, and *planning efficiency*.

2.5.3.2 Building Morphology Indices

Building design shape *complexity* indices:

WF	*Wall to Floor* area ratio (Seeley, 1996)
JCSE	J. Cook's *Shape Effectiveness* index (Ferry *et al.*, 1999)
POP	*Plan Compactness* or *Perimeter over Plan* (POP) ratio (Strathclyde University) (Ashworth, 2004)
VOLM	*Mass Compactness* or VOLM ratio (Strathclyde University) (Ashworth, 2004)
LBI	*Length/Breadth* index (Banks, 1974)
PSI	*Plan/Shape* index (Banks, 1974)
m	*Building Planning* 'm' index (in Zima and Plebankiewicz, 2012)

The relevant mathematical equations for the above indices are:

WF = (env_cov) : (cov_area)

JCSE = $[P : (4 * \sqrt{F})] - 1$

POP = $[2 * \sqrt{(\pi * F)}] / P$

VOLM = $\{2 * [(3V : 2\pi)^{1/3}]^2\} : F$

LBI = $[P + \sqrt{(P^2 - 16F)}] : [P - \sqrt{(P^2 - 16F)}]$

PSI = $[G + \sqrt{(G^2 - 16R)}] : [G - \sqrt{(G^2 - 16R)}]$

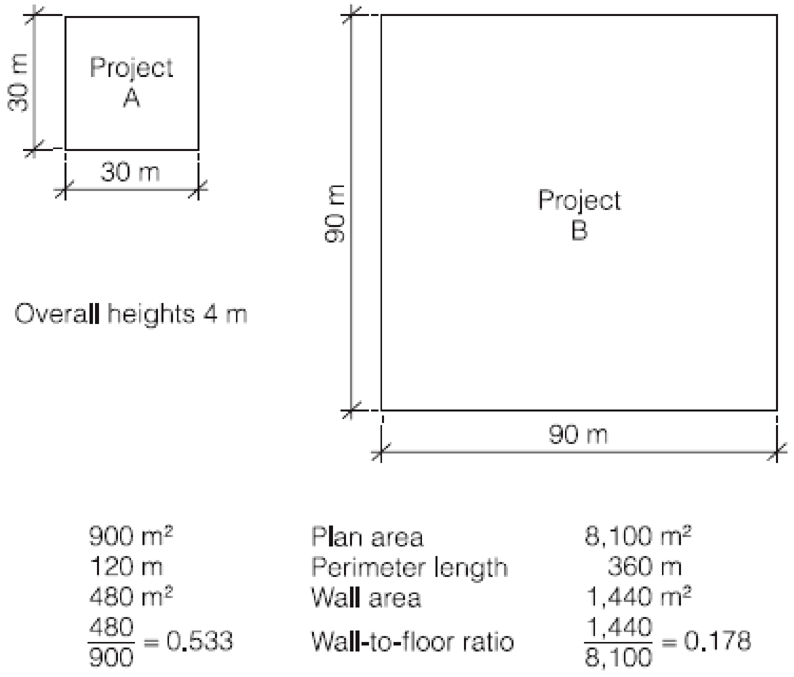
m = $P : \sqrt{F}$

The *plan shape* of any structure has an important effect on the overall cost of the project and this effect is not restricted to the costs of the external envelope, but also applies to the internal division elements (Ashworth, 2004).

In a classic textbook on *Building Economics*, Seeley (1996) suggested that *'as a general rule the simpler the shape of the building the lower will be its unit cost'*. The more complicated and irregular becomes the outline of a building, the more the *perimeter/floor area* ratio is increased, accompanied by a higher cost per unit floor area. Circular buildings, although enclosing the greatest floor area for the smallest perimeter, are uneconomic and result in major internal layout planning problems (Seeley, 1996). The next simplest area to consider is a perfectly squared footprint but, from an architectural perspective, this layout may be unacceptable as overly simplistic; designers normally want to enhance building aesthetics by articulating its form (Dell'Isola, 2002).

Perhaps the most familiar plan shape index is the *wall to floor* (W/F) ratio which is defined as the ratio of the area of external wall (W) to that of the enclosed floor area (F). The larger the value of the index, the more complicated the building shape (Brandon, 1978). An example of wall to floor ratio comparison for two rectangular plan shaped projects is given in Figure 2.6 (page 84). Generally, larger buildings have lower unit costs than smaller-sized projects offering an equivalent quality of specification. For example, a dwelling house on its own individual plot of land will cost more to construct than a similar dwelling which may be part of a large housing estate contract. Smaller factories cost more per unit than their larger counterparts. To some extent this is due to the economic theory of *economies of scale*.

Tall buildings minimise land costs in relation to floor area, but are invariably more expensive to build low-rise buildings than offering the same accommodation, and the taller the building the greater the comparative cost. The only partial exception of this rule is that the additional of a further storey or storeys to a tall building in order to make the best use of lifts or other expensive services that may slightly decrease the cost per storey, but this does not invalidate the general rule (Ferry *et al.*, 1999).



900 m²	Plan area	8,100 m²
120 m	Perimeter length	360 m
480 m²	Wall area	1,440 m²
$\frac{480}{900} = 0.533$	Wall-to-floor ratio	$\frac{1,440}{8,100} = 0.178$

Fig. 2.6 Wall to Floor Ratio Example (Source: Ashworth, 2004)

The main impact when storey height is increased is on the vertical elements, such as external and internal wall finishes. There will also be an impact on services installations with pipe and cable runs increasing. The number of storeys in a building can affect costs in the following ways (Cartlidge, 2012):

- Single-storey structures are comparatively expensive, as the substructure required for a two or three-storey structure is often only marginally bigger than for a single storey;
- Buildings with more than three storeys will require a lift installation;
- Generally, multi-storey buildings require a large substructure;
- Tall buildings require areas devoted to circulation space such as lifts, escape staircases, service floors and plant rooms. These areas have to be deducted from the gross floor area to arrive at net lettable areas;
- Maintenance costs will be greater for high rise buildings; and
- Fire protection will be at a high level.

The cost of the project will be affected by its location. It may be situated on a congested city site with all the problems of access, materials deliveries, close proximity of adjacent structures etc. Alternatively, it may be located in the heart of the countryside with its own peculiar problems and particularly transport costs. The availability mains services or the costs of their provision will be an important consideration. The location of the structure on the site will also affect the overall cost of the scheme. The ground conditions of the chosen site are a factor that can substantially influence constructional costs. Finally, the preparation of the site prior to construction operations needs careful consideration. Artificial strengthening of the ground, the redirection of watercourses, or demolitions can all significantly increase costs and should be avoided where possible (Ashworth, 2004).

A number of factors which influence the costs of the building at early stage can be found in the literature. The most frequently mentioned variables include: location, building type, building height, building quality, number of floors, construction technology employed, and mechanical and electrical (M & E) services (Kouskoulas and Koehn, 1974; Brandon, 1978; Swaffield and Pasquire, 1996; Swaffield and Pasquire, 1999). Belniak *et al.* (2013)

described the basic indices evaluating the shape effectiveness of a building. The authors established the best building shape in relation to the costs of constructing the walls and foundations (square), and to the layout of the inside of the building (rectangle), which led them to the conclusion that the most advantageous solution is the shape of the rectangle with the ratio between its sides not greater than 1:2. Brandon (1978) introduced the *plan shape index* which represents any plan shape of building to a rectangle having an area and perimeter identical to the building it represents. Seeley (1996) explained that the lower the *perimeter to floor ratio*, the more economical the proposal. A *circular* building produces the best wall to floor ratio, but the saving in quantity of wall is usually more than offset by the lowered output, by between 20-30% (Seeley, 1996).

Ferry *et al.* (1999) proposed an efficiency ratio relating the area of external walls to the enclosed floor area, as a multiplier measure to adjust the cost estimate. Perhaps, this is the most widely used of all the efficiency ratios, but it can only be used to compare buildings having similar floor areas and does not have an optimum reference point (Ibrahim, 2007). Seeley (1996) and Chau (1999) stated that J. Cook eliminated some of the noticed shortcomings of previous ratios by introducing a *shape efficiency index* (JCSE) which is defined as the ratio of the perimeter of a floor plan to the perimeter of a square floor plan with the same floor area. The larger the value of the index, the more complicated the shape (Chau, 1999). Researchers in UK's Strathclyde University developed the *plan compactness ratio* (POP) which is defined as the ratio of the perimeter of a circular floor plan (P) to the perimeter of a floor plan with the same area. The smaller the value of the index, the more complicated the shape (Chau, 1999). In this case, the reference point is the circle (a square would have a POP ratio of 88.6% efficiency and yet it is probably the best cost solution in initial cost terms). Other ratios are developed with different points of reference (Ibrahim, 2007): *mass compactness* or VOLM ratio uses a hemisphere as the point of reference for considering the compactness of the building in three dimensions. Rectangular index also called *length/breadth index* (LBI) is defined as the length to breadth ratio of a rectangle with the same area and perimeter as the building. In this index, any right-angled plan shape of building is reduced to a rectangle having the same area and perimeter as the building. Curved walls are dealt with by a weighting system. The larger the value of the index, the more complicated the shape. Chau (1999) critically indicated that most of the existing plan shape indices are based on the geometry of the plan without reference to empirical data. Chau (1999) proposed a new approach which involves an empirical estimation of a Box-Cox cost model; the results suggest that it is better to build a regression model that predicts how much floor area can be built with a fixed sum of money than to predict how much money is required to construct one unit of floor space. Tan (1999) developed a simple analytic model to show how cost variation with building height is affected by technology, building design, demand, and institutional factors. The model was designed to determine the incremental cost of each floor as building height increases. Tan's (1999) model was, however, too simple and does not capture certain institutional realities such as monopolistic pricing and zoning constraints (Ibrahim, 2007). Swaffield and Pasquire (1996) argued that a cost modelling system that considers the building function, level of services provision, and descriptive parameters of the building form, could improve the accuracy of early cost advice of building services.

2.5.4 Cost Accounting (Costing) in Construction Production

Cost accounting (or simply *costing*) is about collecting, analysing, summarising, and evaluating various alternative courses of action based on cost efficiency and capability. Cost accounting provides the detailed cost information that management needs to control current operations and plan for the future (Vanderbeck, 2013). In construction, cost accounting also is regarded as a prognosis process – *cost estimating* by constructors and *cost planning* (or *approximate estimating*) by clients' consultants. These two cost forecasts have different targets: the former seeks to estimate the contractor's costs for executing the project (cost forecasting) whilst the latter seeks to foresee the successful tender for the project (price prediction) (Fellows *et al*., 2002). Thus, costing is the key ingredient in a cost management system, providing the basic data required for *cost estimating and control*. It involves the continuous determination of productivity and cost data, the analysis of this information, and the presentation of the results. It is necessarily concerned with costs, but also with labour and equipment hours, and the amounts of work accomplished (Sears *et al*., 2015). Costing has been carried out in the building industry for many years, but the type of costing used gives the total project cost only when it has been completed. This cost figure is then compared with the revenue received, but 'if the project has lost money, there is little that can be done about it' (Oxley and Poskitt, 1996). Consequently, cost control techniques have been developed towards more *proactive* management. According to Seeley (1996), the main aims of cost control are threefold:

- to give building owner good *value for money* – a building which is soundly constructed, of satisfactory appearance and well suited to perform the functions for which it is required, combined with economical construction and layout, and completed on schedule;
- to achieve a balanced and logical distribution of the available funds between the various parts of the building – thus the sums allocated to building elements will be properly related to the class of the building and to each other; and
- to keep total expenditure within the amount agreed by the client, frequently based on an *approximate cost estimate* prepared by the quantity surveyor in the early stages of the design process.

As Seeley (1996) further suggested, there is a need for strict cost discipline throughout all design and execution stages to ensure that the initial estimate, tender figure, and final account sum are all closely related. This entails a satisfactory frame of cost reference (estimate and cost plan), ample cost checks and the means of applying remedial action where necessary (cost reconciliation). In traditional cost control, work performance is measured with *variance analysis*, which compares actual costs with planned costs to determine the difference between the amount spent and the amount budgeted. For project control, cost variance analysis is *inadequate* (Nicholas and Steyn, 2008). According to Harrison and Lock (2004): ‘All good project managers become part accountants since they are involved in the estimating, budgeting, forecasting, and control of money, whether it is called cost, profit, or loss, for their projects’. The latest definition of *management accounting* is found in the *Global Management Accounting Principles*$^{©}$ published by two of the world’s most prestigious accounting bodies, the Association of International Certified Professional Accountants (AICPA) and the Chartered Institute of Management Accountants (CIMA), which have formed a joint venture to establish the Chartered Global Management Accountant (CGMA) designation to the profession of management accounting: ‘… the sourcing, analysis, communication and use of decision-relevant financial and non-financial information to generate and preserve value for organizations’ (CGMA, 2015). In an earlier well accepted definition by Sizer (1989), management accounting has been described as the application of accounting techniques to the provision of information designed to assist all management levels in *planning*, *decision-making* and *controlling* the activities of an organization. Figure 2.7 (page 90) presents the required steps in the above process. Management accounting lies at the heart of an organisation, at the crossroads between finance and management, providing structured solutions to unstructured problems, by translating the complex into the simple and by making the simple compelling. Bringing together both financial and non-financial considerations, it is the discipline that should be used to run the organisation, to control and improve performance (CGMA, 2015).

Horngren (1965) and Garrison and Noreen (1999) explained the basic difference between management accounting and *financial accounting*: management accounting is concerned with providing information to *internal* decision-makers (like project managers) within the organisation to assist them make better decisions and improve the effectiveness of the existing operations, whereas financial accounting's main objective is to inform *external* parties outside the organisation (such as stockholders, creditors or the government).

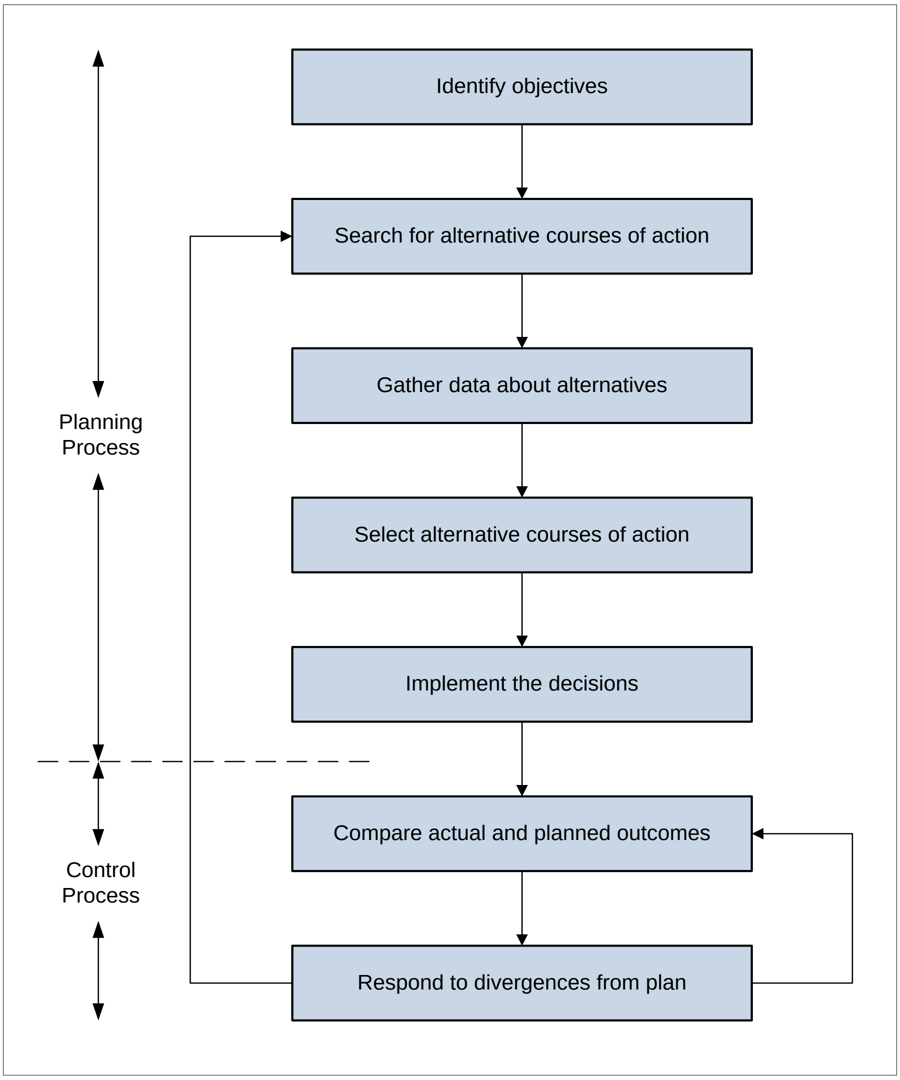


Fig. 2.7 Planning, Decision-Making and Control Process (Source: Drury, 2006)

One of the major functions of cost accounting is that knowing how much it costs to construct a building gives the ability to make specific and detailed identification and measurement of cost elements, thus, permitting management to *reach decisions* and to *evaluate results* with greater intelligence (Brock *et al.*, 2007). The conventional method of construction project costing is still based on determining the direct (variable) costs (for materials, labour, equipment and subcontractors) and then adding on top a cost-plus percentage to arrive at the proposed price. This added gross margin is expected to cover total (site-related plus head-office) indirect (fixed) costs (overheads), contingency, taxation and what remains is profit. Building production costs are distributed in relatively consistent proportions for most building types. Table 2.7 below demonstrates this relationship (Dell'Isola, 2002).

Table 2.7 Approximate Distribution of Building Costs (Source: Dell'Isola, 2002)

Component	Basis of Estimating	approx. %
Materials	(Quantities + waste) * price	55
Labor on-site	Hours * rate per hour	30
Equipment and tools	(Type + length of time required) * rate + setup	3
Site supervision	Nos. * months	3
Site overheads	Type/cost	5
Head-office overheads	%	1
Profit	%	3

2.5.4.1 Direct Cost

Direct cost is defined as the cost of installed equipment, material, and labour directly involved in the *physical* construction of the permanent facility (Westney, 1997). The main direct expenses for a contractor include:

- *labour*, particularly hourly workers, for whom a labour expense can be directly linked to a particular work item;

- *materials*, such as concrete, rebar, bricks, lumber, nails, paint, drywall, carpet, structural steel, and *installed equipment*, such as elevators, air-conditioning units, and kitchen equipment;
- *equipment*, mainly construction site equipment (bulldozers, excavators, cranes, concrete pumps, etc.);
- *subcontractors* (even though subcontractors' charges comprise labour, materials, equipment, overheads, and possibly sub-subcontractors, the general contractor treats these charges as a direct cost); and
- *other miscellaneous costs*, such as government permits and fees, and fees for lawyers and consultants hired for a specific task in a project (Mubarak, 2015).

2.5.4.2 Indirect Cost

Indirect cost is defined as all costs which do not become a final part of the installation, but which are necessary for the completion of the installation; these costs may include (but are not limited to) field administration, direct supervision, capital tools, start-up costs, contractor's fees, insurance, taxes, etc. (Westney, 1997). Contractor's indirect costs include:

- *project (site field) overhead* (or *job overhead*), such as the following: project staff (project manager, project superintendent, project engineer, receptionist or secretary, clerk, etc.); office trailer and other temporary structures; cars and trucks assigned to the project team; office equipment (copying machine, fax machine, computers, etc.); temporary utilities (electricity, water, drinking water and ice, telephones, cell phones, gas, portable toilets, etc.); other indirect project-related expenses, such as power generators and projectors used to provide light during night working hours.

- *general (head-office) overheads*, such as the following: main office expenses (rent, lease, maintenance, utilities, etc.); main office personnel; main office equipment and vehicles; main office services, such as lawyers and accountants (not working exclusively for a specific project); other main office expenses, such as advertising and charity contributions.
- *profit*, which is estimated by the contractor before taking on the project and it usually ranges between 5% and 10%, although it can and does occur outside this range; the profit percentage depends on many project-specific factors, prevailing economic conditions, and the contractor's financial status). The term 'profit' is the contractor's 'return for taking risk'; i.e. the amount (or percentage) that is usually charged in proportion to the risk taken;
- *contingency fees* (an additional sum of money allocated for the *unknown* events that will most likely occur during the construction of the project; they are directly proportional to the risk taken in the project) (Mubarak, 2015).

2.5.4.3 Traditional *vs.* Activity-Based Costing (ABC)

Traditional cost accounting, such as volume-based costing or variance analysis, has long been criticised for cost distortion and lack of relevance (Johnson and Kaplan, 1987). Generally, conventional costing reports 'what money is spent on and by whom', but fails to report the cost of activities and processes (Miller, 1996). Consequently, from the mid 1980s, alternatives to traditional cost accounting have been developed, aiming to regain the lost managerial relevance of cost information. The most popular of these alternatives is probably the *activity-based costing* (ABC) method, which has been proposed as a means for overcoming the systematic limitations of conventional costing (Cooper, 1990; Cokins, 1996) due to its capability to make processes and activities performed within a construction organisation more transparent and observable (Marchesan and Formoso, 2001). In general, calculating costs for products requires tracking and compiling *direct* and *overhead* costs. Whilst identifying and collecting direct cost information is almost always a straightforward task, one of the most difficult parts of managing costs is tracing and allocating overhead costs to individual products (Kim *et al.*, 2011).

ABC is defined as ‘an approach to the costing and monitoring of activities which involves tracing resource consumption and costing final outputs. Resources are assigned to activities, and activities to cost objects based on consumption estimates. The latter utilise cost drivers to attach activity costs to outputs (CIMA, 2005).’ The traditional costing system is using a single overhead *cost pool* and a single overhead *cost rate* to allocate overheads to *cost objects*, in proportion to the amount of resources, such as direct labour costs (Horngren *et al.*, 2012). A cost object refers to any object for which a separate cost measurement is desired (Raffish and Turney, 1991). The one-stage costing system fails to provide accurate product cost, leading to loss of market share and misinformation about where money is being earned or lost (Johnson and Kaplan, 1987).

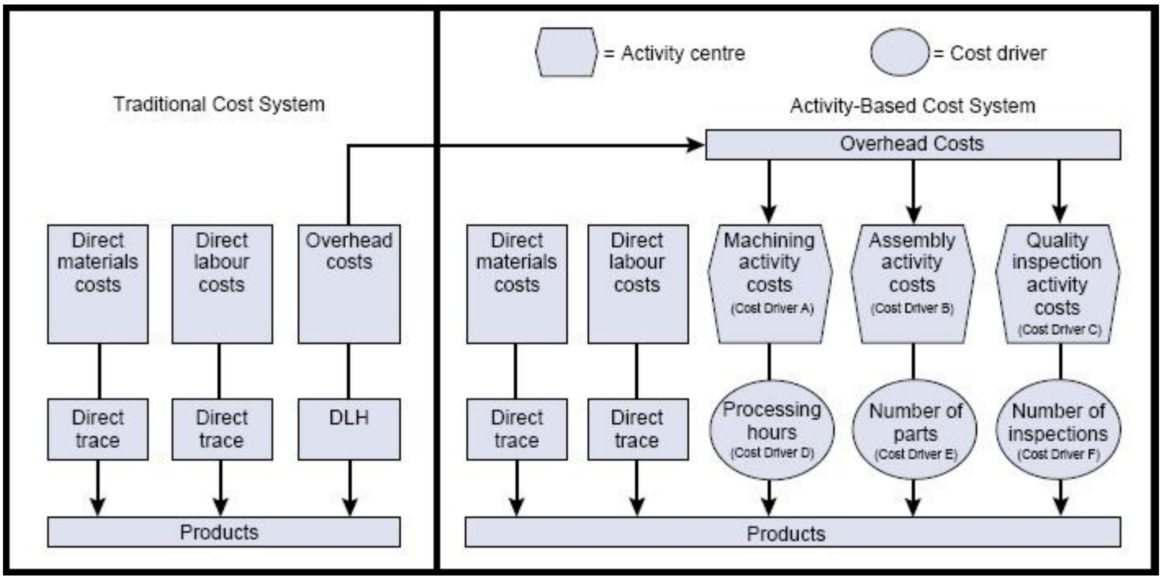


Fig. 2.8 Traditional Costing *vs.* Activity-Based Costing (ABC) (Source: Cooper, 1990)

The fundamental idea behind ABC is to assign overhead costs to customer-required products or services, based on the specific *activities* required to produce these products or services. Cooper (1990) explained that ABC is a two-stage procedure: at first, indirect costs are assigned to activity cost pools according to the way resources are consumed by the activities; in the second stage, overheads are allocated from each activity cost pool to each cost object in proportion to the amount of the *cost driver* consumed by the product. Thus, resources are assigned to activities, and activities are assigned to cost objects based on their purpose. The main difference between traditional costing and ABC is illustrated in Figure 2.8 (page 94).

Organisations that are engaged in projects are keenly interested in accurate estimates of the costs of the projects. Contractors bid on projects and, once they win a contract, have to execute according to the budget in their proposal. Thus, it is important for them to bid the correct price that will recover all their expenses, including the fair share of overhead, and allow reasonable profits whilst remaining competitive (Raz and Elnathan, 1999). Primary components of the project price include direct costs, indirect costs, general overheads, profit and contingency. The term general overheads in the construction company is made-up of home-office and site-project overheads (Aretoulis *et al.*, 2006). Relevant research conducted by Assaf *et al.* (2001) and Enshassi *et al.* (2008) revealed that general overheads' rates have significantly increased in the last decade (ranging from 11,1% to 13% of total project cost) and, therefore, should be considered as critical to the success of construction projects. The staff wages are the highest overhead costs component. The currency exchange rates, inflation, and increase in financial costs also lead to increasing overhead costs (Enshassi *et al.*, 2008). However, the construction industry has not changed the method of controlling overhead costs in construction projects. Traditionally, construction overhead uses resource-based costing and volume-based allocation (Kim and Ballard, 2001; Holland and Hobson, 1999). Resource-based costing is the method in which costs are assigned by each resource whilst volume-based allocation is the method of cost allocation in which costs are allocated to cost objects in accordance with the volume of direct labour hours, direct labour costs or contract amount (Kim and Ballard, 2002). Indeed, traditional costing systems may still continue to conventionally pricing *bills of quantities* (BoQ) and marking-up, in a simplistic manner, percentage-based overheads and profits on main contractor's construction costs and preliminaries (site-project overheads) (CIOB, 2010). According to Sommer (2001), the problem of current practice regarding overhead assignment is that construction projects have different cost codes for each resource (such as site engineer or project manager) and overheads are treated separately without being assigned to work divisions (such as earthworks or footings) or to participants (such as subcontractors). However, they assign overhead costs to work divisions in proportion to direct labour hours or direct labour costs when owners request the assignment of overhead costs. Such volume-based allocation results in cost distortion (Johnson and Kaplan, 1987; Cokins, 1996; Horngren *et al.*, 2012). Cost distortion occurs because traditional costing combines all indirect costs into a single cost pool. This pool (or driver) is allocated on the basis of some resource common to all of the company's products, typically direct labour and, as a result, construction companies do not know real costs for each work division and those for each participants because either they do not assign overhead costs or they use a uniform cost driver (i.e. direct labour costs) for their assignment. Therefore, it is difficult to find 'where money is being made and lost' because progress payments for each work division or building from clients contain overhead costs. In other words, project managers have difficulty in doing a profitability analysis. Another problem is that little management attention is paid to (supporting) activities or processes since every cost is assigned and reported resource by resource. Therefore, there is a lack of relevant information on how much resources and what services are provided to participants such as subcontractors (Kim and Ballard, 2002). Notwithstanding the benefits of its application, such as improving product (project) costing, providing timely cost information suitable for decision-making and allowing more tracking of indirect costs, and leading to classifying activities as value-added and non-value-added (Al-Sudairi, 2008), ABC presents an important drawback compared to simplistic traditional costing: the large amount of data usually needed in order to implement ABC systems. According to Krieger (1997) and Cokins (1999), the excessive level of detail required is a major cause of unsuccessful ABC applications. This problem can be even worse considering unstable and complex production processes such as those observed in the construction industry (Marchesan and Formoso, 2001). Efforts to apply ABC to construction can be found in the work of Maxwell *et al.* (1998); Raz and Elnathan (1999); Fayek (2000); Back *et al.* (2000); Kim and Ballard (2001); Marchesan and Formoso (2001); Aretoulis *et al.* (2006); and Qian and Ben-Arieh (2008). An attempt to introduce ABC in the design process can be found in Al-Sudairi (2008).

2.5.5 Financial Management in Construction

The acquisition of a constructed facility usually represents a major *capital investment*, whether its owner happens to be an individual, a private corporation or a public agency (Hendrickson, 2008). Thus, a crucial decision-making for any potential investor relates to whether or not a particular capital investment project is worth undertaking, or if they are faced with a set of alternative projects, which one represents the best proposition. In such situations, it is necessary to use a valid method of *investment appraisal* (Ruddock, 1992). Holmes (1998) points out that it is normal to consider investment in terms of consumption rather than in terms of money and defines investment as any act which involves the sacrifice of an immediate and certain level of consumption in exchange for the expectation of an increase in future consumption. *The Penguin Dictionary of Economics* (Bannock *et al.*, 1992) defines investment appraisal as 'The evaluation of the prospective costs and revenues generated by an investment in a capital project over its expected life. Such appraisal includes the assessment of the risks of, and the sensitivity of the project's viability to, forecasting errors. The appraisal enables a judgment to be made whether to commit resources to the project'. Once a capital investment has been decided, one of the major problems facing any construction business enterprise is that of obtaining *finance*. This is a problem not merely of quantity but also of type. The situation is compounded by legislation and by the dynamism of the economy but, perhaps more fundamentally, by the requirement to minimize costs (Fellows *et al.*, 2002).

A construction company is a risky venture and, each year, many construction companies go out of business. Operating a successful construction company requires a specialised set of *financial management* skills, because of the unique nature of the construction industry (Peterson, 2009). A study by Hlaing *et al.* (2008) revealed that among the top general risks that construction contractors are normally facing, the following financial risk factors exist: the lack of contractor's financial resources; the financial instability of the client; and the project cost overruns. Therefore, the financial management of a construction company is as vital to its success as its technical management; one of the prime considerations is sufficiency of work and this requires sufficiency of financial resources. A common cause of financial failure is due to too much work in progress for the available capital; funds become so widely and thinly spread among the firm's projects, that individual activities in some of them lack enough *working capital* to be continued in the working capital cycle (Christian and Kallouris, 1990).

The three main project financial management processes are (Purnus and Bodea, 2015):

- financial planning, i.e. identification of financial needs, understanding the contract requirements, estimating financing costs, establishing the financing points, sensitivity analysis, developing and testing the financial project plan, assigning responsibilities;
- financial control, i.e. monitoring key influences and taking corrective measures when necessary; and
- administration and records, i.e. designing and maintaining a financial information database.

The financial function plays a significant role in ensuring that company objectives are compatible with its resources. Therefore, by its very nature, financial management performs two complementary roles in ensuring the survival of a corporate establishment: monitoring and evaluating the implementation of its business strategy, involving a reporting role, and serving as a basic instrument for future planning of organisational objectives, which assumes a predictive status (Edum-Fotwe *et al.*, 1996).

2.5.5.1 Selection of Capital Investment Projects

Any theory of investment needs to address the following question: ‘How should a corporate manager facing uncertainty over future market conditions decide whether to invest in a new project?’ (Dixit and Pindyck, 1995). The building industry produces, in the main, investment goods rather than consumer goods and, as a consequence, it is subject to all of the uncertainties that characterise investment decisions – this implies that the industry, almost by definition, operates in an unstable environment (Centre for Strategic Studies in Construction, 1988). In the context of construction, investment appraisal is most widely related to decisions of whether to purchase, or acquire by some other means, fixed assets, usually in the form of buildings. It is used by clients and consultants in their evaluation of proposed new build, refurbishment or rehabilitation construction works and by contractors to assess the envisaged capital requirements of their own capital investments (plant, equipment, buildings, etc.) and in their assessments of potential projects for *bidding* purposes (usually through competitive tendering) (Fellows *et al.*, 2002). Therefore, careful analysis of a potential project is a *sine qua non* for profitability in the construction business. Only the incremental (marginal) costs and revenues directly attributable to the project under scrutiny should be included; sunk costs incurred prior to the selection should be ignored as they are irrelevant to decisions about the future (Davis and Pointon, 1984). Evaluation and selection methods for capital projects broadly fall into *numeric* and *non-numeric* categories. Non-numeric methods, as their name implies, do not use numbers as inputs. Numeric methods, on the other hand, are based either on profitability or on unweighted or weighted scoring analyses (Meredith and Mantel, 2012). This research focuses specifically on numeric techniques that are using profitability as the sole measure of acceptability; these tools can be *conventional*, *discounting*, *life-cycle* and more recently *real options*:

2.5.5.1.1 Conventional Methods

Conventional methods are less complex since they do not take account of the timing of the cash-flows arising from a project. *Payback period* is the number of years it takes for extra annual income resulting from the investment to equal the investment cost of an item of real capital. Many corporations use the payback method in their investment decisions, where it can be appropriate when the asset value is expected to decline rapidly through time, so that both resale value and expected long-term profits from the asset are low. This is not normally the case with buildings, although it may apply to construction equipment (Ive and Gruneberg, 2000). The major drawback of the payback method is its disregard of the cash-flows that arise beyond the payback period (Holmes, 1998). The *average rate of* *return* (ARR) of a project is found by taking the ratio of total returns to the capital outlay, averaged over the life of a project and expressed as a percentage. The purpose is to find the project with the higher ARR but the fact that this method only considers the returns in aggregate not taking account of their incidence is its major shortcoming (Ruddock, 1992).

2.5.5.1.2 Discounting Techniques

Discounting techniques allow for the fact that money has a 'time value' – the *time value of money* refers to the ability of money to earn interest over time and the importance of the concept lies in the fact that any fixed sum of money varies in its value to a recipient, dependent upon the point in time in which it is received. An investor, concerned with making comparisons between a capital sum that has to be laid out now and returns that arise next year, the year after that or ten years in the future, has to ensure that he is comparing sums on an equivalent basis. Discounting involves taking the time value of money into account by recognising that money payments in the future are worth less than money payments made in the current period (Ive and Gruneberg, 2000). Most business schools teach future managers a simple rule to apply to such problems: first, calculate the present value of the expected stream of cash that the investment will generate; then, calculate the present value of the stream of expenditures required to undertake the project; and, finally, determine the difference between the two – the *net present value* (NPV) of the investment. If NPV is greater than zero, the rule tells the manager to invest. A positive NPV means that a project is viable and is worth undertaking (Dixit and Pindyck, 1995).

The *internal rate of return* (IRR) of a project is that rate of interest which, when used to discount the cash-flow of a proposed project, reduces the NPV to zero. If IRR is higher than the going rate of interest, the project is viable. An attraction of this method is that it is easy to understand since the investor is presented with a rate of return that he can compare with the rate of interest on borrowed capital and if he has several alternative projects open to him, he can rank them in order for comparison. Generally, the project with the higher IRR is the one with the higher NPV and is therefore preferred under both methods. However, there may not be a unique value of the IRR – a project can have several values or none at all (Mole, 1985).

Return on investment (ROI) first calculates the average annual profit, which is simply the project outlay deducted from the total gains, divided by the number of years the investment will run. The profit is then converted into a percentage of the total outlay using the following equations:

$$(\text{average annual profit}) = (\text{total gains} - \text{total outlay})/\text{number of years} \tag{2.1}$$

$$\text{ROI} = (\text{average annual profit}/\text{original investment})*100 \tag{2.2}$$

ROI has the advantage of being simple whilst considering the cash-flow over the whole project. The main criticism is that it averages out the profit over successive years. An investment with high initial profits would be ranked equally with a project with high profits later if the average profit was the same. Clearly the project with high initial profits should take preference (Burke, 2003). To address this shortcoming, the time value of money must be considered using *discounted cash-flow* (DCF) techniques. The discount factor is derived from the reciprocal of the *compound interest* formula:

$$(\text{discount factor}) = 1/(1 + i)^n \tag{2.3}$$

where: i = the forecast interest rate and n = the number of years from start time.

The NPV is a measure of the value added to the firm by carrying out a project. If the NPV is positive, the project merits further consideration. When ranking projects, preference should be given to the project with the highest NPV. Although NPV quantifies profit, this is expressed in absolute terms. Managers tend to prefer profitability expressed as a percentage. This is addressed by the IRR discounting method. One of the limitations with

IRR, however, is that it uses the same interest rate throughout the project, therefore as the project duration extends, the limitation will become more significant (Burke, 2003).

2.5.5.1.3 Life-Cycle Models

Life-cycle models suppose that investors making decisions to build take into account the costs and benefits of construction projects throughout their useful existence, including their disposal or demolition (Figure 2.9). Thus, as well as estimates of construction cost and the cost of borrowing to pay for construction, estimates of the costs of maintaining and operating the built structure are taken into account. Estimates of additional revenue resulting from the project are extended to cover the whole-life of the building, possibly including revenues and costs from rebuilding on the same site (Ive and Gruneberg, 2000).

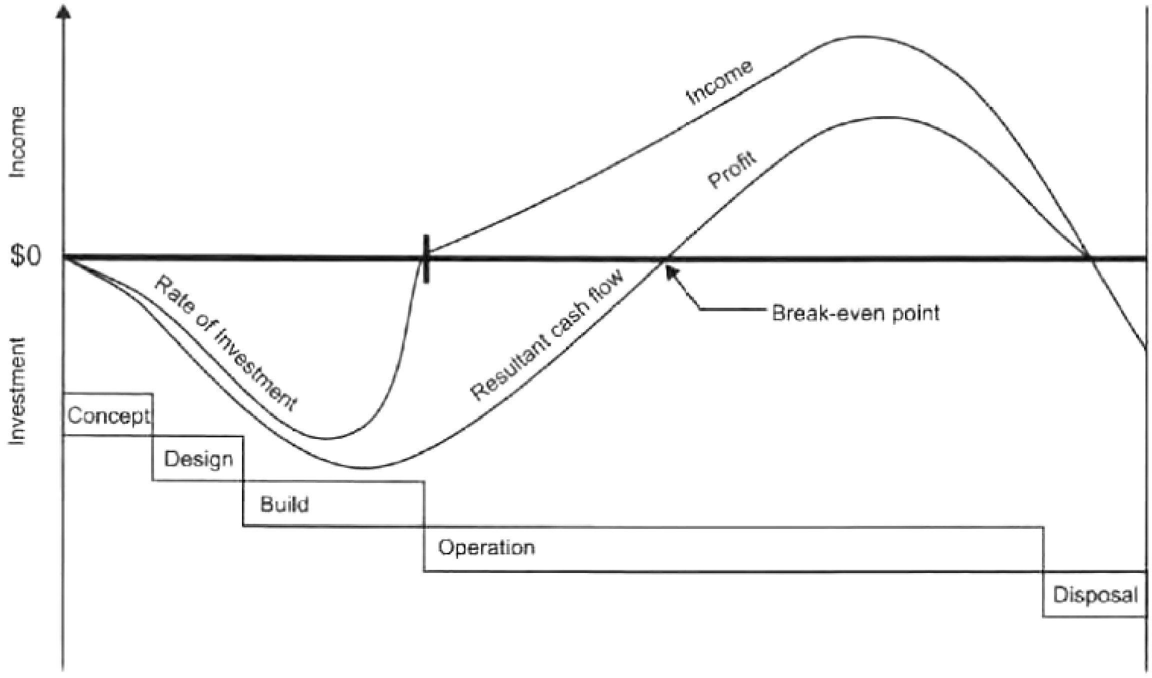


Fig. 2.9 An Example of a Life-Cycle Investment Appraisal Model (Source: Burke, 2003)

Life-cycle economic models of project proposals can be of use in bringing together the large number of variables involved in any project, ensuring that at least some of the consequences and implications of decisions to build are considered systematically (Gruneberg and Weight, 1990).

2.5.5.1.4 Real Options

Recently, in order to assist managers in their decision-making process in uncertain environments, new techniques and theories have been developed. One of them is the *real options* theory, where a real option is the right, not the obligation, to take some action in the future (Dixit and Pindyck, 1995).

This project selection approach was developed based on a notion well known in financial markets: when an investment is decided, the value of alternative future opportunities is foregone (*opportunity cost*). The argument is that a project may have greater NPV if delayed to the future. If the investment can be delayed, its cost is discounted compared to a present investment of the same amount. Further, if the investment in a project is delayed, its value may increase (or decrease) with the passage of time because some of the uncertainties will be reduced. If the value of the project drops, it may fail the selection process. If the value increases, the investor gets a higher pay-off. The real options approach acts to reduce both technological and commercial risk (Meredith and Mantel, 2012). The formal approach, which originated from financial models, deals with future uncertainty and opportunities a firm can seize, and aims at valuing the flexibility that often managers have to 'react' to uncertainty. In this sense, the real option potential to estimate the value of this flexibility is appealing for managers. As Leslie and Michaels (1997) report, over the past years, the theory has drawn a growing body of literature and has gathered support across the business world in academia, consulting, and the corporation. Copeland and Weiner (1990) observe that the 'use of options methodology gives managers a better handle on uncertainty'. Despite the growing support the real option theory has been attracting in academia and its apparent relevance in business decisions, few corporate managers and practitioners have truly recognised or applied the power of real options in managing their businesses (Leslie and Michaels, 1997; Lander and Pinches, 1998). Thus, real options application to managerial practice is poor, and is often limited to a conceptual level. Several reasons could explain why real options are not widely used in practice (Lander and Pinches, 1998; Borison, 2003). Anyway, all these reasons could be traced back to a fundamental issue, that is, the 'financial' origin of the real option theory and their evaluation models.

2.5.5.2 Financial Analysis of Building Contractors

The reasons for the liquidity problems of building contracting firms can be explored by analysing their financial structure – the framework within which their financial activities occur.

2.5.5.2.1 Fixed Asset Structure

Building contractors have a high percentage of their assets in receivables (trade and other debtors). High dependence on debtors is a result from the industry's common payment procedures. Contractor's income is dependent on periodic (usually monthly) contractual payments arising from interim certificates of completed work. At the simplest it may be payment on account of some proportion of work done (stage payments). Receipt of payment generally takes up to one month. Moreover, because latent defects may emerge some time after the construction work has been completed, it is usual for the client to retain a part of the payment (retention) until a defects-liability period has expired (Cooke and Jepson, 1979). Clearly, monies owed from debtors are troublesome assets representing a delay to the cash inflow of a building contractor. They cannot be used for operations and growth and their existence constitutes a lengthening of the working capital cycle (Figure 2.10, page 114). The working capital cycle shows that cash is only released once debts have been collected. Although receivables could be converted to cash by the process of debt factoring (where the contractor receives a reduced amount of cash but at an earlier time), this procedure is not very common in construction. Interest costs and factoring services fees are relatively unfavourable. Briscoe (1988) argued that factors (banks or other specialist financial institutions) will only provide the factoring service to few selected firms and many of the very small firms in the construction sector will not prove acceptable to the factoring companies. Thus, receivables do not aid contractors in resolving any liquidity problems. In addition, a contractor seldom enjoys interest from the future building owner. In fact, the latter is financing the project by using the contractor's money since the contractor is '… required to finance at any time the difference between the cumulative contractual value of work done, less retention monies, and the cumulative cost of doing the work (Cooke and Jepson, 1979:41)'.

Uncertainty and risk associated with delays in receiving interim (or stage) payments from the client is not a favourable financial consideration for a building firm. Where the client is suffering liquidity problems, the contractor is put under pressure, and the need for court action to collect debts is frequent (Woollett, 1978). Moreover, settlement of final accounts is a notoriously lengthy process in which delays may offset the gains effect through good control of costs, credit and cash-flows during the construction phase. Newcombe *et al.*, (1990:89) suggest that contracting organizations should pursue a vigorous settling of final accounts: 'It may be far more economic to settle a claim at a lower level to secure early payment than to establish entrenched stances resulting in 'bad feelings' delays in settlement and, ultimately, expenditure on arbitration or litigation.' Legal proceedings entail years of expense and anguish, and require from the claimant strong willing and patience.

Furthermore, building contracting firms have a relatively high percentage of their total assets tied up in cash (at bank and in hand). Cash is an element of the working capital cycle but it is of major importance in its own right. Sufficient cash is needed to pay wages, materials, plant, subcontractors' accounts rendered and overheads expended during the progress of construction operations. Although an adequate amount of cash is desirable in order to avoid cash-flow problems, assets in the form of cash are not earning a return and so may have a high opportunity cost. Thus, any surplus of cash should be invested in order to generate income and growth (Clough, 1986).

The field of operations is likely to govern a construction company's investment in fixed assets. Fixed assets include land and buildings, plant and machinery, fixtures and equipment, trucks and cars. It could be argued, however, that since contracting is labour-intensive, there is little requirement for funds to finance investment in fixed capital. As Hillebrandt and Cannon (1989:63) explained: 'The site belongs to the client, the plant may be hired and the buildings on site are minimal and in any case part of the project cost. The growth of a contracting company is thus not as dependent on the availability of finance as it is for most other types of business.' Small dependence on fixed assets means that cash is free for other purposes (such as the move towards diversification into other non-contracting businesses or the creation of assets as a collateral for loans), but contracting firms with small amounts of investment in such fixed assets tend to be less financially stable. The reason behind this was explained by Hillebrandt and Cannon (1990) who asserted that the disadvantage of a low level of fixed assets is that it is difficult to raise funds on the stock market and the company has no assets on which to fall back in case of losses or low profits.

2.5.5.2.2 Capital Structure

The capital side of the building contractor's balance sheet is characterised by a high degree of debt as the total (long-term plus current) liabilities of a contractor are in excess of its equity capital (ordinary or preference share capital plus reserves acting to increase the owner's investment in the firm). This high dependence on debt is associated with the limitations contractors meet when raising investment capital. As has been pointed out, their small size (and low asset base) places contracting companies not in a favourable position to issue stock to provide equity capital. Briscoe (1988) explained that raising new finance through issues of shares may not be viable for small firms because of large costs related to the services of financial intermediaries (merchant banks) or difficulties in attracting prospective purchasers for the new shares associated with poor records of profitability. In addition, according to Fellows *et al.* (2002) the cost to the building contractor of the other types of capital will encourage it to raise debt finance, especially due to the advantageous tax position of the interest payments (direct cost of debt) being offset against the firm's tax liability. But, debt finance has also an indirect cost – it increases the cost of capital. As the amount of debt increases so does the amount of risk and, hence, since lenders in the capital market are more willing to provide funds to firms with relatively stable earnings (as unstable earnings raise the risk of insolvency), the cost of capital rises. Therefore, the amount of debt which a building contractor can safely contract is limited.

A high proportion of the builder's liabilities are current (short-term) liabilities. The nature of contracting operations causes a lack of significant long-term liabilities: bank overdrafts are easily renewable; suppliers provide trade credit for materials; and subcontractors are paid (usually) on a monthly basis. However, this dependence on short-term liabilities results in a high financial risk often compounded by slow payments by the client and third parties' reluctance in committing funds to the building firm on a long-term basis (Woollett, 1978).

In addition, building contracting is faced with a high danger of liabilities that arise irregularly and unexpectedly. These liabilities may come from: management failure which can be very costly and damaging to the reputation and future profitability of the firm; technical problems during the construction process; long litigation (or arbitration) with clients; or problems related to political conditions (Hillebrandt and Cannon, 1989). Unexpected liabilities can be catastrophic for builders, especially during recessionary periods. Whenever the market takes a downward turn, the competition for contracts becomes fierce resulting in underpriced tenders ('buying work'). Any unforeseen difficulties occur during the course of the contract's execution, insufficient capital resources are available to pay the creditors and then insolvency follows (Harris and McCaffer, 2001). The common behaviour of contracting firms during recession periods is to accept a large number of risks, beyond their power to mitigate them, only to stay in business. In order to be successful in tendering, they are bidding at cost (and often lower than cost) which makes them vulnerable to unexpected events during the execution of contracts, especially from financial aspects (Purnus and Bodea, 2015).

It is the lack of liquidity of building contractors to meet their short-term and unexpected liabilities which is the most common cause of failures within the industry (Al-Issa and Zayed, 2007).

2.5.5.3 Sources of Construction Project Funding

A major construction project requires an enormous amount of capital that is often supplied by lenders who want to be assured that the project will offer a fair return on the investment. The direct costs associated with a major construction project may be broadly classified into two categories:

- the construction expenses paid to the contractor for erecting the facility on site;
- the expenses for land acquisition, legal fees, architectural and engineering fees, construction management fees, interest on construction loans and the opportunity cost of carrying empty space in the facility until it is fully occupied.

The direct construction costs in the first category represent approximately 60% to 80% of the total costs in most construction projects. Since the costs of construction are ultimately borne by the owner, careful financial planning for the facility must be made prior to construction (Hendrickson, 2008).

Developers who undertake the construction of a development purely to sell it once completed, usually obtain their finance for the development period, to cover site acquisition and construction costs, from a commercial bank. Long-term investment in property though, is the objective of property development companies who retain a property once development is completed. Commercial buildings are especially valuable financial assets and are held and traded by those institutions with funds for investment. Some commercial and industrial firms develop and redevelop their own properties but it is mainly the financial institutions that directly or indirectly provide the capital for development. The most important source of finance is the banking system, usually through subsidiaries. Yet the institutions with the most funds to invest in property are the very large pension funds, who invest in a wide variety of properties (Ruddock, 1992). Project funding and financial management have a significant impact on construction project cost, cash-flow and, more importantly, success. It is important to recognise that the means a firm uses to finance its projects can have a huge impact on their ability to successfully control costs, manage cash-flow, and maintain an acceptably positive degree of value for the project. At the outset, according to Venkataraman and Pinto (2008), it is important to understand the difference between the terms *financing of projects* and *project finance*. Typically, most projects are paid for by the parent organization, either from *revenues* or *capital expenditures*. If the parent organization borrows the finances needed, the money must be repaid, regardless of project success or failure. This type of financial arrangement is referred to as financing of projects. Project finance is defined as the financing that, as a priority, does not depend on the soundness and creditworthiness of the sponsors, namely, parties proposing the business idea to launch the project. Approval does not even depend on the value of assets sponsors are willing to make available to financers as collateral. Instead, it is basically a function of the project's ability to repay the debt contracted and remunerate capital invested at a rate consistent with the degree of risk inherent in the venture concerned (Gatti, 2008).

The sources of capital available to the construction firm are quite numerous and the type of capital is dictated by the time period for which it is needed by the firm and the degree of risk involved, the former denoting the possible sources and the latter determining the most economic solution. Typically, capital is classified into three types by time period of the requirement: *short*, *medium* and *long*. The short period is considered to be that length of time during which only the variable costs of the enterprise may change (usually less than one year). The long period is that length of time during which all the costs of the enterprise (variable costs, fixed costs and semi-variable costs) may change. The medium term lies between the two extremes and is that length of time during which only the fixed costs cannot be changed (usually one year to about seven years) (Fellows *et al.*, 2002).

Construction loans to contractors are usually provided by banks or savings and loan associations for construction financing. Upon the completion of the facility, construction loans will be terminated and the post-construction facility financing will be arranged by the owner. Construction loans provided for different types of construction vary. In the case of residential housing, construction loans and long-term mortgages can be obtained from savings and loans associations or commercial banks. For institutional and commercial buildings, construction loans are usually obtained from commercial banks. Since the value of specialized industrial buildings as collateral for loans is limited, construction loans in this domain are rare, and construction financing can be done from the pool of general corporate funds. For infrastructure construction owned by government, the property cannot be used as security for a private loan, but there are many possible ways to finance the construction, such as general appropriation from taxation or special bonds issued for the project. Traditionally, banks serve as construction lenders in a three-party agreement among the contractor, the owner and the bank. The stipulated loan will be paid to the contractor on an agreed schedule upon the verification of completion of various portions of the project. Generally, a payment request together with a standard progress report will be submitted each month by the contractor to the owner which in turn submits a draw request to the bank. Provided that the work to date has been performed satisfactorily, the disbursement is made on that basis during the construction period. Under such circumstances, the bank has been primarily concerned with the completion of the facility on time and within the budget. The economic life of the facility after its completion is not a concern because of the transfer of risk to the owner or an institutional lender (Hendrickson, 2008).

Financial structures for projects include short-term and long-term equity and debt:

- Initial project planning and preparation is likely to be funded from equity.
- Construction is commonly funded on a project finance basis, in which short-term debt is provided with the project itself as the debt security. The requirement for project finance may be faster, larger and longer than planned, so top-up facilities are often required. Project finance tends to be expensive, as the risks are large in

this phase of the project life.

- Once the project has been commissioned and achieved stable operation, much of the risk has been dissipated. It is now possible to sell the project to equity investors and the long-term bond market, to pay back the construction debt and recompense the initial equity providers for the risk have taken (Cooper *et al.*, 2005).

2.5.5.3.1 Weighted Average Cost of Capital (WACC)

According to Callahan *et al.* (2007), a company's assets are financed with either *debt* or *equity*. In today's world of finance, almost all companies have debt. That debt component has a cost associated with it as well, called *interest* expense. If a company's assets are financed with both debt and equity, it is important to know the percentage of each relative to total assets. The sum of the percentage of equity and debt multiplied by their respective costs is called the *weighted average cost of capital* (WACC).

It is extremely important to note that in reference to WACC, the debt component includes only interest-bearing debt. Given the weight of debt and equity in the company's liabilities, a new investment project concerning the company's core business will cost it a weighted average of the cost of debt (k_d) and the cost of equity (k_e). The WACC formula is expressed as follows:

$$\mathrm{WACC} = k_e * (\mathrm{NC}/\mathrm{NC} + \mathrm{D}) + k_d * (1 - t) * (\mathrm{D}/\mathrm{NC} + \mathrm{D}) \qquad (2.4)$$

The company's debt and its equity are also called its *capital structure*. In the construction industry, capital structures will vary: a property company will have a very large proportion of fixed assets; a precast concrete manufacturer will have considerable fixed assets but also a considerable stock of materials and work-in-progress; a main contractor will have fixed assets of a head office, yard, some plant but a large amount of work-in-progress; while a jobbing builder may have almost no fixed assets, a negligible stock of materials but a reasonable amount of work-in-progress (often including a significant amount of completed work for which no payment has been received due to inadequate credit control). Thus, each type of firm will need a different capital structure to suit its operational requirements (Fellows *et al.*, 2002).

2.5.5.3.2 Working Capital

Due to the nature of construction, *stocks* and *work in progress* form a relatively large proportion of a firm's *working capital*. The working capital cycle for a building firm is illustrated in Figure 2.10. Good management of working capital is critical to financial success. Hence it is helpful to relate the cycle to the payment processes under the standard contracts employed to ensure that the need for working capital is kept to a minimum and that the cycle is kept as short as possible, i.e. that it circulates quickly, minimizing the use of 'own' funds and maximizing the use of 'others' funds.

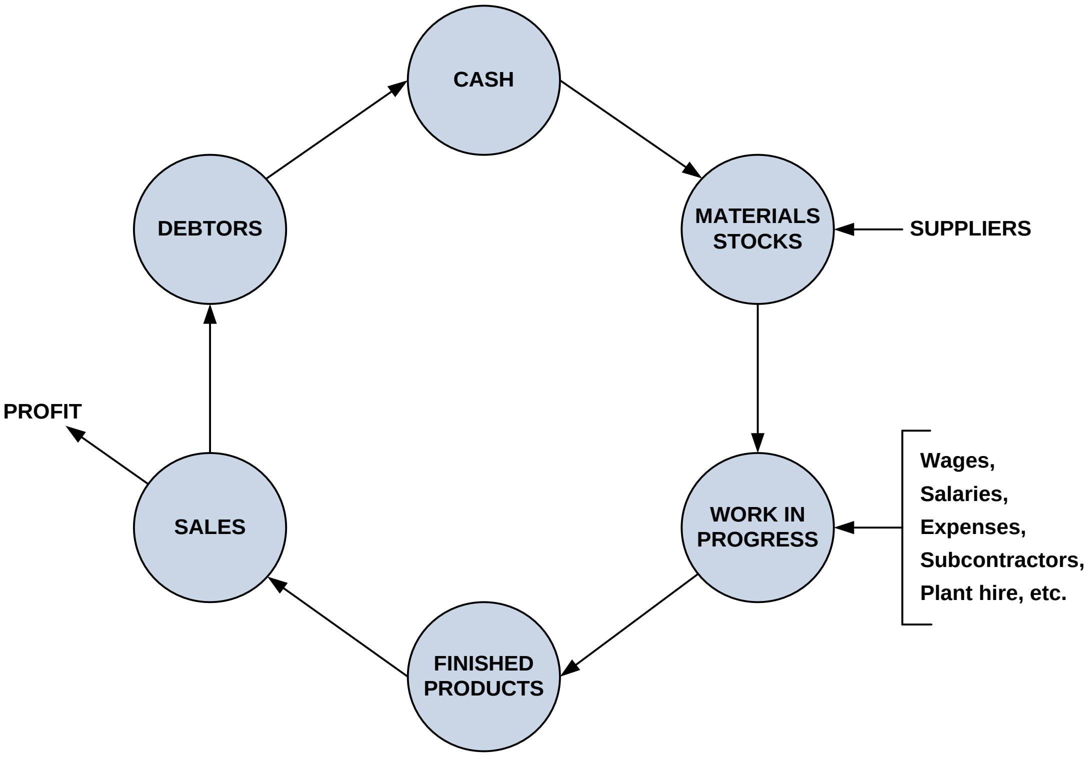


Fig. 2.10 The Working Capital Cycle (Source: Fellows *et al.*, 2002)

Work in progress is included in the accounts of most businesses at a valuation which accords with the principle of *'cost or market value, whichever is the lower'* and is included to reflect *fairly* the value of the goods which are actually within the production process. Clearly, this is reasonable for manufacturing industries, but construction represents an exception (Fellows *et al*., 2002). As Ross and Williams (2013:3) stated: 'Work in progress is the *bête noir* of construction accounting'; it represents an amount of money that has not been agreed or certified for payment and is, therefore, subject to question, disagreement or dispute. Thus, accountants see work in progress as a problem because it is frequently the case that the amount received is less than that expected; this can have a serious impact on cash flow and the availability of working capital.

2.5.5.4 Construction Project Cash-Flow Management

The construction industry is notorious for high levels of liquidations, a considerable proportion of which have been attributed to the problems associated with the lack of funds at the right time (Khosrowshahi, 1993). Consequently, financial management has been recognized as crucial for the survival of any construction company and the industry at large is seriously concerned with the problem of *cash-flow forecasting* (Navon, 1995). Solvency is the ability of a contractor to raise cash or 'near cash' to meet outstanding debts. Liquidity is the ability to meet short-term demands for cash so as to pay wages and other crucial demands for payment. Cash-flow may be defined as the actual movement of money in and out of business. Money flowing into a business is termed positive cash-flows and is credited as cash received. Money paid out is termed negative cash-flows and is debited to the business. The difference between the positive and negative cash-flows is termed net cash-flow. Cash-flow forecasting refers to the predicting of the net cash-flows on each individual contract undertaken by a building contractor and aggregate across all projects to obtain the overall net cash-flow (Cooke and Jepson, 1979). The need to know the likely effects of future events on the cash position of a building company arises (Hardy, 1970):

- to ensure that sufficient cash is available to meet normal trade variations;
- to indicate where and when additional funds will be required;
- to maintain a satisfactory level of liquidity throughout each financial year;
- to reveal surplus cash resources which may be available either for internal expansion or external investment;
- to indicate whether expansion may be financed internally or whether external sources will be required; and
- to provide firm data as a basis for negotiation with banks or finance companies.

Consequently, cash-flow forecasting provides a valuable early warning management system to predict possible insolvency and, thus, enables preventative actions to be considered and taken in good time. Some examples of these actions are given below:

- Not taking on a new contract if, when the contract is included in the cash-flow forecast, the projected cash requirements are much more than the overdraft limit;
- Renegotiation of overdraft constraints supported by reliable forecasts;
- Adjustment of the work schedules of existing contracts;
- Negotiation of extended credit with materials suppliers; and
- Accepting suppliers’ full credit facilities even if it means temporarily losing some discounts (Harris and McCaffer, 2001).

Cash-flow forecasting is an essential tool for project managers to ensure the project’s financial integrity and can be used for a number of purposes including (Cartlidge, 2015):

- by a client to secure funding;
- by a client to illustrate when and how much is due to the contractor at various

stages in the contract period;

- by a contractor to reconcile income with expenditure; and
- by a project manager to compare anticipated progress against actual progress in terms of cash-flow.

Figure 2.11 shows a cash-flow curve for a typical building project. Net and maximum cash-flows may be determined directly from the relevant *S*-curves:

- the area between the abscissa and the net cash-flow curve, whilst the latter is below the abscissa, shows the long-term finance required for the project;
- the area between the maximum cash-flow curve, while below the abscissa, and the lower of the abscissa and the net cash-flow curve, shows the short-term finance required for the project;

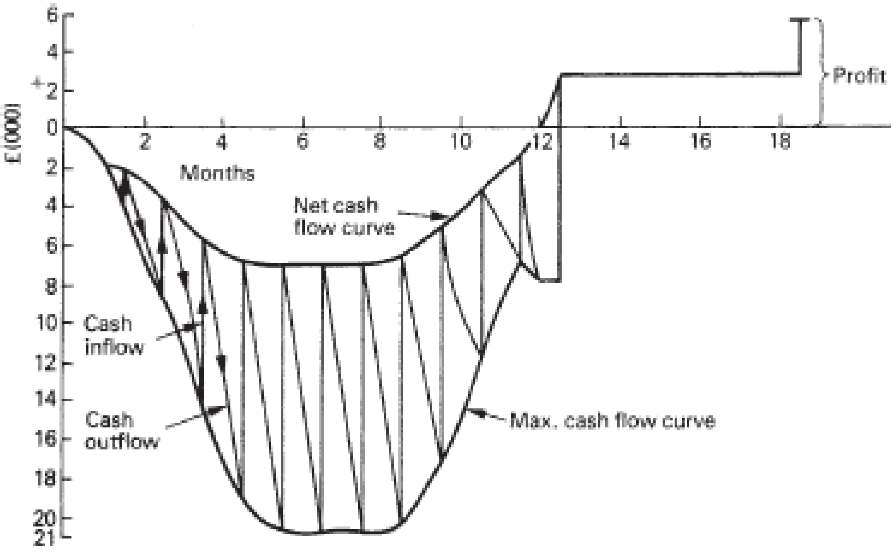


Fig. 2.11 Cash-Flow for a Typical Building Project (Source: Fellows *et al.*, 2002)

- the project is entirely self-financing only when both net and maximum cash-flow curves are above the abscissa;
- payments delay (of one month weighted average) by the contractor obviates the requirement for long-term capital for the project;

- in neither instance shown in the example does the project become entirely self-financing until the payment (inflow) following practical completion is received (month $12^{1/2}$); and
- the payments delay by the contractor also greatly reduces the project's short-term finance requirements (Fellows *et al.*, 2002).

Cash-flow forecasting can be undertaken by contractors at two levels: one is at the estimating and tendering stage when the forecast is for the single project being estimated – this gives managers the opportunity to select the contracts which can be financed by the available resources; the other level is the calculation of a cash-flow forecast for the whole company – this involves aggregating cash-flows for all active projects and can be done regularly every quarter or every month (Kaka and Price, 1991). Cash-flow forecasting at the tendering stage needs to be simple and fast considering the short time available and the associated expenses. As a result, several cash-flow forecasting models for individual projects have been developed to assist owners and contractors in their pre-tender cash-flow forecasts. However, their accuracy and reliability is in question (Kaka, 1996).

Accordingly, often, cash-flow forecasting is used as a procedural necessity without much faith in the outcome or they are used fatalistically where the forecast is accepted on the whole (Khosrowshahi, 1993). A method that has long been developed and found to be useful in practice is the *S-curve analysis*. The technique is fully described by Cooke and Jepson (1979), and in application to health service projects in Hudson (1978). Cooke and Jepson (1979) utilise a model of a typical building project in which the pattern of value accrual is based upon the cost accrual over the project duration (pre-contract costs are recovered as part of overheads). In the typical project, the cost accrual assumes the following pattern:

- During the first third of project duration, the cost accumulates in a *parabolic* pattern to achieve one-quarter of costs incurred at one-third project duration.

- During the second third of the project duration, the cost accumulates in a *linear* fashion such that at two-thirds project duration, the accumulated costs total three-quarters of project total costs.
- During the final third of project duration, the cost accumulation is a mirror image of the first third duration, to achieve 100% cost at physical completion.

The project value accumulates in the same pattern but exceeds the cost accumulation by the mark-up applied for contractor's profit. Obviously, it is equally possible to construct the cost pattern from the value pattern as it is to construct the value pattern from the cost pattern. In its simplest form, only the value (or cost), mark-up and duration are required to carry out this projection. Using the typical parabolic equations, the *S*-curve is given by:

$$
\begin{array}{ll}
y = \frac{9x^2}{4}; & 0 \le x \le \frac{1}{3} \\
y = \frac{3x}{2} - \frac{1}{4}; & \frac{1}{3} \le x \le \frac{2}{3} \\
y = \frac{9x}{2} - \frac{9x^2}{4} - \frac{5}{4}; & \frac{2}{3} \le x \le 1
\end{array}
$$

where: x is the cumulative proportion of project *duration* ($0 \le x \le 1$) and y is the cumulative proportion of project budget *cost* or *value* ($0 \le y \le 1$). The equation developed by DHSS, in Hudson (1978), is slightly at variance but was devised specifically for DHSS projects.

2.6 Advanced Project Management Techniques

2.6.1 Construction Project Management Fundamentals

Probably the most authoritative definition of a *project* is that provided by the *Project Management Vocabulary* (BS 6079-2:2000): ‘A unique process, consisting of a set of co-ordinated and controlled activities with start and finish dates, undertaken to achieve an objectives conforming to specific requirements, including constraints of time, cost and resources (Lester, 2014)'. According to the (latest) fifth edition of *A Guide to the Project Management Body of Knowledge (PMBOK© Guide)*, published by the Project Management Institute (PMI, 2013), a project is a temporary (with a definite beginning and end) endeavour undertaken to create a unique (tangible or intangible) product, service or result. Turner (2009:2) defined a project as '… an endeavour in which human, financial and material resources are organized in a novel way, to undertake a unique scope of work, of given specification, within constraints of cost and time, so as to achieve beneficial change defined by quantitative and qualitative objectives'. In an earlier definition, Steiner (1969) considered a project as '… an organisation of people dedicated to a specific purpose or objective. Projects generally involve large, expensive, unique or high risk undertakings which have to be completed by a certain date, for a certain amount of money, within some expected level of performance'. This threefold objective definition to meet *budget*, *due date* and *performance* set targets (Figure 2.12) has become widely accepted as the standard triangular criterion of *project success*.

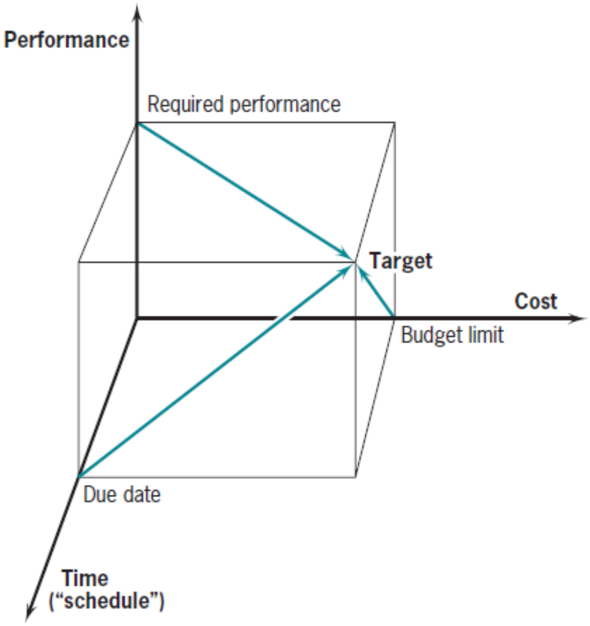


Fig. 2.12 Project Management Objectives (Source: Meredith and Mantel, 2012)

The *iron triangle* (Atkinson, 1999) is generally deemed to catch not only the main project management task but also the essential *trade-offs* since working towards achieving one objective is usually detrimental towards the other two (Williams, 2003).

Lester (2014) recently stated that, notwithstanding the numerous published definitions of *project management*, the one that covers all the important ingredients is the following: 'The planning, monitoring, and control of all aspects of a project and the motivation of all those involved in it, in order to achieve the project objectives within agreed criteria of time, cost, and performance'. The *PMBOK*© *Guide* (PMI, 2013) provides the following definition: the application of knowledge, skills, tools and techniques to project activities in order to meet the needs and expectations of project stakeholders – this is accomplished through the appropriate application and *integration* of the forty seven logically grouped project management processes, which are categorized into five main Process Groups: *initiating*; *planning*; *executing*; *monitoring and controlling*; and *closing* (Figure 2.13). Morris (1997) described project management as '… the process of integrating everything that needs to be done as the project evolves through its life-cycle in order to meet the project's objectives'.

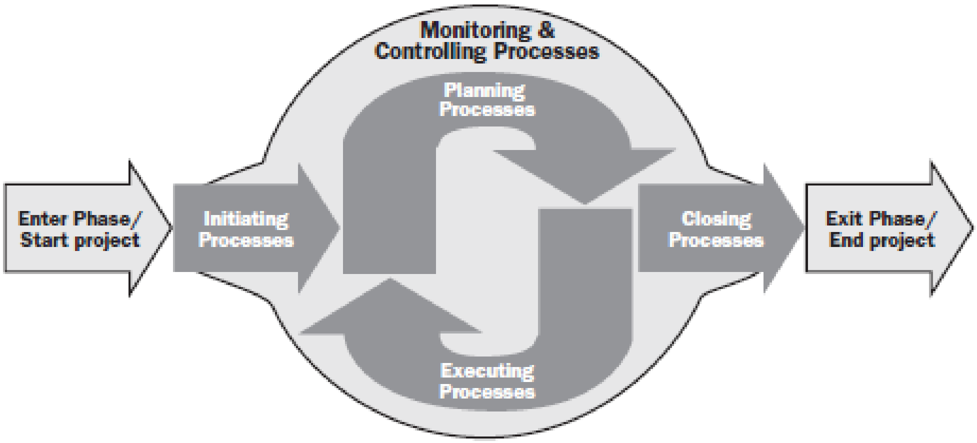


Fig. 2.13 Project Management Process Groups (Source: PMI, 2013)

Walker (2002) defines *construction project management* as: 'The planning, co-ordination and control of a project from conception to completion (including commissioning) on behalf of a client requiring the identification of the client's objectives in terms of utility, function, quality, time and cost, and the establishment of relationships between resources, integrating, monitoring and controlling the contributors to the project and their output, and evaluating and selecting alternatives in pursuit of the client's satisfaction with the project outcome’. The *project life-cycle* includes all the distinct sequential project phases, associated with a time-scale, from the point of project inception to its final termination (Archibald, 1976). Running through the project life-cycle period are control systems and decision points at which the position and performance of the project is reviewed. The interfaces of the life-cycle stages form convenient *milestones* for progress payments and reporting progress to top-level management, who can then make the decision to abort the endeavour or provide further funding (Lester, 2014).

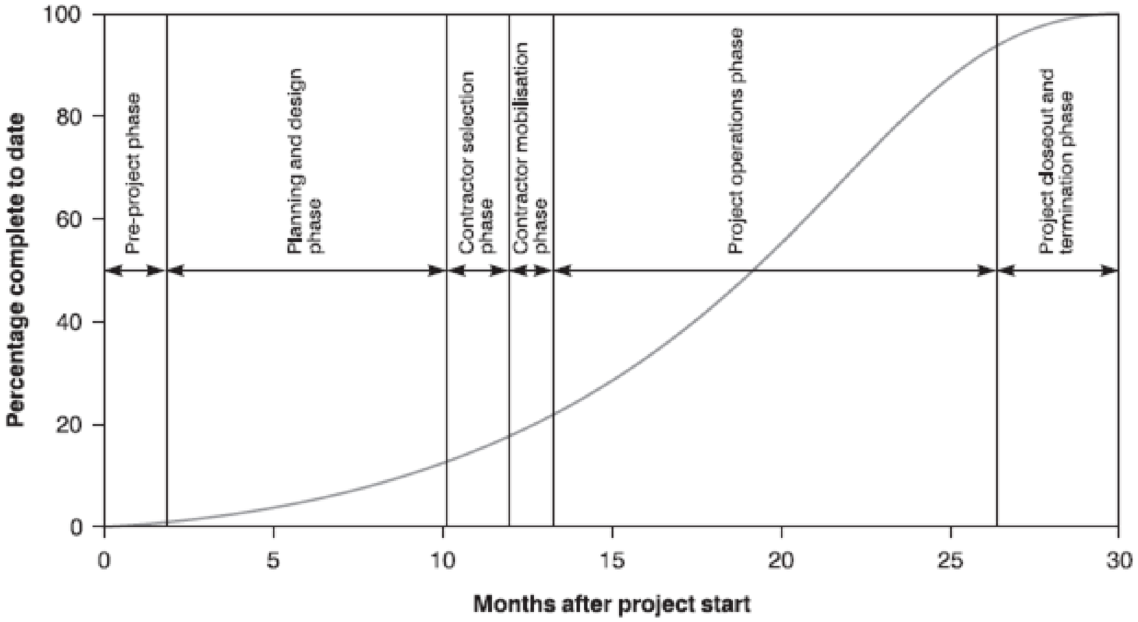


Fig. 2.14 Typical Project Life-Cycle (Source: Bennett, 2003)

An illustrative example of a typical project with a 30-month life-cycle period is presented in Figure 2.14.

The classic 'sigmoid' *S-curve* pattern of slow-rapid-slow progress towards the project goal is common, as a result of the changing levels of resources used during the successive stages of the project life-cycle. The traditional project life-cycle as normally viewed by the contractor, only considers the project from conception to handover, however the client's perspective entails a wider picture – what is termed the *product life-cycle* – which considers the facility from *'the cradle to the grave'* (Burke, 2003).

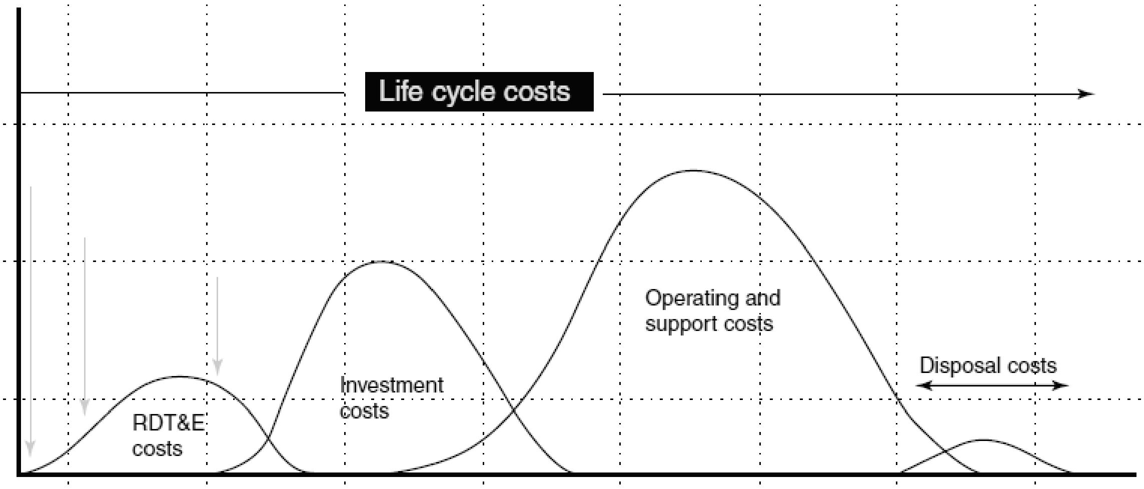


Fig. 2.15 Life-Cycle Costs of a Constructed Facility (Source: Cooper *et al.*, 2005)

The product life-cycle of a constructed facility is illustrated graphically and schematically in Figures 2.15 and 2.16 (pages 123-124) respectively. In essence, a project is conceived to meet market demands or needs in a timely fashion. Various possibilities may be considered in the *conceptual* stage, and technological and economic feasibility of each alternative will be assessed and compared to select the best possible project. The financing schemes for proposed alternatives must also be examined, and the project will be programmed with respect to the timing for its completion and for cash-flow availability. After the project scope is clearly defined, detailed engineering *design* will provide the blueprint for construction, and the definitive *cost estimate* will serve as cost control baseline. In procurement and construction stages, the delivery of materials and the erection of the project on site must be carefully planned and controlled. After construction is completed, there is usually a brief period of start-up or shake-down of the constructed facility when it is first occupied. Finally, the management of the asset is turned over to the owner for full occupancy until the facility lives out its *useful life* and is designated for demolition or conversion (Hendrickson, 2008).

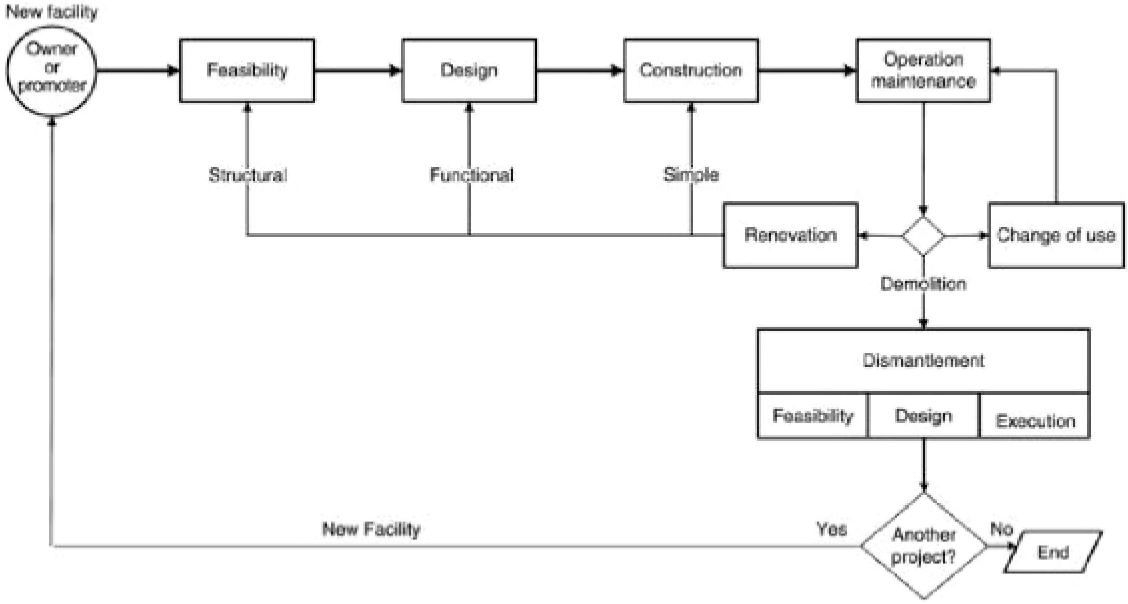


Fig. 2.16 Phases of a Constructed Facility Life-Cycle (Source: Pellicer *et al.*, 2014)

This product whole life-cycle view emphasises the need to early stage decision-making where changes can usually be accommodated without major disruption to the project. Often, a significant change at the design development phase may cause a prohibitive cost to implement that change (Dell'Isola, 2002).

Figure 2.17 (page 125) shows the *trade-off* relationship between project time and cost of changes in project requirements. Thus, designers are able to *trade-off* the cost of construction with the cost of maintenance, upgrading, expansion or disposal over the whole life of the facility. The extreme case would be a cheap construction which turned out to be expensive to maintain, difficult to upgrade and expand, and environmentally sensitive to dispose of (Burke, 2003).

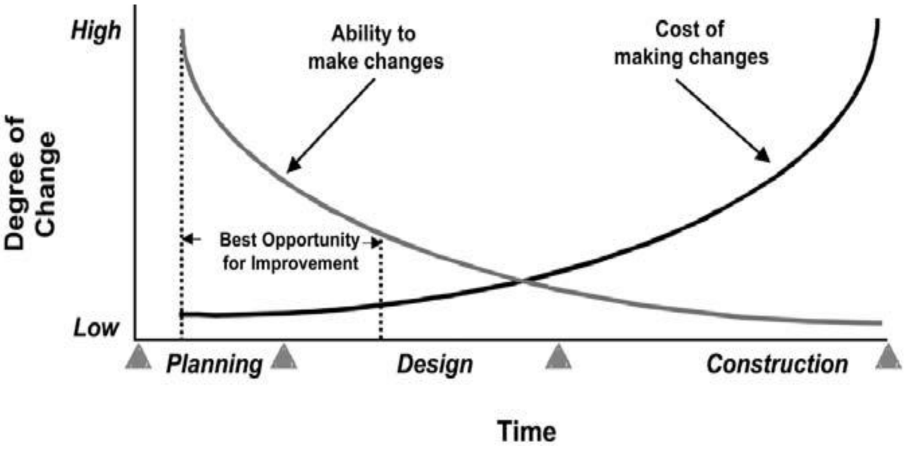


Fig. 2.17 Relationship between Time and Degree of Change (Source: Dell'Isola, 2002)

Two further terms that require clarification at this stage in relation to the aforementioned definitions of project management are (Cartlidge, 2015):

- *Programme management* – the management of groups of related but inter-dependent projects; more concerned with outcomes of strategic benefit, whereas project management concentrates on defined outputs or *one-off* deliverables.
- *Portfolio management* – refers to the total investment by a client in a variety of projects for the purpose of bringing about strategic business objectives or change.

2.6.2 Network-Based Project Management

When construction projects are simple, consisting of few defined activities, it might be possible for a single person to grasp the total construction effort with little difficulty. Unfortunately, most projects for which formal plans are prepared tend to be defined with dozens or even hundreds of activities: the larger the project, the greater the number of activities and the higher the level of detail managers have to handle. When a project plan consists of numerous activities, it is often advisable to organise the activities in some way to allow communication of plan information to others and to maintain an understanding of the various aspects of the project. While there are many ways that a plan can be organized, probably the most common practice is the *work breakdown structure* (WBS) (De Marco, 2011). The WBS (Figure 2.18) is the use of a formal structure to break-down the project *logically* and *systematically* into its component parts to:

- enable the planning to be done effectively by defining the work to be done to complete the project and to subdivide it into manageable tasks that can be planned, budgeted and controlled;
- assign responsibility for the completion of these tasks to internal functional groups or organisations and/or contractors, and thus to integrate the organisation structure with the work to be done, i.e. the work breakdown structure; and
- design and integrate the control and information systems, with the work to be done and who is responsible for it (Harrison and Lock, 2004).

Garcia-Forniels *et al.* (2003) assert that the WBS is perhaps the most important tool for project management because it provides a basis for planning, scheduling, control, assignment of responsibility and information management. Given the level of importance, several organisations have embraced its use in managing their projects.

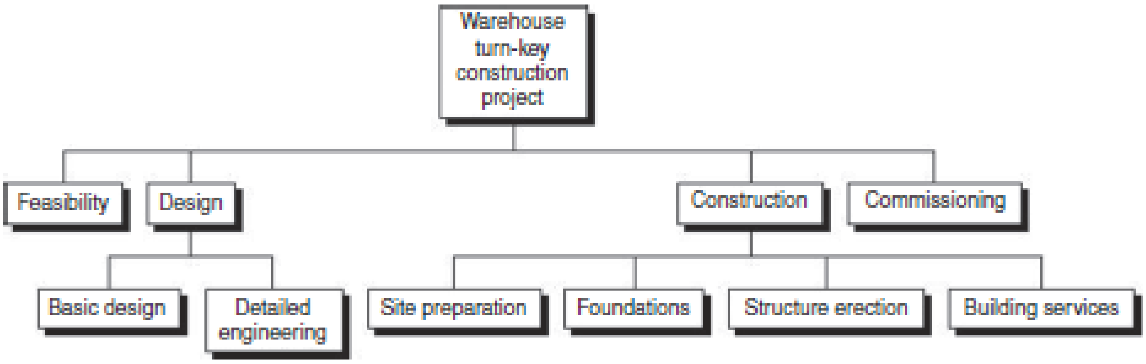


Fig. 2.18 Work Breakdown Structure (WBS) for a Warehouse Building (Source: De Marco, 2011)

Determining the project cost is done through the *cost breakdown structure* (CBS). The CBS is a system for dividing a project into cost categories; it is a hierarchical structure that classifies resources, typically labour, materials and other direct costs, into cost accounts. Furthermore, it represents the economic breakdown of the project into budgets per work package. This will allow the project manager to track project progress and expenditure according to planning breakdown of activities and responsibilities. A CBS includes all direct full cost of labour, materials, as well as project-level overheads (which is treated as a direct cost required to execute the project). CBS does not have to include the company-level overheads which are not associated with the site field work (De Marco, 2011).

Until the advent of *critical path method* (CPM) [first appeared in the article by its originators, Kelley and Walker (1959)] and *program evaluation and review technique* (PERT) [reported by its developers in Malcolm *et al.* (1959)] in the late 1950's, there was no generally accepted formal procedure to aid in the management of projects. Each manager had their own scheme, which often involved limited use of *bar* or *Gantt charts* (developed in 1917 by an American mechanical engineer, Henry L. Gantt, in the context of a World War I military requirement) – 'a useful tool in production management but inadequate for the complex interrelationships associated with contemporary project management' (Moder *et al.*, 1983), however, still remaining a popular tool especially in the construction industry, mainly due to its ability to graphically represent a project's activities in a clear, simple, and time-scaled manner (Cooke, 2015) (Figure 2.19, page 128). The development of network-based PERT/CPM planning methods formed the foundation for a more systematic approach towards a discipline of project management. As Mubarak (2015) pointed out: 'Network-based scheduling has revolutionised the management of construction projects. It has provided management with a more objective and scientific methodology than simply relying completely on the project manager's experience and personal skills'. PERT/CPM techniques involve a graphical portrayal of the interrelationships among the project activities, and an arithmetic procedure which identifies the relative importance of each task in the overall schedule.

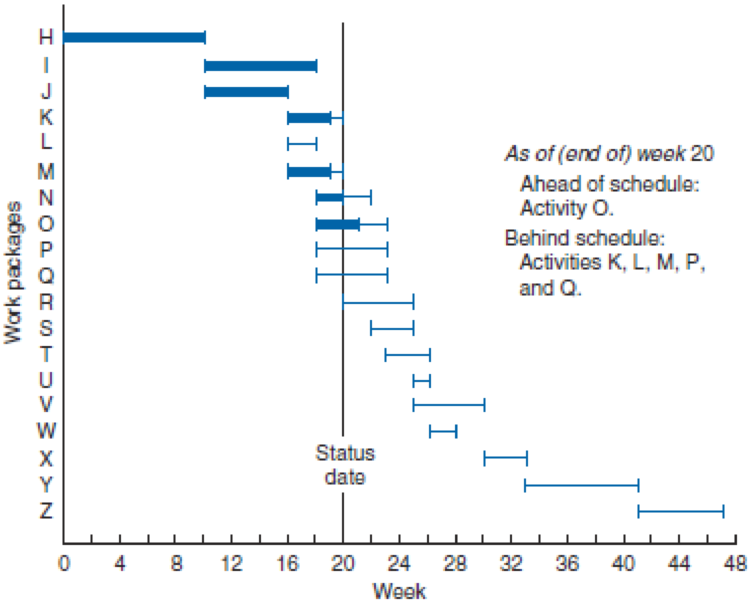


Fig. 2.19 Gantt Chart for a Typical Project (Source: Nicholas and Steyn, 2008)

According to Demeulemeester and Herroelen (2002), a project consists of a number of *events* (milestones) and *activities* or *tasks* that have to be performed in accordance with a set of *precedence constraints*. Each activity has a *duration* and normally requires *resources* (except for the so-called *dummy* activities that consume neither). An event (milestone) refers to a stage of accomplishment of activities associated with a certain point in time. Resources may be of different types, including financial resources, manpower, machinery, equipment, materials, energy, space, etc. The best known type of precedence relationship is the *finish-to-start* relationship with a zero time-lag: an activity can only start as soon as all its predecessor activities have finished. Other precedence relations also exist such as *start-to-start*, *finish-to-finish*, and *start-to-finish* relations, with various types of minimal and/or maximal time-lags.

There are two possible modes of representation of a project network: a). the *activity-on-arc* (AoA) representation which uses the set of arcs E to represent the activities and the set of nodes V to represent events, and b). the *activity-on-node* (AoN) representation which uses the set of nodes V to denote the activities or events and the set of arcs E to represent the precedence relations (Demeulemeester and Herroelen, 2002). Vanhoucke (2013) argued that the construction of an AoN network is very simple and is, in contrast to an AoA network, not subject to a set of rules. Dummy activities are not necessary, apart from a single initial start and a single end activity, which makes an AoN network always unique. Schwindt (2005) explained that a project network can be considered to be an (acyclic and directed) graph $G = (V, E)$, consisting of a set of interacting activities (or tasks) requiring time and resources for their completion. The structural analysis of the project provides a decomposition of these activities and the precedence relationships among them into a set V of vertices (nodes) and a set E of edges (arcs), respectively. Set V consists of n activities $i = 1, \ldots, n$ to be scheduled and two auxiliary (dummy) activities 0 and $n + 1$, representing project start and finish, respectively. The precedence relationships can be represented as activity pairs (i, j) where $i \neq j$, denoting that the beginning time of activity i affects the earliest start time of activity j. A duration p_i is given to each activity $i \in V$ and a time-lag δ_{ij} to each pair $(i, j) \in E$ where $\delta_{ij} \leq S_j - S_i$ being the *temporal constraint* with S_i and S_j the start times of activities i and j, respectively. If $(i, j) \in E$, activity j cannot start earlier than δ_{ij} units of time after the start of activity i. If $\delta_{ij} = p_i$ the above constraint is referred to as *precedence constraint* between activities i and j.

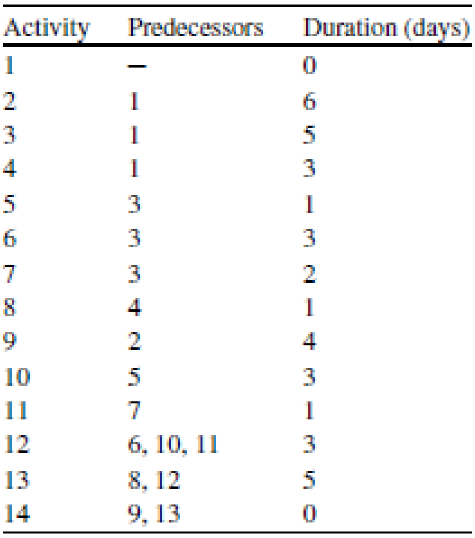
The network analysis then consists of (Oxley and Poskitt, 1996):

- calculating earliest event times by working *forwards* through the network and selecting the longest path (earliest time for the final event gives project duration);
- calculating latest event times by working *backwards* through the network and selecting the longest path (latest time for the final event is the same as its earliest time and gives the same project duration);

- calculating the *total float* of activities, which is either the latest start time minus the earliest start time or the latest finish time minus the earliest finish time (both methods give the same result); and
- identifying the critical activities with zero total float and thus determining the *critical path*.

Today’s project scheduling practice uses solely AoN networks. This technique is much more flexible due to its enhanced modelling capabilities. Minimal and maximal relations give the opportunity to create a model of the project that is closer to reality (Hajdu, 2013a). In the remainder of the thesis, the AoN network format will be used for the representation of project networks. An example of a typical AoN project network with twelve *real* activities and two *dummy* (start and finish) activities is illustrated in Figure 2.20 (page 131).

Table 2.8 Required Data for Project Network Construction (Source: Vanhoucke, 2013)



Activity	Predecessors	Duration (days)
1	–	0
2	1	6
3	1	5
4	1	3
5	3	1
6	3	3
7	3	2
8	4	1
9	2	4
10	5	3
11	7	1
12	6, 10, 11	3
13	8, 12	5
14	9, 13	0

The network was developed based on the project of Table 2.8 which shows the duration of each activity and its immediate predecessors. The three steps to follow in order to construct an AoN network are to (Vanhoucke, 2013):

- draw a node for each network activity;
- draw an arc for each immediate precedence relation between two activities; and
- add dummy start and end nodes to force that the network begins with a single start activity and finishes with a single end activity.

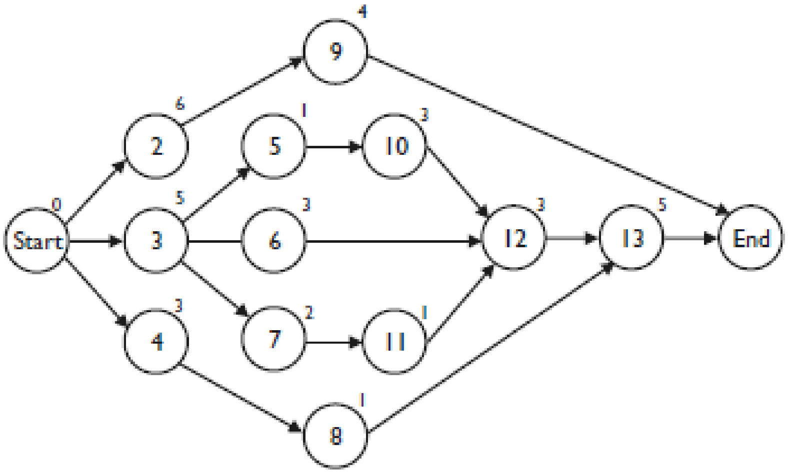


Fig. 2.20 Activity-on-Node (AoN) Network Example (Source: Vanhoucke, 2013)

Advantages of network scheduling techniques include (Kerzner, 2009):

- They form the basis for all planning and predicting and help management decide how to use its resources to achieve time and cost goals;
- They provide visibility and enable management to control ‘one-of-a-kind’ programs;
- They help management evaluate alternatives by answering such questions as how time delays will influence project completion, where slack exists between elements, and what elements are crucial to meet the completion date;
- They provide a basis for obtaining facts for decision-making;
- They utilise a so-called time network analysis as the basic method to determine manpower, material, and capital requirements, as well as to provide a means for checking progress;

- They provide the basic structure for reporting information;
- They reveal interdependencies of activities;
- They facilitate *'what-if'* exercises;
- They identify the longest path or critical paths; and
- They aid in *scheduling risk analysis*.

Difficulties arise because, for the hundreds of activities in a project, there are various options of completing these activities using different crew sizes or equipment. This creates the classic combinatorial search problem for construction engineers to identify the best selections of resources that produce the minimum cost possible to complete the project. Because of the time-cost relationship among activities, it usually takes several iterations to select the proper methods, equipment, crew sizes and working hours to obtain an acceptable overall project duration within the contractual time limit (Feng *et al.*, 2000). Depending on whether the sets of activities execution modes are countable or uncountable, a *discrete* or a *continuous* multi-mode resource allocation scheduling problem exists respectively (Schwindt, 2005).

Conventional project scheduling (known under the general PERT/CPM abbreviation) assumes that projects need to be done within the presence of an *infinite* resource capacity. Despite its simplicity, it is still considered as the basic construction scheduling approach, and its principles are applicable to more advanced techniques. However, it is generally accepted that the presence of resources under limited availability may result in a dramatic increase in problem complexity when constructing a project baseline schedule (Vanhoucke, 2013). PERT technique is extended to Monte-Carlo simulation analyses, which permit the analysis of the distribution of the critical path without the restricted PERT assumptions. An overview of the pitfalls of following the traditional PERT assumptions can be found in Elmaghraby (1977) and Chase *et al.* (2003).

2.6.3 Time-Cost Trade-off (TCT) Problem

The time and cost parameters of a construction project have been identified as major facets of the decision-making process. The optimal timing for a project is a function of the technological order of its various project activities, the resources required and the related cost. To establish the relationship between project time and cost can be a quite complex problem, and even more challenging is the task of optimising this relationship (Cusack, 1985).

In the scheduling of construction projects, project duration can be compressed (crashed) by expediting some of its activities in several ways, including: increasing gang size above the normal level; working overtime; or using alternative construction methods. The crashing alternatives cause additional costs. This *time-cost trade-off* (TCT) problem has been studied extensively since the development of the CPM (Vanhoucke and Debels, 2007). The objective of TCT problem is to identify the set(s) of time-cost alternatives that will optimise the schedule.

In construction, penalties are commonly imposed on projects that exceed contract duration; failure to meet the contractual time requirement will put the contractor in breach of contract and thus liable for any damages suffered by the owner because of the late project completion. Furthermore, on a job in progress, the owner may desire an earlier completion date than originally called for by the contract and may request that the contractor quote a price for expediting the work. On the other hand, the contractor may wish to complete the project by a certain date to avoid adverse weather, to free workers and equipment for other work and/or to receive an early completion bonus from the client (Sears *et al.*, 2015). The construction planner then normally aims at three possible schedule objectives: minimising the project makespan subject to a fixed upper bound of money (the *budget* restriction), minimising the total cost of the project subject to a given bound on the project duration (the *deadline* restriction) (Brucker *et al.*, 1999) or combining the two previous objectives by generating an efficient time-cost profile over a set of feasible project durations (the complete horizon objective) (Vanhoucke, 2013). Reducing project duration is accomplished by compressing the duration of some of its constituent critical activities by increasing the direct costs of the resources required. However, by saving project time, there will also be savings in the indirect project costs (overheads). Thus, balancing between increasing direct costs and decreasing indirect costs of the project is the subject of time-cost trade-off (TCT) or time-cost optimisation analysis. Increasing the resources allocated for the activity reduces the duration of the activity, but a point is reached where the use of additional resources does not result in any overall savings on the project (Baldwin and Bordoli, 2014). This point that represents the minimum total project cost at the optimum total project duration is shown in Figure 2.21.

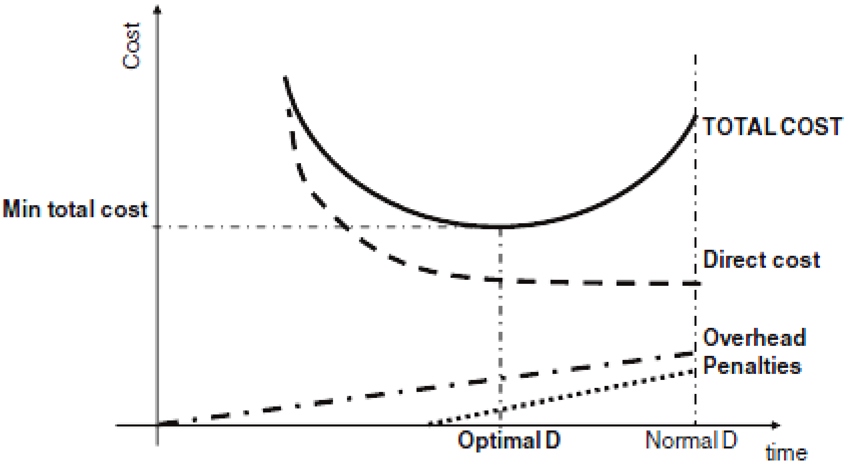


Fig. 2.21 Optimum Time-Cost Trade-off (TCT) Point (Source: De Marco, 2011)

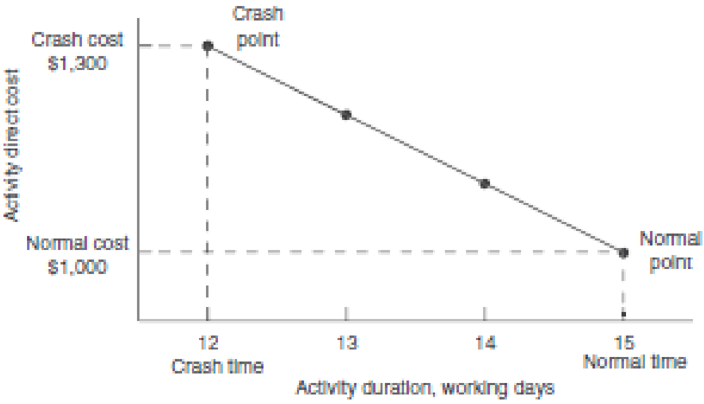
Once a decision to build has been reached, the client will be anxious to have the building completed as quickly as possible. For many clients early completion may be the overriding priority, for example where staging a major sporting event is scheduled, or where a client is attempting to establish a market presence ahead of competitors, or to avail of tax incentives. Time is also of the essence in emergency situations such as fire or flood damage or where stabilisation works are required to dangerous structures (Cunningham, 2013). ‘Simply because schedule compression techniques may exist does not mean that they will work. There is a tendency for managers to be aggressively positive in their thinking at the onset of a project, believing that compression techniques can be applied effectively (Kerzner, 2009).’ There are five common techniques for schedule compression, and each technique has significant limitations that may make this technique more of a myth than reality – this is explained in the following Table 2.9.

TCT analyses in construction project scheduling have been recognised since the 1950s, simultaneously with the development of CPM by Kelley and Walker (1959) and PERT reported in Malcolm *et al.* (1959). Since then, a vast amount of literature has proposed various solutions to the basic TCT problem.

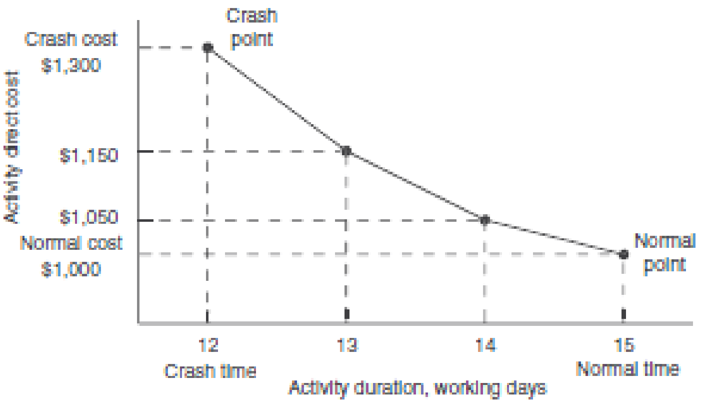
Table 2.9 Myths and Realities of Schedule Compression (Source: Kerzner, 2009:529)

Compression Technique	Myth	Reality
Use of overtime	Work will progress at the same rate on overtime	The rate of progress is less on overtime; more mistakes may occur; and prolonged overtime may lead to burnout
Adding more resources (i.e. crashing)	The performance rate will increase due to the added resources	It takes time to find the resources; it takes time to get them up to speed; the resources used for the training must come from the existing resources
Reducing scope (i.e. reducing functionality)	The customer always requests more work than actually needed	The customer needs all of the tasks agreed to in the statement of work
Outsourcing	Numerous qualified suppliers exist	The quality of the suppliers’ work can damage your reputation; the supplier may go out of business; and the supplier may have limited concern for your scheduled dates
Doing series work in parallel	An activity can start before the previous activity has finished	The risks increase and rework becomes expensive because it may involve multiple activities

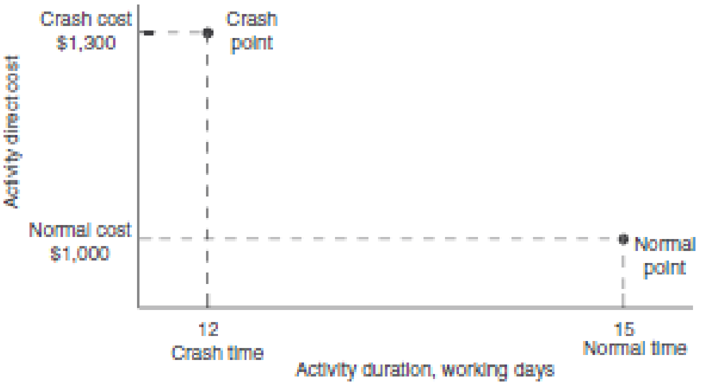
Early TCT approaches assumed a *continuous* relationship between time and cost (Figures 2.22.a and 2.22.b) (Yang, 2005). However, in construction projects, resources are usually available in *discrete* units, such as the number of equipment or the number of crews. Working overtime or implementing alternative construction methods also usually provide discrete crashing options (Figure 2.22.c).



(a) Continuous Linear Variation



(b) Continuous Piecewise Linear Variation



(c) Noncontinuous Variation

Fig. 2.22 Activity Time-Direct Cost Variation (Source: Sears *et al.*, 2015)

Due to its practical relevance, numerous methods have been suggested to solve the *discrete* time-cost trade-off (DTCT) problem. According to Sonmez and Bettemir (2012), these methods can be classified in the following three groups: *mathematical* models (commonly mixed integer linear programming) which search for *exact* solutions; *heuristic* procedures which search for *near-optimal* results; and *meta-heuristic* algorithms in search for *optimal* or *near-optimal* results.

The following subsections briefly discuss the main approaches to the TCT problem.

2.6.3.1 Mathematical Programming

Mathematical (exact) methods convert the project TCT problems to mathematical models and utilize linear programming (LP), integer programming (IP), or dynamic programming (DP) to solve the problem (De *et al.*, 1995; Burns *et al.*, 1996; Moussourakis and Haksever, 2004; Chassiakos and Sakellaropoulos, 2005). In the early 1960s, Kelly (1961) and Fulkerson (1961) formulated models using LP and network flow computations by assuming bounded, piecewise linear (Figure 2.22.b, page 138), continuous, convex, non-increasing time-cost relationships. Meyer and Shaffer (1963) used IP to handle more complex time-cost functions. The practicality of the above approaches was questioned by Cusack (1985) due to the large number of variables and constraints needed and the necessity for time consuming mathematical analysis to transform the project data into standard IP form. Cusack (1985) suggested an IP model based on convex time-cost curves joined together by points of breakthrough, thus reducing the number of variables and constraints so that the analysis could be automated using a microprocessor. However, the proposed model was limited to a maximum number of hundred activities. Robinson (1975) developed a DP approach to solve TCT problems which require special network relationships. Reda and Carr (1989) used mixed IP to solve time-cost trade-off problems within related activities. Recently, Maghrebi *et al.* (2013) proposed a novel mathematical deterministic model based on path constraints, rather than activities. The simplicity of the model and the shorter time required for the solution are the main strengths of the model. The advantages of mathematical models include efficiency and accuracy. However, formulating constraints and objective function is time-consuming and error-prone. Besides, mathematical programming knowledge is necessary for correct formulation of the model and few construction planners are trained to perform this type of formulation, especially for large networks (Williams, 2003).

According to Williams (2003) reviews of these attempts can be found in Brucker *et al.* (1999); Ahuja and Thiruvengadam (2004); Moselhi and Roofigari-Esfahan (2013). Yang (2005) points out that the time-cost relationship of each activity can be piecewise linear (Fondahl, 1961; Kelly, 1961; Cusack, 1985), convex (Foldes and Sourmis, 1993), concave (Falk and Horowitz, 1972), quadratic (Deckro *et al.*, 1995) and discrete (De *et al.*, 1995; Liu *et al.*, 1995; Skutella, 1998).

2.6.3.2 Heuristic Algorithms

Heuristics are non-computer approaches which require less computational effort than mathematical methods. Early examples of heuristic approaches can be found in the work of Fondahl (1961); Prager (1963); Siemens (1971); and Goyal (1975). Moselhi (1993) developed an algorithm based on schedule compression. Generally, heuristic methods provide a way to obtain nearly optimal solutions with a reasonable amount of computational effort but do not guarantee optimality. In addition, the solutions offered by heuristic methods do not provide the range of possible solutions, making it difficult to experiment with different scenarios for what-if analysis (Burns *et al.*, 1996).

2.6.3.3 Meta-Heuristics

Subsequently, *meta-heuristic* approaches that search for optimal or near-optimal solutions have been developed: *genetic algorithms* (GA) (Feng *et al.*, 1997; Li and Love, 1997; Hegazy, 1999; El-Rayes and Kandil, 2005; Eshtehardian *et al.*, 2009; Sonmez and Bettemir, 2012), *neural networks* (NN) (Adeli and Karim, 1997) *particle swarm optimisation* (PSO) (Yang *et al.*, 2007; Elbeltagi *et al.*, 2005) and *ant colony optimisation* (ACO) (Ng and Zhang, 2008; Kalhor *et al.*, 2011).

2.6.4 Earned Value Analysis (EVA)

Once a project starts, certain aspects can easily deviate or go astray. This deviation can be overspending, a schedule slippage, a departure from the objective/scope, or something else. It is of the utmost importance to know at all times where one stands in comparison with where one planned to be (the baseline) at this time. If any variance is found, one must know the amount and causes of the variance and then take corrective action to get back on track or, at the very least, to minimize the variance. If the variance is positive (i.e., the project is ahead of schedule or under budget), actual performance was probably better than that expected in the baseline plan. This process exemplifies *project control* (Mubarak, 2015).

Earned Value Analysis (EVA) is a methodology used to measure and communicate the real physical progress of a project and to *integrate* the three critical elements of project management: scope; time; and cost management. It takes into account the work completed, the time taken and the costs incurred to complete the project and it helps to evaluate and control project risks by measuring project progress in monetary terms (Vanhoucke, 2013). The status of the project (or any portion of it) can be assessed with the following three variables, namely the *budgeted cost of the work scheduled* (BCWS), the *actual cost of the work performed* (ACWP), and the *budgeted cost of the work performed* (BCWP). These are industry-standard acronyms but to conform to PMI (2013) the abbreviated terms PV, AC and EV can also be used:

- PV is the *planned value*, i.e. the total cost of all work and apportioned effort scheduled to be completed in a given time period as specified in the *original budget*.
- AC is the *actual expenditure* incurred in a given time period, i.e. it is the sum of the actual costs for all completed and started (but not completed) work packages plus the associated overheads.
- EV is the *earned value* which is determined by looking at the amount of work performed thus far (fully and partially completed work packages) as well as the amount that work was supposed to have cost according to the *budget*.

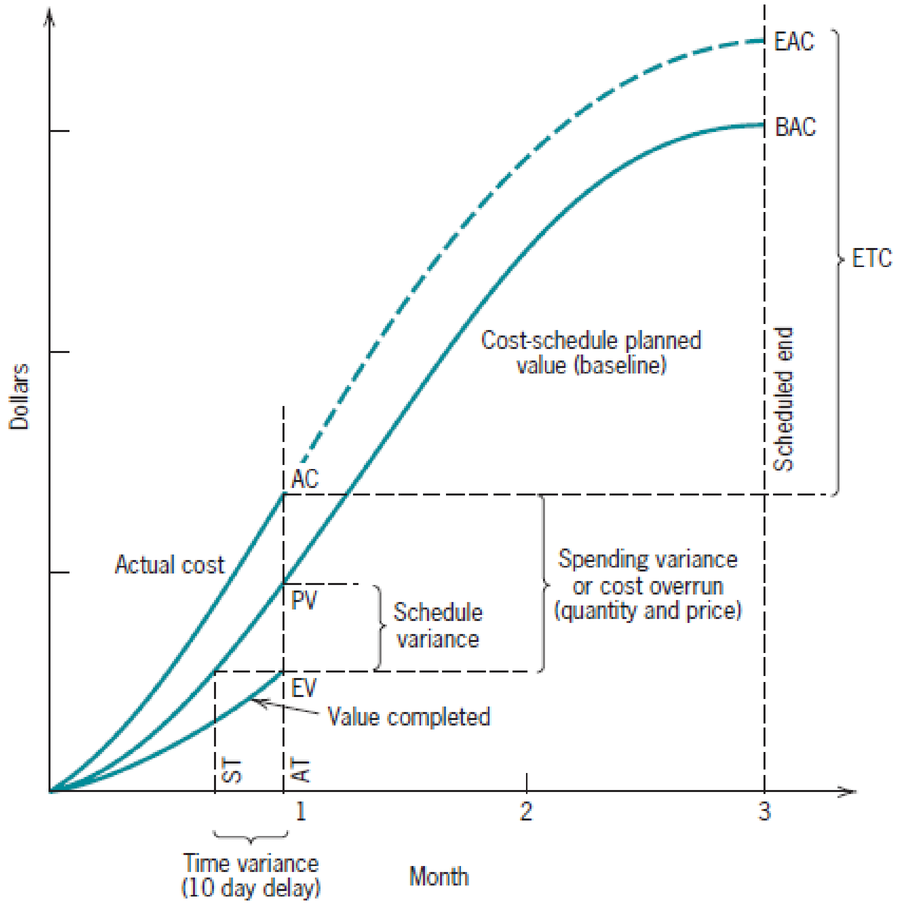


Fig. 2.23 Earned Value Analysis (EVA) Cost-Time *S*-curve (Source: Meredith and Mantel, 2012)

Thus, the EV for a completed work task is the same as the PV for that task, the EV for a partially completed work task is computed based upon the estimated *percent complete* of the task (or it is alternatively computed by taking 50% of PV when the task is started, then the other 50% when the task is completed).

Burke (2003); Shtub *et al.* (2005); Fleming and Koppelman (2010); Meredith and Mantel (2012); and Vanhoucke (2013) also provide comprehensive descriptions of the EVA procedure. According to PMI (2013), the EVA methodology can be described as follows (Figure 2.23, page 140).

Cost/schedule *planned value* (PV) is the project authorized (baseline) budget assigned to scheduled work (not including management reserve). This baseline budget is allocated by phase over the life of the project, but at a given moment, PV defines the physical work that *should* have been accomplished. The total PV for the project is also known as *budget at completion* (BAC). *Earned value* (EV) is a measure of work performed expressed in terms of the baseline budget authorized for that work. The EV being measured *cannot* be greater than the authorized PV budget and is often used to calculate the percent complete of a project. *Actual cost* (AC) is the realized cost incurred for the work performed on an activity during a specific time period. It is the total cost incurred in accomplishing the work that the EV measured. The AC needs to correspond in definition to what was budgeted in the PV and measured in the EV (e.g. direct hours only, direct costs only, or all costs including indirect costs). The AC will have no upper limit; whatever is spent to achieve the EV will be measured. *Schedule variance* (SV) is a measure of schedule performance expressed as the difference between the EV and the PV (SV = EV – PV). It is the amount by which the project is ahead or behind the planned delivery date, at a given point in time. The SV is a useful metric in that it can indicate when a project is falling behind or is ahead of its baseline schedule and will ultimately equal zero when the project is completed because all of the PVs will have been earned. SV is best used in conjunction with PERT/CPM scheduling and risk management. *Cost variance* (CV) is the amount of budget deficit or surplus at a given point in time, expressed as the difference between the EV and the AC (CV = EV – AC). It is a measure of *cost performance* on a project and at the end of the project will be the difference between the *budget at completion* (BAC) and the actual amount spent. CV is particularly critical because it indicates the relationship of physical performance to the costs spent; with a negative CV is often difficult for the project to recover.

The SV and CV values can be converted to *efficiency indicators* to reflect the cost and schedule performance of any project for comparison against all other projects or within a portfolio of projects. The variances are useful for determining project status.

The *schedule performance index* (SPI) is a measure of schedule efficiency expressed as the ratio of EV to PV (SPI = EV/PV). It measures how efficiently the project team is using its time and is sometimes used in conjunction with the *cost performance index* (CPI) to forecast the final project completion. An SPI value less than 1.0 indicates less work completed than planned. An SPI greater than 1.0 indicates more work completed than planned. Since the SPI measures all project work, the performance on the *critical path* also needs to be analysed to determine whether the project will finish ahead of or behind its planned finish date. The SPI is equal to the ratio of the EV to the PV. The *cost performance index* (CPI) is a measure of the cost efficiency of budgeted resources, expressed as a ratio of EV to AC (CPI = EV/AC). It is considered the most critical EVA metric and measures the cost efficiency for the work completed. A CPI value of less than 1.0 indicates a *cost overrun* for work completed. A CPI value greater than 1.0 indicates a cost underrun of performance to date. These efficiency indices are useful for determining project status and providing a basis for estimating project cost and schedule outcome. The three parameters of PV, EV and AC can be monitored and reported on both a period-by-period basis (typically weekly or monthly) and on a cumulative basis. As the project progresses, the project team may develop a forecast for the *estimate at completion* (EAC) that may differ from the *budget at completion* (BAC) based on the project performance. If it becomes obvious that BAC is no longer viable, the project manager should consider EAC. Forecasting EAC involves making projections of conditions and events in the project's future based on current performance information and other knowledge available at the time of the forecast. Forecasts are generated, updated, and re-issued based on work performance data that is provided as the project is executed. The work performance information covers the project past performance and any information that could impact the project in the future. EAC is typically based on the AC incurred for work completed, plus an *estimate to complete* (ETC) the remaining work. The most common EAC forecasting approach is a manual, bottom-up summation by the project team (EAC = AC + Bottom-up ETC). The bottom-up EAC method builds upon the actual costs and experience incurred for the work completed, and requires a new estimate to complete the remaining project work. The project manager's manual EAC is quickly compared with a range of calculated EACs representing various risk scenarios. When calculating EAC values, the cumulative CPI and SPI values are typically used. The three more common methods are summarised as follows:

- EAC = AC + (BAC – EV): This method accepts the actual project performance to date (whether favourable or unfavourable) as represented by the AC, and predicts that all future ETC work will be accomplished at the budgeted rate. When actual performance is unfavourable, the assumption that future performance will improve should be accepted only when supported by project risk analysis.
- EAC = BAC/CPI: The assumption here is that what the project has experienced to

date can be expected to continue in the future. The ETC work is assumed to be performed at the same cumulative CPI as that incurred by the project to date.

- EAC = AC + [(BAC – EV)/(CPI * SPI)]: In this forecast, the ETC work will be performed at an efficiency rate that considers both cost and schedule performance indices. This method is most useful when the project schedule is a factor impacting the ETC effort. Variations of this method weight the CPI and SPI at different values (e.g. 80/20, 50/50, or some other ratio) according to the project manager's judgment.

Each of these approaches is applicable for any given project and will provide the project management team with an *early warning* signal if the EAC forecasts are not within acceptable tolerances. TCPI is a measure of the cost performance that is required to be achieved with the remaining resources in order to meet a specified management goal, expressed as the ratio of the cost to finish the outstanding work to the remaining budget.

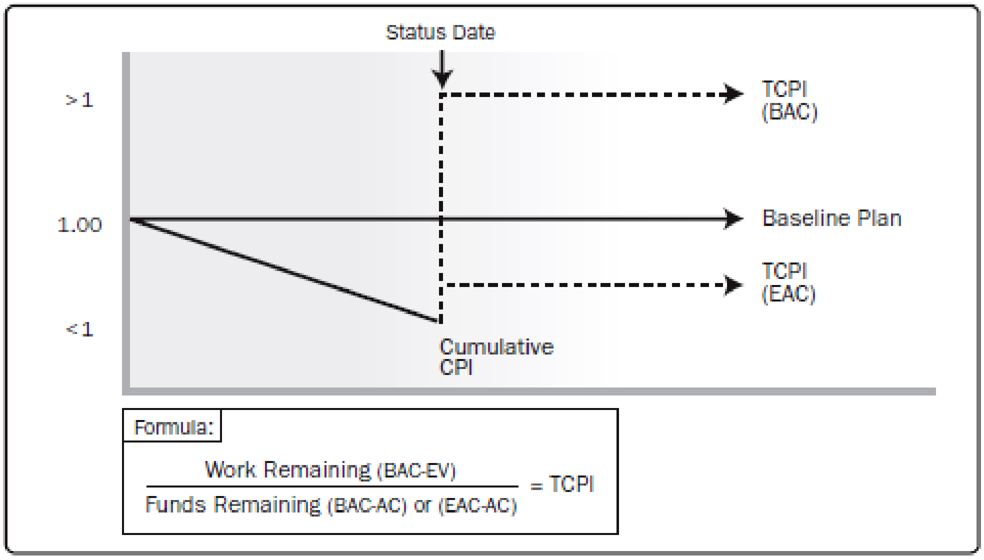


Fig. 2.24 To-Complete Performance Index (TCPI) for a Project (Source: PMI, 2013)

TCPI is the calculated cost performance index that is achieved on the remaining work to meet a specified management goal, such as the BAC or the EAC. If it becomes obvious that the BAC is no longer viable, the project manager should consider the forecasted EAC. Once approved, the EAC may replace the BAC in the TCPI calculation. The equation for the TCPI based on the BAC: (BAC – EV)/(BAC – AC). The TCPI is conceptually displayed in Figure 2.24 (page 144). The equation for the TCPI is shown in the lower left as the work remaining (defined as the BAC minus the EV) divided by the funds remaining (which can be either the BAC minus the AC, or the EAC minus the AC). If the cumulative CPI falls below the baseline, all future work of the project will need to be performed immediately in the range of the TCPI (BAC) to stay within the authorized BAC. Whether this level of performance is achievable is a judgment call based on a number of considerations, including risk, schedule and technical performance. This level of performance is displayed as the TCPI (EAC) line. The equation for the TCPI based on the EAC: (BAC – EV)/(EAC – AC).

2.6.5 Reasons for Time and Cost Overruns in Construction Projects

Time and cost overruns present major issues for governments, clients, contractors, financiers and the whole supply chain in the building sector. It also has broader global economic and social implications where funding for projects is limited and the value for money invested is critical. The recent Global Financial Crisis in 2008 has heightened the problem with a significant global reduction in funding for projects and financiers introducing stringent controls on project lending criteria. Critical to these controls is the certainty (or lack thereof) of the project meeting cost and time targets. Whilst project cost overruns in developed countries are a major issue, the ramifications of cost overruns are arguably higher in developing countries due to limited funding budgets (Smith, 2014). According to the Building Cost Information Service (BCIS) of the Royal Institute of Chartered Surveyors (RICS), 48% of construction projects experience schedule (time) overruns (Kennett, 2009 as cited in Love *et al.*, 2013). Schedule overruns can adversely influence the organisational performance and profitability of clients, contractors and key stakeholders. Clients' demands for early completion to minimise finance costs and increase ROI to satisfy investors and stakeholders can lead to over-optimistic schedules being produced (Mansfield *et al.*, 1994). Cost overrun is a chronic problem across most projects (Doloi, 2011). Increasing complexity and involvement of multitude of stakeholders with varied stakes make it nearly impossible for the modern construction projects to avoid cost overruns. While numerous methods and models have been published on the issue of cost management in construction, the root cause associated with the project development environment impacting cost performance still remains unexplored (Doloi, 2011). In a study of the relationship between contractors and subcontractors in Saudi Arabia (Al-Hammad, 1993), it was found that a number of factors significantly affected these relationships causing overruns: delays in contract progress payments, lack of construction quality, errors and delays in shop drawings, and approval of sample materials were ranked highest as contractor-subcontractor interface problems; ranking lowest among these factors were legal disputes, scheduling conflicts among subcontractors, geological problems and weather conditions. Koushki *et al.* (2005) studied time delays and cost increases in the construction of private residential projects in Kuwait and found that these were greater when the total cost of residential projects were higher. A major factor contributing to the time delay and cost overrun was the inadequacy of money and time allocated to the design phase. The three main causes of time delays were, in order, the number of change orders, financial constraints and owners' lack of experience in construction. The three main causes of cost overruns on the other hand were, in order, contractor's delays, material-related problems and, again, owners' financial constraints.

Table 2.10 summarises the main findings from research work on time and cost overruns in construction (Doloi, 2011).

Table 2.10 Studies on Time and Cost Overruns in Construction (Source: Doloi, 2011)

Author	Findings
Mansfield *et al.* (1994)	Poor contract management; Financing and payment of completed works; Changes in site conditions; Shortages of materials; Imported materials and plant items; Design changes; Subcontractors and nominated suppliers.
Arditi *et al.* (1985)	Problems with materials; Financial problems of both owner and contractors; Organisation deficiencies in both owners' and contractors' companies; Lack of qualified/technical workers; Extra works.
Frimpong *et al.* (2003)	Monthly payment difficulties from agencies; Poor contractor management; Material procurement; Poor technical performances; Escalation of material prices.
Kaliba *et al.* (2009)	Bad or inclement weather due to heavy rains and floods; Scope changes; Environmental protection and mitigation costs; Schedule delay; Strikes; Technical challenges; Inflation and local government pressures.

Chan and Kumaraswamy (1997) conducted a survey to evaluate the relative importance of 83 potential delay factors in Hong Kong construction projects and found five principal factors: poor risk management and supervision; unforeseen site conditions; slow decision-making; client-initiated variations; and work variations. Kaming *et al.* (1997) studied influencing factors on 31 high-rise projects in Indonesia and found out that cost overruns occur more frequently and are more severe problem than time overruns. The major factors influencing cost overrun are: material cost increase due to inflation; inaccurate material estimation; and degree of complexity. While in time overrun, the most important factors causing delays are: design changes; poor labour productivity; inadequate planning; and resource shortages. Al-Barak (1993) discussed the main causes of failure in the construction industry in Saudi Arabia by surveying 68 contractors and about 34 different causes of failure. The study concluded that lack of experience, poor estimation practices, bad decisions in regulating company’s policy, and national slump in the economy are the severe factors (Assaf and Al-Hejji, 2006).

2.7 Risk Analysis in Construction Projects

Project risk analysis is concerned with the assessment of the risks and uncertainties that threaten a project and typically consists of two parts: *schedule* risk analysis and *cost* risk analysis. There will also be an analysis of project *cash-flow*, especially at the conception and bidding stages (Vose, 1996).

Projects are one-time and largely unique efforts of limited time duration that involve work of a non-standardised and variable nature. Field construction work can be affected profoundly by events that are difficult, if not impossible, to anticipate. Under such uncertain and shifting conditions, field construction costs and time requirements are changing constantly and can seriously deteriorate with little or no advance warning. The presence of uncertainty in construction does not suggest that planning is impossible but rather that it will assume a monumental role in the success or failure of the project. The greater the level of uncertainty in the project, the greater is the need for exhaustive project planning and skilled and unremitting management (Sears *et al.*, 2015).

Although most risks are generally regarded as negative or undesirable, and indeed most mitigation strategies have been devised to reduce the impact or probability of negative risk, there is paradoxically also such a thing as positive risk, or opportunistic risk. This is basically the risk that any entrepreneur or investor takes when he/she invests in a new enterprise. A simple case of ‘nothing ventured, nothing gained.’ A case may also arise where a perceived negative risk becomes a positive risk or opportunity. For example, in an attempt to reduce the risk of skidding, a car manufacturer may invent an anti-skid device that can be marketed independently at a profit. If there had been no risk, there would have been no need for the antidote (Lester, 2014).

2.7.1 Schedule and Cost Risk Analysis

A cost risk analysis consists of looking at the various costs associated with a project, their uncertainties and any risks or opportunities that may affect these costs. Risks and opportunities are defined as *discrete* possible events that will increase or decrease the project costs respectively. They are both characterised by *estimates* of their *probability of occurrence* and the magnitude of their impact. The distributions of cost are then added-up in a risk analysis to determine the uncertainty in the total cost of the project (Vose, 1996). A schedule risk analysis looks at the time required to complete the various tasks associated with a project, and their inter-relationship between these tasks. Risks and opportunities are identified for each task and an analysis is performed to determine the total duration of the project and, usually, the durations until specific *milestones* within the project are achieved. A schedule risk analysis is generally more complex to perform than a cost risk analysis because the logical connections between the tasks have to be modelled in order to determine the *critical path*. In reality, a project's cost and duration are linked together. Tasks in a project are often quantified by *inter alia* the number of person weeks (work) needed to complete them. The duration of the task is then equal to (person weeks/people on the job) and the cost equals (person weeks x labour rate). Costs and durations are also linked if the model includes a *penalty clause* for exceeding a deadline (Vose, 1996). Project simulation uses a model that translates the specified detailed uncertainties of the project into their potential impacts on project objectives. Simulations are typically performed using the Monte Carlo technique whereas the project model is computed (iterated) many times, with the input values (e.g., cost estimates or activity durations) chosen at random for each iteration from their selected probability distributions. A *histogram* (e.g., total cost or total duration) is calculated from these iterations. For a cost risk analysis, a simulation uses cost estimates. For a schedule risk analysis, the schedule network diagram and duration estimates are used. The output from a cost risk simulation using the triangular distribution is shown in Figure 2.25.

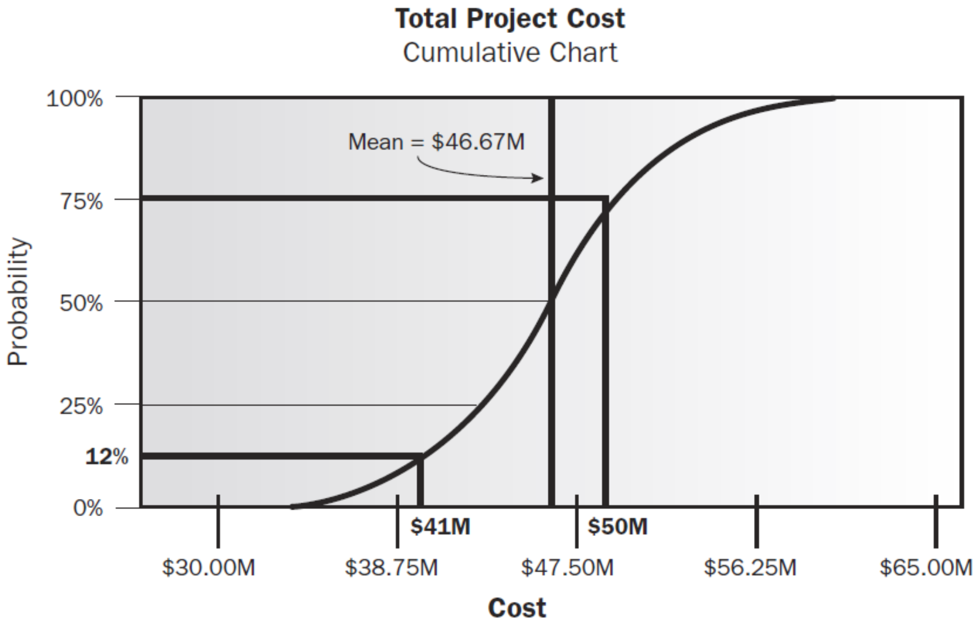


Fig. 2.25 Project Risk Analysis Output for Total Project Cost (Source: PMI, 2013)

The cumulative distribution indicates that the project is only 12% likely to meet the $41 million most likely cost estimate. If a conservative organisation desires a 75% likelihood of success, a budget of $50 million is required, thus a contingency of nearly 22%. Similar curves can be developed for other project objectives (PMI, 2013).

Schedule (time) risk analysis uses the same principles as cost risk analysis for modelling general uncertainty and risks and opportunities. However, it must also cope with the added complexity of modelling the inter-relationships between the various tasks of a project. A cost risk analysis will usually be developed from a top-down WBS with the various *work packages or elements* (WP/E) of which the project consists. There will usually be a number of cost items associated with each WP/E that has an element of uncertainty. In addition, there may be *discrete* events (risks or opportunities) that could change the size of these costs. The *normal* uncertainties in the cost items are modelled by *continuous* distributions like the *PERT* or the *triangular*. The *impact* of risks and opportunities will similarly be modelled by *continuous* distributions but *whether they occur or not* is modelled with the *discrete* distribution (Vose, 1996).

2.7.2 Monte Carlo Simulation (MCS)

In cost management, *Monte Carlo simulation* (MCS) aids in better understanding of the project budget and estimate final budget at completion. Instead of assigning a probability distribution to the project task durations, project manager assigns the distribution to the project costs. These estimates are normally produced by a project cost expert, and the final product is a probability distribution of the final total project cost. Project managers often use this distribution to set aside a project budget reserve, to be used when contingency plans are necessary to respond to risk events (Kwak and Ingall, 2007).

In summary, MCS provides a number of advantages over 3-point deterministic analysis:

- *probabilistic analysis* – showing not only what could happen, but how likely each outcome is;
- *graphical analysis* – due to the data a MCS generates, it is easy to create graphs of different outcomes and their chances of occurrence and thus to communicate findings to stakeholders;
- *sensitivity analysis* – working with just three scenarios, deterministic analysis makes it difficult to see which risks impact the project outcomes most;
- MCS allows one to see which risks have the biggest effect on project results; and

- *risk correlation* – it is important to represent real-life interdependences so that when a particular risk occurs, the probability or impact of others goes up or down accordingly (Kwak and Ingall, 2007).

2.7.3 Probability Distributions

Continuous probability distributions, which are used extensively in modelling and simulation, represent the uncertainty in values such as durations of schedule activities and costs of project components. *Discrete* distributions can be used to represent uncertain events. Two examples of widely used continuous distributions are shown in Figure 2.26.

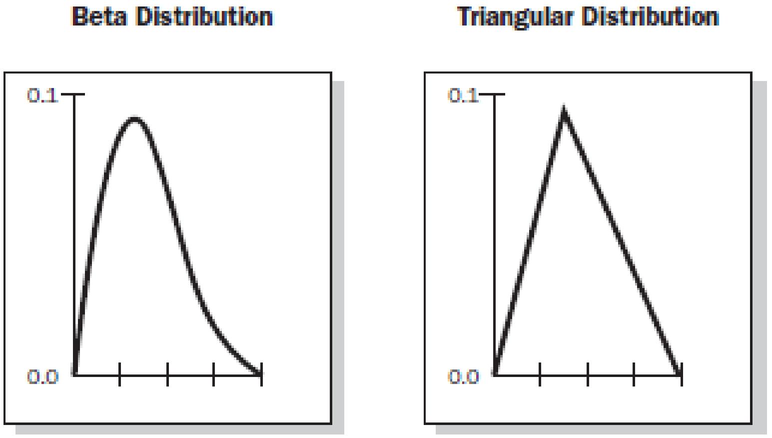


Fig. 2.26 *Beta* and *Triangular* Probability Distributions (Source: PMI, 2013)

Beta and *triangular* distributions depict shapes that are compatible with the data typically developed during *quantitative risk analysis* (QRA). *Uniform* distributions can also be used if there is no obvious value that is more likely than any other between specified high and low bounds, such as in the early concept stage of design (PMI, 2013).

The *discrete* distribution has the form discrete($\{x_i\}$,$\{p_i\}$) where $\{x_i\}$ is an array of the possible values of the variable with probability weightings $\{p_i\}$. The $\{p_i\}$ values do not have to add up to unity as it is actually often useful just to consider the ratio of likelihood of the different values and not to worry about the actual probability values. This distribution has three distinct uses:

- to model a discrete variable – that is, a variable that may take one of a set of identifiable values, each of which has a calculable probability of occurrence.
- to model a variable that may be affected by an uncertain event. This is known as *conditional branching*.
- to combine two or more conflicting *expert* opinions.

The vertical scale of a relative frequency plot of the *discrete* distribution is the actual probability of occurrence, sometimes called the *probability mass*. The sum of all these values must add up to one (Vose, 1996).

The *PERT* distribution gets its name because it uses the same assumption about the mean as PERT networks used in project planning. Technically, it is a version of the *beta* distribution and is widely employed in risk analysis for modelling the uncertainty of a variable. It is based on the assumption that mean $(\mu) = (minimum + 4 * most\ likely + maximum)/6$, therefore, the mean for the *PERT* distribution is four times more sensitive to the *most likely* value than to the *minimum* and *maximum* values. It requires the same three parameters as the *triangular* distribution (*minimum-a*, *most likely-b*, *maximum-c*) without suffering to the same extent the potential systematic bias problems of the *triangular* distribution, that is in producing too great a value for the mean of the risk analysis results where the *maximum* for the distribution is very large. The standard deviation of the *PERT* distribution is also less sensitive to the estimate of the extremes and systematically lower than the *triangular* distribution, particularly where the distribution is highly skewed. As for the *triangular* distribution, the *PERT* distribution is *bounded* on both sides, hence, may not be adequate for some modelling purposes when it is desired to capture tail or extreme events.

Figure 2.27 shows typical *PERT* assumptions for project duration: normal (a), optimistic (b) and pessimistic (c).

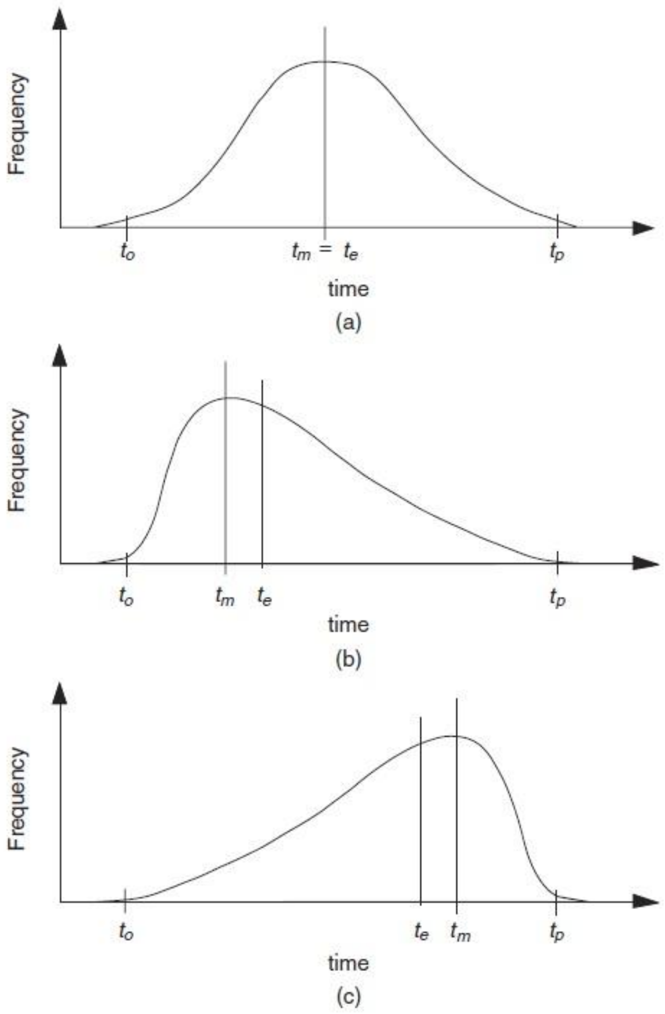


Fig. 2.27 *PERT* Probability Distribution (Source: Sears *et al.*, 2015)

The equation of the *PERT* distribution is related to the *beta* distribution as follows:

$$PERT(a,b,c) = \text{beta}(\alpha_1,\alpha_2) * (c - a) + a \tag{2.5}$$

where:

$$a_1 = [(\mu - a) * (2b - a - c)]/[(b - \mu) * (c - a)] \tag{2.6}$$

$$a_2 = [a_1 * (c - \mu)]/(\mu - a) \tag{2.7}$$

and the mean is:

$$\mu = (a + 4 * b + c)/6. \tag{2.8}$$

The *variance* of the *PERT* distribution derives from the equation:

$$\sigma^2 = \frac{(\mu - a) * (c - \mu)}{7} \tag{2.9}$$

The *probability density function* (pdf) of the *PERT* distribution is:

$$f(x) = \frac{(x - a)^{\alpha_1 - 1} * (c - x)^{\alpha_2 - 1}}{\text{Beta}\ (\alpha_1, \alpha_2) * (c - a)^{\alpha_1 + \alpha_2 - 1}} \tag{2.10}$$

Sonmez (2004) studied the *fit* of several probability distribution functions to historical cost data from thirty building projects in the US, to determine appropriate probability function selection for probabilistic project cost estimation. The *beta* distribution provided the ‘best fit’ to the project cost data; however *Weibull*, *triangular* and *normal* distributions also provided reasonably good fits. The goodness-of-fit of the distributions depends on the characteristics of the data set used. Sonmez (2004) further suggested that more research is needed to conclude on the specific probability distribution function for probabilistic cost estimation of construction projects.

Hajdu and Bokor (2014) recently examined, through various both artificial and real-life sample construction projects, the effect of the application of different activity duration distribution functions to the analysis results compared to the use of the traditional *PERT* distribution. The authors’ investigation showed that $^+/_-$ 10% difference in the *PERT* three-point estimation causes greater deviation than the application of different activity distributions and, thus, from a practical point of view it was concluded that the use of other probability distributions does not result in significant differences.

2.8 The Need for a Holistic Thinking to Cost Management in Construction

Kishk *et al.* (2003) argued that the traditional approach to costing building projects has been to focus primarily on initial capital costs and since the capital costs of construction is almost always separated from the running costs, it is normal practice in the building industry to accept the lowest initial cost and then hand-over the building to be maintained by others. Tietz (1987) pointed out that the initial building costs can be wholly misleading because capital savings can result in major life-time expenses caused by extra maintenance work or earlier obsolescence. Furthermore, with occupancy costs representing up to 70% of the total cost of a building over its entire life-cycle (Flanagan and Norman, 1987), this pre-occupation with capital expenditure has led to designs which do not meet clients' desire to set the right budget and to reduce their life-cycle costs, and it is important to understand the benefits of *life-cycle costing* (LCC) (Kirk and Dell'Isola, 1995). In addition, energy prices have also risen and are subject to wide price fluctuations and, as a result, clients are more aware that running costs should be examined very closely from a sustainable development perspective. These rising concerns over the long-term environmental impact of a building have forced designers to adopt a more *holistic* attitude and to look more closely at the costs incurred over the project life-cycle, from conception to demolition (Al-Hajj and Horner, 1998). It is not only original designs that matter for building productivity, but the nature of the materials used, and the manner in which buildings are monitored, maintained, and re-evaluated over their *whole life-cycle*. Good design and construction does not, therefore, end at the erection of the building – it involves the provision of building services over the product life-time (*n*CRISP, 2003).

A study conducted by the UK Royal Academy of Engineering on the long-term costs of owning and using buildings (Evans *et al*., 1998), revealed that for a typical commercial project (office building), over a 30-year period, the operational expenditure is 5 times the capital cost and the operating cost of businesses occupying the building is 200 times the initial costs (the 1:5:200 rule). A similar study in building design and management claimed the aforementioned ratio to be 1:10:100 (Kernohan *et al*., 1996). These approximate 'rules of thumb' indicate that only a 1% reduction of business operating cost in the life-time of a building would effectively payback its initial capital cost and that substantial level of economic activity are affected by relatively small design, construction and maintenance inputs (*n*CRISP, 2003). Herein is located the key impetus for implementing LCC, that is: '… to reduce costs during the operation and maintenance phases as these are greater proportion of the whole life cost of the asset, even if this means increased capital expenditure at the outset (Olubodun *et al.*, 2010)'. Accordingly, LCC has become more important to real property owners (private clients or public sector Authorities) with a long-term interest in the property concerned who demand evidence of what their costs of ownership will be, and to consortia formed to procure Private Finance Initiative (PFI), Public-Private Partnerships (PPP) or Build-Operate-Transfer (BOT) projects trying to assess the financial risks of taking long-term responsibility for building operation and maintenance (BRE, 2004). The increased usage of LCC could well be due to the fact that in contractual partnerships of this nature the risk and the long-term financial implications of design decisions rest with the building contractors and, therefore, it is their interest to minimise the life-cycle cost of the asset (Kirkham *et al.*, 2004). Furthermore, funding and insurance organisations are also interested in LCC as part of their *due diligence* enquiries into how robustly cost estimates have been prepared and how successfully the risks of designing and delivering property projects have been tackled (Constructing Excellence, 2003). As Clift (2003) explained, until recently, lending institutions have considered that most financial risk occurs during the building production phase when project cost can be affected by unexpected ground conditions, inclement weather, labour/material shortages, time overruns, defects and/or poor budgeting. Now that financial institutions are funding long-term PFI projects (lasting over 25 years) they realise that lack of understanding of how buildings perform makes predicting future costs a long way ahead an unreliable exercise.

2.8.1 Life-Cycle Costing (LCC) and Whole-Life Costing (WLC)

Several definitions of LCC have developed over the years. The first International Standard for property life-cycle costing, BS ISO 15686-5:2008 'Buildings and constructed assets – Service life planning – Part 5: Life cycle costing' (BSI, 2008) defines LCC as the: 'methodology for the systematic economic evaluation of life cycle costs over a period of analysis, as defined in the agreed scope'. Life-cycle cost, in turn, is defined as the 'cost of an asset, or its parts throughout its life cycle, while fulfilling the performance requirements'. Ferry and Flanagan (1991) in their report for the UK Construction Industry Research and Information Association (CIRIA) described the LCC method as: 'putting the estimated capital, maintenance, operating and replacement costs into a comparable form and bringing them into a single figure which allows for the fact that these items of expenditure will take place at different stages within the time-scale'. Norman (1993) defined LCC as the process of economic analysis that assesses the total cost of investment in and ownership, operation and subsequent disposal of the system or product to which the LCC method is being applied. This process takes the functional requirements and operational constraints that apply to the system or product and translates these into a common cost measurement known as life-cycle cost. Another useful definition is included in Kishk *et al.* (2003) – at its most basic, LCC 'includes the systematic consideration of all costs and revenues associated with the acquisition, use and maintenance and disposal of an asset'. The important point to be drawn from the above definitions and expressions is that LCC deals with present and future costs and attempts to relate the two as a basis for decision-making. LCC should also be distinguished from life-cycle assessment (LCA) since LCA only addresses ecological aspects with no connection to economy (Pelzeter, 2007).

The Norwegian Standard NS 3454 (NS, 2000) defines LCC as including both original costs and costs incurred throughout the whole functional property life-time. Mainly in the

UK and Canada the expression whole-life costing (WLC) is preferred. WLC is defined in BS ISO 15686-5:2008 (BSI, 2008) as the 'methodology for the systematic economic consideration of all whole life costs and benefits over a period of analysis, as defined in the agreed scope'. Hence, WLC is considered to have a broader scope than LCC emphasising not only on economic life-span but on the entire span of constructed asset existence including non-construction costs such as finance, business costs, incomes from sales/disposals etc. and external social/environmental costs and benefits [see a whole-life cost breakdown structure (WLBCS) in Figure 2.28].

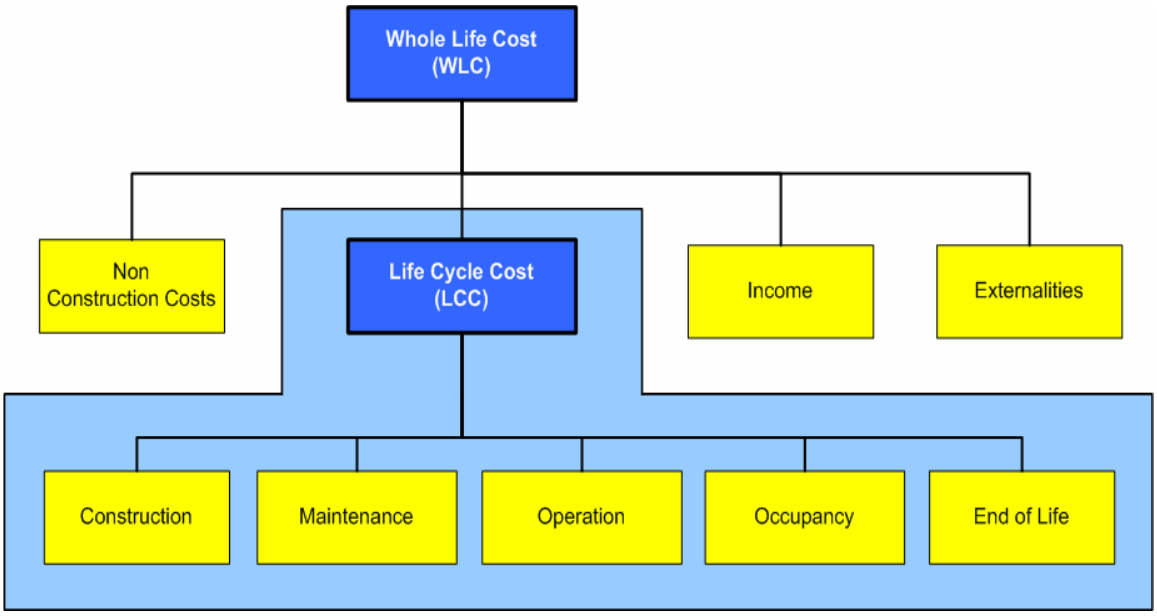


Fig. 2.28 Whole-Life Cost Breakdown Structure (WLCBS) (Source: BS ISO 15686-5:2008)

However, in the literature the two terms are still used interchangeably by the majority of those who are interested in the technique. To prevent confusion, in this research both terms are used but according to their above definitions in BS ISO 15686-5:2008. Notwithstanding, since the proposed methodology is based on whole-life costing calculations, the term WLC is mainly used throughout the thesis.

2.8.2 Whole-Life Costing (WLC) Benefits and Disadvantages

WLC objectives as identified by the Royal Institution of Chartered Surveyors (RICS, 1986) are:

- to enable investment options to be more effectively evaluated and facilitate choice between alternative scenarios;
- to consider the impact of all costs rather than only initial capital costs; and
- to assist in the effective management of completed buildings and projects.

The use of WLC particularly assists in determining (Clift, 2003):

- whether a higher initial cost is justified by reductions in future costs (for new build or when considering alternatives to 'like for like' replacement);
- whether a proposed change is cost-effective against the 'do nothing' (or *status quo*) alternative, which has no initial investment cost but higher future costs.

Client's benefits, as found in the Client's Guide to Whole Life Costing (CCF, 2000), include:

- encouraging analysis of business needs and their communication to project team;
- optimising the total cost of ownership/occupation by balancing initial capital and running costs;
- ensuring risk and cost analysis of loss of functional performance due to failure or inadequate maintenance occurs;
- promoting realistic budgeting for operation, maintenance and repair;
- encouraging discussion and recording of decisions about the durability of materials and components at the outset of the project; and
- providing data on actual performance and operation compared with predicted performance for use in the future planning and benchmarking.

In general terms, all stages during the management of a typical building project have a potential use of WLC (Ferry and Flanagan, 1991). However, the potential for influencing the full life-cycle performance is higher in the early design stages and decreases dramatically through construction and use phases, and the earlier WLC can be considered in the procurement process, the more effective the outcome will be (Kohler and Moffatt, 2003). It has been estimated that 80% to 90% of the costs of running, maintaining and repairing a building is determined at the design stage (Mackay, 1999).

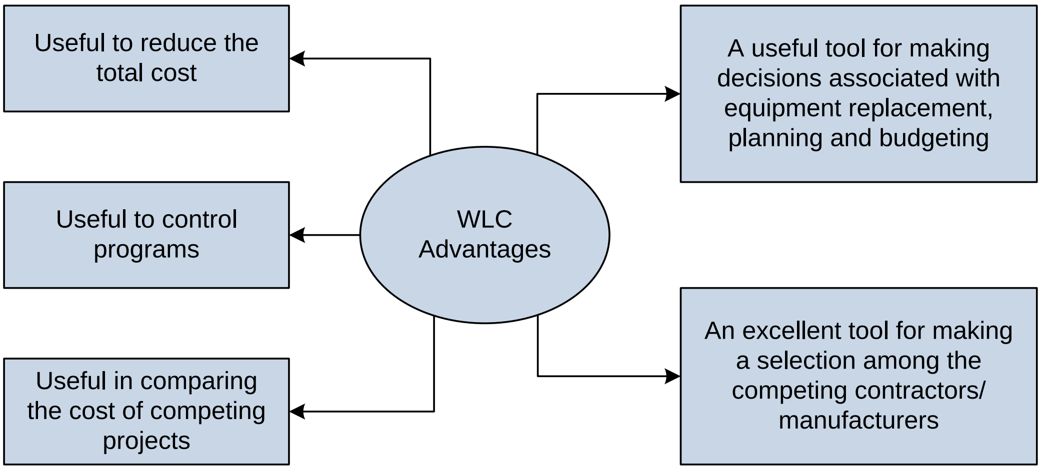


Fig. 2.29 Whole-Life Costing (WLC) Advantages (Source: Dhillon, 2010:33)

Some of the important advantages of WLC are shown in Figure 2.29. In contrast, some of the main disadvantages of WLC include: time consuming and costly; with doubtful data accuracy; and a trying task when attempting to obtain data for analysis (Dhillon, 2010).

2.8.3 Critical Variables and Basic Steps in Whole-Life Costing (WLC)

In order to achieve WLC objectives, the following critical variables have been identified in numerous papers and textbooks on the subject (Flanagan and Norman, 1983; Ferry and Flanagan, 1991; Hoar, 1993; Bull, 1993; Norman, 1993; Kirk and Dell'Isola, 1995; Woodward, 1997; Kishk *et al.*, 2003):

- project life-time (the analysis period);
- the discount rate (to address 'time value of money');

- inflation and taxation;
- construction cost;
- operating cost;
- repair and maintenance cost;
- occupancy cost;
- end of life/disposal cost;
- non-construction costs;
- incomes;
- externalities (social/environmental costs/benefits); and
- uncertainty (risk assessment/sensitivity analysis).

WLC analysis is conducted through the following steps (Constructing Excellence, 2003):

- identify/estimate all property costs and incomes in its entire life-cycle;
- employ an effective *cost breakdown structure* (CBS) (BCIS, 2012);
- decide when these costs and incomes are likely to occur;
- use 'discounted cash-flow' techniques to bring costs and incomes back to a common basis – items should normally be entered into the analysis at the current cost and income and a discount rate applied; and
- address uncertainty issues by undertaking risk assessment and/or sensitivity analysis of the variables such as the discount rate, the study period, the predicted design lives of various components, assumptions about running costs, etc.

2.8.4 Whole-Life Costing (WLC) Implementation Difficulties

WLC enables the consideration of long-term implications of a decision and provides a way of showing cost consequences. However, Ferry *et al.* (1999) have identified a number of potential implementation problems in WLC approach. Firstly, initial and running costs cannot really be equated:

- the maintenance charges will fall upon the purchaser not on the developer;
- even with public buildings, for example, schools, the bulk of the construction costs are paid for by one authority with another authority responsible for maintenance;
- money for capital developments is often more difficult to find than money for current expenditure;
- hardwearing materials may give an old-fashioned appearance and may be replaced before they are life expired.

Secondly, the future cannot really be forecast:

- the cost of maintenance is pure guesswork;
- the amount of money spent on decoration and upkeep is determined more by the body responsible for maintenance; for example, new owners than by any quality inherent in the materials;
- major expenditure on repairs is usually caused by unforeseen failure of detailing, faulty material or poor workmanship and is almost impossible to forecast;
- interest rates cannot be forecast with any certainty, particularly over long periods.

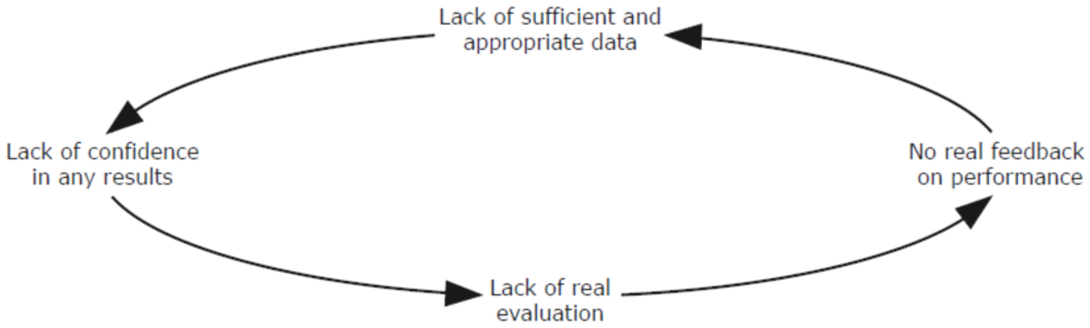


Fig. 2.30 The ‘Vicious Circle’ of Whole-Life Costing (WLC) Implementation (Source: Al-Hajj, 1991)

Despite its obvious long-term benefits, the application of WLC remains limited to large PPP projects and is mostly undertaken at the early stages of procurement (Davis Langdon, 2007). The lack of sufficient and appropriate historical data and databases on building operation and maintenance and the complexity of calculating the factors involved in WLC have been determined as reasons for this (Kehily and Hore, 2012). WLC application, in a way, is trapped in a 'vicious circle' (Figure 2.30, page 163), containing a series of causes and consequences. In order to move forward in WLC implementation, the circle would have to be broken somewhere (Al-Hajj, 1991).

National Audit Office Report on *Improving Public Services through better construction* (NAO, 2005), identified the following key barriers to WLC wider application:

- confusion over scoping and terminology (i.e. WLC, LCC and LCA);
- lack of a common methodology and standard cost data structure;
- lack of the ability to present information to enable project stakeholders to understand the interrelationship between cost (over the whole-life), time and design quality and also take account of wider environmental (notably energy performance and CO2 emissions) and also social aspects; and
- lack of tangible evidence and 'know-how' skills.

2.8.5 Mathematical Expression of Whole-Life Costing (WLC)

Almost all WLC mathematical models found in the literature employ the *net present value* (NPV) approach (Kishk *et al.*, 2003). NPV is determined by calculating the costs (negative cash flows) and benefits (positive cash flows) for each period of an investment (typically one year). After the cash flow for each period is calculated, the *present value* (PV) of each one is achieved by discounting its *future value* at a periodic *rate of return* (as dictated by the market). NPV is the sum of all the discounted future cash flows. Because of its simplicity, NPV is a useful tool to determine whether a project or investment will result in a net profit or a loss. A *positive* NPV results in profit, while a *negative* NPV results in a loss. NPV measures the excess or shortfall of cash flows, in present value terms, above the cost of funds. In a theoretical situation of unlimited *capital budgeting*, a company should pursue every investment with a positive NPV. However, in practical terms a company's capital constraints limit investments to projects with the highest NPV whose cash outflows, or initial cash investment, do not exceed the company's capital. NPV is a central tool in DCF analysis and is a standard tool for using the time value of money to appraise long-term projects. Because NPV focuses on costs rather than revenues, it is usual practice to treat cost as positive and income as negative.

The basic equation of NPV is found in Kishk *et al.* (2003):

$$\mathrm{NPV} = \mathrm{C_0} + \sum_{t=1}^{T} \mathrm{O_t} + \sum_{t=1}^{T} \mathrm{M_t} - \mathrm{SAV} \qquad (2.11)$$

$\mathrm{C_0}$: the initial construction costs (at time zero)

$\sum_{t=1}^{T} \mathrm{O_t}$: the sum of discounted operation costs at time t

$\sum_{t=1}^{T} \mathrm{M_t}$: the sum of discounted maintenance costs at time t

SAV : the discounted salvage value, where:

$$\mathrm{SAV} = \mathrm{RV_T} - \mathrm{DC_T} \qquad (2.12)$$

$\mathrm{RV_T}$: the discounted resale value (at the end of the analysis period)

$\mathrm{DC_T}$: the discounted disposal costs (at the end of the analysis period)

T : the analysis period in years (project life-cycle)

The NPV method is always consistent with the firm's overall objective of shareholders' profit maximisation unlike the *internal rate of return* (IRR) approach, which is a measure of relative and not absolute wealth (Davis and Pointon, 1984).

2.8.6 Taxation Implications

The tax regime within which building owners operate may determine which future costs are allowable for tax (tax deductibles) – in the UK for example, capital allowances are currently available on new industrial buildings, hotels, industrial and commercial buildings in Enterprise Zones, agricultural buildings and on small workshops. Many items of plant, equipment, leased plant and, sometimes, associated builders' work are eligible for allowances. These allowances also vary depending on the financial situation of the property owner – whether or not taxable profits against which allowances can be claimed (BRE, 2004).

There are two aspects in considering taxes in WLC calculations. The first deals with the probability that environmentally inefficient structures will attract future environmental taxes, and hence, WLC is an essential activity insuring elimination of this kind of risks. This can be addressed in the same way as any other risks. For each risk, the probability of occurrence and the likely impact can be established and a risk allowance is made. The second deals with general allowances for unspecified taxes in the calculations. There are several areas where costs might increase at a rate higher than inflation for a variety of reasons. Although capital costs for plant and equipment are usually a budgeted one-off attracting various tax allowances, the ongoing reliability, efficiency and maintainability will affect the bottom line for the life of equipment (Davis Langdon, 2007). Ashworth (2004) believes that inclusion of taxes in WLC calculations is important in the assessment of projects for the private sector; this tends to favour alternatives with lower initial cost because taxation relief is generally available only against repairs and maintenance.

The taxation environment is traditionally presented by tax rates and fees for indirect, direct and property taxes. According to the Greek relevant legislation, a summary of the current main taxation rates and bases in Greece are presented in Appendix (A).

2.8.7 The Accounting Framework for Fixed Assets

Fixed assets are tangible assets that are used by a business to produce income: buildings; plant; equipment; transportation means; machinery; computers; anything that will probably bring future economic benefits. Fixed assets share common characteristics: they are used in the production of business income; they have a useful economic life of at least one year; and they are used up or wear out over time. As accounting elements, assets are ruled by a set of basic aspects such as: cost (cost of land, construction cost etc.), residual value, useful life estimation and depreciation impact. The above elements are correlated with type and the use form of the asset. Asset accounting is subject to the accounting framework instituted by the Accounting Board of each country. The most famous Accounting Boards are the International Accounting Standards Board (IASB – IFRS, IASs) and the Financial Standards Board (FASB – US GAAP). Both the IASB and FASB aim to develop a set of high quality global accounting standards that require transparent and comparable information in general purpose financial statements. In pursuit of this objective FASB and IASB co-operate with national accounting standard-setters to achieve convergence in accounting standards around the world. The accounting framework provides a general set of accounting principles. Some of the principles that apply to this study are: prudence; historical cost; substance over form; going concern; and true and fair view. Other principles and qualitative characteristics of the financial statements are: matching principle; accrual basis; understandability; relevance; materiality; reliability; faithful representation; comparability; neutrality; completeness; timeliness; materiality; cost and benefit balance and consistency.

According to IFRS, *fair value* is the price at which the property could be exchanged between knowledgeable, willing parties in an arm’s length transaction (IASB, 2009). According to US GAAP *fair value* is the price that would be received to sell an asset or paid to transfer a liability in an orderly transaction between market participants at the measurement date (FAS, 2010).

2.8.8 Depreciation of Fixed Assets

The *Oxford Dictionary* defines the term *depreciation* as ‘a reduction in the value of an asset over time, due in particular to wear and tear’. Peterson (2009) points out that for the owners of *depreciable assets*, such as buildings, the need for depreciation calculation for these assets stems from the following three reasons:

- for a company to prepare its *financial statements* the value of the company’s fixed assets must accurately be determined – the value of depreciable assets equals the price paid for the assets less the depreciation of the assets;
- for a company to allocate the *cost of owning* its fixed assets used to complete projects and support company operations, the annual cost of owning these assets must be determined – the asset’s depreciation is a significant cost of owning an asset; and
- in most cases, there is a *taxation* requirement for the cost of a construction asset to be spread over the *useful life* of the asset – the useful life of an asset is the number of years it is useful to the company and is most often based on economics rather than the number of years an asset can be used.

Depreciation is calculated differently for non-tax purposes (financial statements and the billing of equipment) than for tax purposes, mainly due to the inclusion or non-inclusion respectively of the *salvage value* of real property to the calculations (Peterson, 2009).

The depreciation of buildings includes the necessary infrastructure, together with any demolition that might be required prior to construction and the relevant professional fees that are required. It specifically excludes the cost of land, although it can include the costs of any ground stabilisation that may be a necessary part of the building construction. When new plant or equipment is purchased, its value from the time of purchase will begin to decrease. This may be, for example, five years for some items of equipment, possibly a much shorter period for equipment such as computers that are rapidly changing, or perhaps a longer period of time for some heavy items of plant installed in a factory. Buildings, however, have tended to appreciate in value over time, and are one of the few items of capital expenditure to do so. Some of this increase is attributable to the land on which the building is placed, rather than the actual building itself. However, the majority of buildings do not remain forever. Most buildings constructed today would be expected to have a life approaching a hundred years. Depreciation is the term given to the reduction in value over time. It is necessary to assess this for the company's balance sheet. A building contractor normally recovers a part of this loss on plant and machinery by including an appropriate amount in the rates charged for doing the work. There are several different ways of calculating depreciation, in order to distribute the appropriate costs over the expected life of the project. Where depreciation occurs over a long period of time it may be necessary to allow for the time value of money through use of one of the discounting methods (Ashworth, 2004).

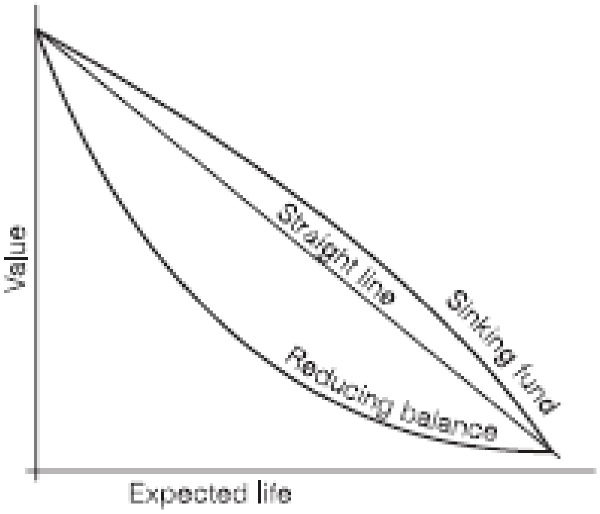


Fig. 2.31 The Main Depreciation Methods (Source: Ashworth, 2004)

The different methods of depreciation are shown graphically in Figure 2.31 (page 169). The three commonly used depreciation methods are the *straight-line* (SL) method, the *sum-of-years-digits* (SYD) method, and the *declining-balance* (DB) method (Dhillon, 2010). Two more depreciation methods are the *sinking-fund* method (Ashworth, 2004) and the *written-down value* method (Tempelmans Plat, 2001).

2.8.8.1 Straight-Line (SL) Method

This method assumes a *linear* decrease with time in the value of a product; thus, during the service life of the asset an equal sum of money is charged each year for depreciation. The annual depreciation is expressed by (Dhillon, 2010):

$$\mathrm{DC_a} = (\mathrm{C_a} - \mathrm{V_s})/\mathrm{L_s} \qquad (2.13)$$

The book value of the product, item, or system at the end of year *n* is given by

$$\mathrm{V_{bn}} = \mathrm{C_a} - n(\mathrm{DC_a}) \qquad (2.14)$$

Using equation (2.13) in equation (2.14) yields:

$$\mathrm{V_{bn}} = \mathrm{C_a} - n[(\mathrm{C_a} - \mathrm{V_s})/\mathrm{L_s}] \qquad (2.15)$$

This is sometimes described as the *fixed instalment* method. The original value of the asset, less any residual value, is divided by the number of years of its estimated life. While the method is simple to calculate, it has the disadvantage that it does not represent the actual depreciation of an asset; this will be higher during the first few years of ownership and decreases as it reaches the end of its useful life. If these figures were used in a company's accounts, then it would be necessary to amend the final year's figures by a balancing adjustment to agree with the actual amounts involved. If the equipment was to be replaced at the end of its useful life then it might be necessary to allocate these amounts to a sinking fund for the equipment's replacement, in which case, due to inflation, it would probably be insufficient (Ashworth, 2004).

2.8.8.2 Sum-of-Years-Digits (SYD) Method

The name of the method is derived from the calculation procedure used and it provides a larger depreciation charge during the early life years of the product than during its later life years. The annual depreciation charge is expressed by (Riggs, 1968):

$$DC_a = (C_a - V_s)[(L_s - n + 1)/(1 + 2 + 3 + \dots + L_s)] = 2(C_a - V_s)(L_s - n + 1)/L_s(L_s + 1) \qquad (2.16)$$

where:

DC_a annual depreciation charge

C_a product or item acquisition cost

V_s product or item *salvage value* at the end of its service life

L_s product or item service life expressed in years

n total number of years of the product or item in actual service.

The *book value* V_{bn} of the product or item at the end of year n is given by:

$$V_{bn} = 2(C_a - V_s)[1 + 2 + 3 + \dots + (L_s - n)/L_s(L_s + 1)] + V_s \qquad (2.17)$$

2.8.8.3 Declining-Balance (DB) Method

In this approach, the annual depreciation is a *fixed percentage* of the book value at the beginning of the year. Although the annual depreciation is different for each year, the declining-balance factor remains constant throughout the useful life of the product. This method *writes-off* the cost of the building early in its life at an accelerated rate and at correspondingly lower annual charges close to the final years of the asset service. The depreciation factor or rate is expressed by (Dhillon, 2010):

$$R_d = 1 - [V_s/C_a]^{1/L_s} \qquad (2.18)$$

where R_d is the depreciation rate or factor and assuming that the salvage value of the equipment or item is always positive.

The *book value* V_{bn} of the product or item at the end of year n is defined by:

$$V_{bn} = C_a (1 - R_d)^n \qquad (2.19)$$

By inserting equation (2.13) into equation (2.14):

$$V_{bn} = C_a [V_s/C_a]^{n/L_s} \qquad (2.20)$$

The annual depreciation charge is expressed by:

$$DC_a = [V_{b(n\text{-}1)}]R_d \qquad (2.21)$$

where $V_{b(n\text{-}1)}$ is the equipment or item book value at $(n - 1)$ years.

Using equation (2.18) in equation (2.21) yields:

$$DC_a = [V_{b(n\text{-}1)}][1 - (V_s/C_a)^{1/L_s}] \qquad (2.22)$$

2.8.8.4 Sinking-Fund (SF) Method

A fixed proportion of the initial cost is transferred each year from the revenue account to the depreciation reserve. If this is allowed to accumulate with compound interest, it should at the end of the asset's life produce an initial cost less value. An alternative to this method is referred to as the sinking fund method, where the annual sum is then reinvested. The advantage of this method is that it provides the actual cash to replace the asset. A further alternative approach is the insurance policy method, whereby a policy is taken out with an insurance company for the amount of the asset, due when the asset is to be replaced (Ashworth, 2004).

2.8.8.5 Written-Down Value (WDV) Method

Under this method of calculating depreciation, the amount charged for depreciation declines over the asset's expected life. This method is suitable in cases where: a). the receipts are expected to decline, as the asset gets older; and b). it is believed that the allocation of depreciation should be related to the pattern of asset's expected receipts. The WDV method is also known as the reducing, diminishing, or declining balance method.

The depreciation charge is calculated by multiplying the net book value of the asset (acquisition cost less accumulated depreciation) at the start of each period by a fixed rate. Under the WDV method, it is impossible to reduce the asset value to zero, because there is always some balance to reduce the asset value even further. When the asset is sold, abandoned, or retired from use, the WDV appearing in books is *written-off* as depreciation for the final period. Under this method, the fixed depreciation rate used charges the acquisition cost less salvage or residual value of the asset over its service life:

$$R_d = 1 - (V_s/C_a)^{1/n} \quad (2.23)$$

where:

R_d the depreciation rate or factor

C_a product or item acquisition cost

V_s product or item *salvage value* or residual value at the end of its service life

n total number of years of the product or item in actual service.

Depreciation at a certain rate is applied to the WDV of the asset as at the beginning of each year; the depreciation amount charged every year is an amount less than the previous year and larger amounts are charged to depreciation during the initial years of the asset's useful life. At first, the focus is on the initial (and most substantial) new investment; later on, the influence of a changing price level on the annual operation and maintenance expenditures should be examined. Clearly, land and building play different roles as part of the real property; a building has to be depreciated, whereas land has an eternal life – though not necessarily without changing value (Tempelmans Plat, 2001).

According to *Investopedia*, *depreciated cost* is the value of an asset net of all accumulated depreciation that has been recorded against it. It follows the formula:

Depreciated Cost = Purchase Price (or cost basis) – {Cumulative Depreciation} (2.24)

Depreciated cost is also known as the 'net book value' or 'adjusted cost basis'. The depreciated cost method of asset valuation is an accounting tool used by both corporations and individuals. It allows for the books to always be carrying an asset at its current worth, and allows cash flows based on that asset to be measured in proportion to the value of the asset itself. It also allows for even tax treatment of large capital assets like homes, factories and equipment. *Accumulated depreciation* is the cumulative depreciation of an asset up to a single point in its life. Regardless of the method used to calculate it, the depreciation of an asset during a single period is added to the previous period's accumulated depreciation to get the current accumulated depreciation. An asset's carrying value on the balance sheet is the difference between its purchase price and accumulated depreciation.

2.8.9 Cost Accounting *vs.* Fair Value Accounting

During the useful life period, clients wish to know at any point in time the *value* of their constructed facilities. IFRS 13 *Fair Value Measurement* has been recently released by the International Accounting Standard Board (IASB, 2013).

The IASB defines *fair value* in the context of IFRS as the price that would be received to sell an asset or paid to transfer a liability in an orderly transaction between market participants at the measurement date (i.e. an exit price). This differs from the International Valuation Standards (IVSC, 2007), which states in its proposed revised IVS Framework1: 'Fair value is the estimated price for the transfer of an asset or liability between identified knowledgeable and willing parties that reflects the respective interests of those parties'. IFRS 13 (IASB, 2013) does not prescribe the valuation techniques that must be used in any particular circumstance. The valuation technique used to measure fair value should be appropriate for the circumstances, and should be a technique for which sufficient data is available. Valuation techniques that are typically used include:

- the *market approach* (or market comparison approach), that uses prices and other relevant information generated by market transactions involving identical or comparable assets;
- the *income approach* (or income capitalization/*discounted cash-flow* method), that convert future amounts (e.g. cash-flows or income and expenses) to a single current (discounted) figure; and
- the *cost approach* (or *depreciated* replacement cost method), that reflects the amount that currently would be required to replace the service capacity of an asset (often referred to as current replacement cost).

The choice between fair value and historical cost accounting is one of the most widely debated issues in the accounting literature (Christensen and Nikolaev, 2012).

Accounting fairness refers mostly to the fair presentation and, therefore, measurement or valuation of an element recognised in the entity's financial statements. According to the GAAP across countries, two basic valuation methods exist under the estimate that the firm is under going concern: The accounting of *fair value* and the accounting of *historical cost*. Applying different accounting methods across firms or countries makes financial statements incomparable to each other. Even within the IFRS framework the choice between the two valuation models for certain asset portfolios is a given option. US GAAP, also seem to have a different approach in measuring property. The measurement method choice is of great importance because it affects the comprehensive income of the firm (income and shareholder's equity). Valuation of property results, therefore, to a change in financial statements. This result can directly affect contracts linked to accounting numbers, e.g. it can loosen the stranglehold of debt covenants and reduce the informational asymmetry. The accounting frameworks of US GAAP, IFRS and Greek GAAP differ between each other. US and Greek GAAP are more prudent in compare to

IFRS. Also, US and Greek GAAP are rule-based, while IFRS are principle-based. Therefore, IFRS leave decision choices to the management of the firm, while US GAAP set also numbered boundaries above or under which the accounting treatment methods change. IFRS comprise the most ‘fair’ approach, because they provide the choice of the presentation of financial statements at fair value, although calculation of fair value of fixed assets is a difficult issue which requires professional skills. The full convergence of the three studied accounting frameworks in a common-global framework is a challenge. The framework that is proposed shall use fair values, meaning values that will resemble economic reality at measurement dates, as much as possible, as the accounting valuation principle used to value fixed assets irrespectively of their use and their portfolio categorization. Revaluations shall affect the firm’s equity special reserve by passing P/L, as unrealised gain or loss and shall be recycled to the firms’ profit and loss only by realization, e.g. sale, disposal, destruction. Such a framework eliminates any motivations of the management to classify property in certain portfolios and prohibits the choice between avoiding and undertaking the risk of affecting the profit and loss account when revaluating assets. Therefore, profit becomes more prudent and balance sheet becomes more timely and relevant, resulting to uniformity of financial accounting and representation of fixed assets and succeeding comparability between firms and countries (Liapis and Christodoulopoulou, 2011).

2.9 Towards More Effective Cost Management in Construction

Betts (1992) described a critical framework of *effective financial control* of construction projects. First, financial control should be considered in terms of the broadest range of its project management activities. In this regard, total building evaluation within project management should be seen as the time, cost and quality, and the certainty with which these targets can be achieved. Financial control should be judged not in terms of the extent to which it measures expenditure in isolation but should be viewed in terms of how it leads to the achievement of *value for money* in construction procurement. An effective understanding is needed of the trade-offs between time, cost and quality, and, ultimately, a means of their *integration* is also needed. This *holistic* approach to financial control can be extended to apply to the time-scale of the project process. So many project management approaches in general, and financial control systems in particular, appear to be oriented to control over finite periods that correlate with the times over which the evaluator holds responsibility and not with the times over which the owner of a project bears a financial responsibility and interest. Management implies the control of the outcome of a process through one's own actions. It is a more proactive role than the reactions that control involves. Control is usually interpreted as a negative activity that exercises restraint on what would otherwise be a free activity. However, if a systems view is taken, control is the capacity that a system has for the continual attainment of its objectives through management. Whether a 'true cost management' system either exists or is workable in practice is debatable. At this point, it is pertinent to contrast a true cost management system with one that is based on the certification, reporting and authorisation of expenditure after the cost-incurring activity is complete. This latter type of process is more aptly described as cost administration. The emergence of techniques of *value engineering* is a good example of the cost management approach. To complete the description of what ideal financial control should be, the life time of projects and the part of the life that any system embraces must be considered. A financial control system should cover as many of the cost-incurring activities as possible at all the stages of a project. However, the most effective time to apply financial control is during the early stages of projects. It is at this point that the greatest scope exists for economies, and it is when the consequences of making changes to projects are at a minimum. An ideal financial control system should, therefore, start at the earliest possible stage in the project, and then be applied to the complete life-cycle. In summary, an ideal financial control system should:

- integrate the requirements for time, cost and quality by allowing informed trade-off decisions throughout all stages;
- be managerially proactive rather than administratively reactive;
- be initiated at the earliest possible stage in a project; and
- apply to as broad a range of a project’s life-cycle costs and revenues as possible.

An essential principal of effective cost management is the integration of cost management into the overall design and delivery process. If cost management is treated as an afterthought of design and construction decisions, then it is, effectively, ‘reactive management’, a practice that makes it difficult to achieve good value in decision-making. Therefore, integrating cost management into the overall delivery process is the first step of effective cost management (Del’Isolla, 2002).

The Project Management Institute (PMI, 2013) suggests that project cost management should also consider the effect of project decisions on the costs of using, maintaining and supporting the product, service or result of the project. This *life-cycle costing* (LCC) broader view of project cost management combined with advanced project management techniques used for *time-cost optimisation* can improve decision-making, reduce cost and execution time, and enhance the quality and performance of the project deliverable. Cost management should also include investment appraisal techniques in predicting and analysing the prospective project financial performance.

The possibility of trading-off initial enhanced capital cost against subsequent life-time revenue savings is one of the underlying principles of a whole-life appraisal analysis (Woodward, 1997). This aspect can be described by reference to the following Figure

2.32 (Department of Industry, 1977). An increase in capital expenditure (Curve A), results in increased asset availability and reduced maintenance costs (Curve B). Where total cost (Curve C) is at a minimum, the optimum LCC of asset ownership is derived. The lowest capital cost alternative can, in contrast, be seen to have a very high LCC. In many cases, the optimum LCC is not critical, such that different combinations of capital and maintenance cost levels (between points V and W) will not significantly affect LCC (Woodward, 1997).

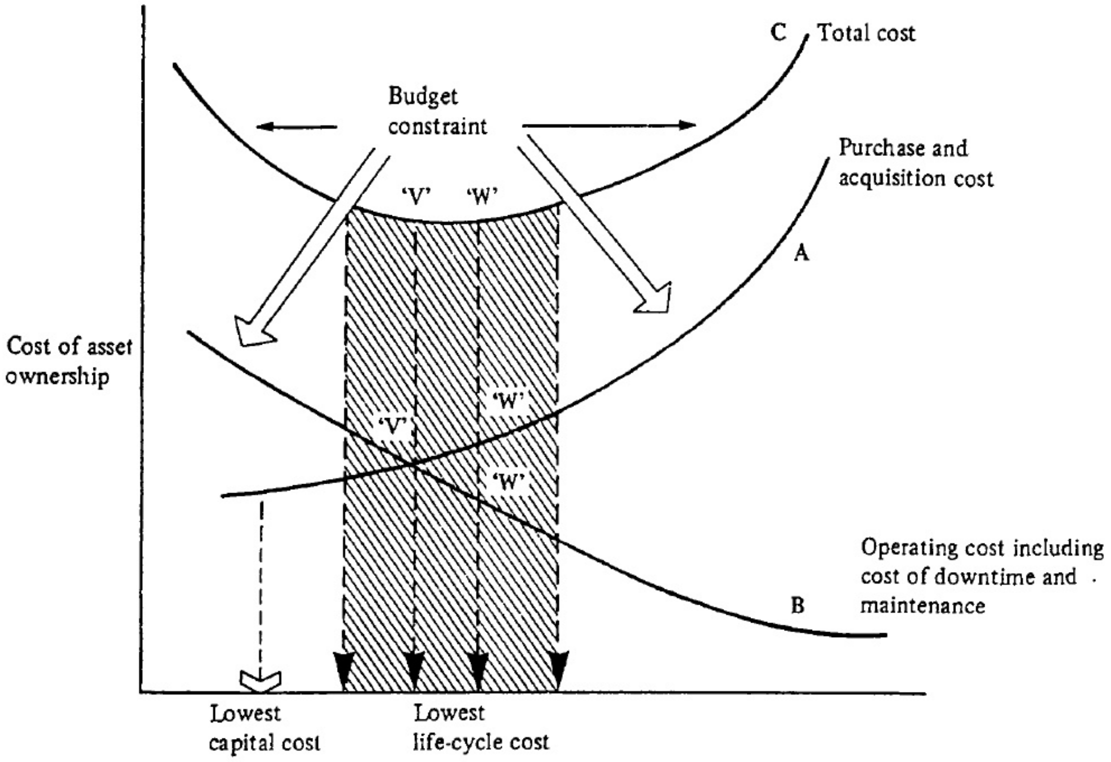


Fig. 2.32 Cost Trade-off in Fixed Asset Ownership (Source: Department of Industry, 1977)

Effective cost management requires having a 'big picture' focus, using Pareto's '80-20' principle of cost distribution, as presented in Figure 2.33 (page 180) (Del'Isolla, 2002). Vilfredo Pareto (1848-1923), an Italian economist of the late nineteenth and early twentieth centuries, developed the principle of *The Maldistribution of Costs,* which essentially stated that in any item made up of a large number of components, a very small number would contain the vast majority of cost; this rule is a common thread in cost management.

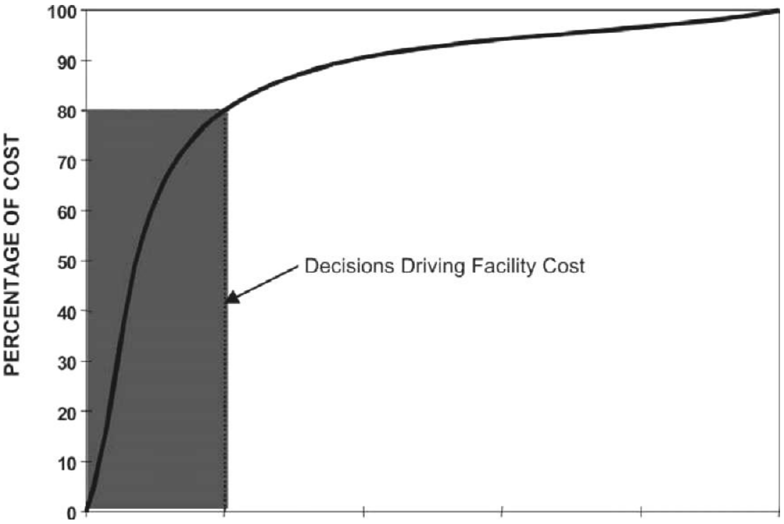


Fig. 2.33 Pareto’s Principle (‘80-20’ Rule) (Source: Del’Isolla, 2002)

There is increasing recognition from project clients and financiers that effective project management and control requires the use of highly specialised expert cost management professionals. The problems with project managers, architects, designers, engineers and other professionals undertaking cost management as simply a subset of their array of activities are becoming increasingly apparent. This presents tremendous opportunities for expert cost management professionals but also many challenges in terms of the global development of the profession. The construction and infrastructure market is now truly global and major projects are often undertaken with a range of international participants. This brings together firms and professionals from advanced developed industries and their counterparts from developing industries. The gulf in the sophistication and expertise of service provided between the two is often vast and presents a major challenge to raise the standards of operators in the developing markets. This applies equally to cost management and heightens the importance of the development of global cost management standards, education and certification/registration programs (Smith, 2014).

This page intentionally left blank

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

The *Concise Oxford Dictionary* defines *research* as: a) ‘the systematic investigation into and study of materials, sources etc. in order to establish facts and reach new conclusions’ and b) ‘an endeavour to discover new or collate old facts etc. by the scientific study of a subject or by a course of critical investigation’. From the above definition(s), it could be argued that research concerns *what* (‘facts’ and ‘conclusions’) and *how* (‘scientific’; ‘critical’) components (Fellows and Liu, 2008).

Methodology is defined in the *Business Dictionary* as ‘a system of broad principles or rules from which specific methods or procedures may be derived to interpret or solve different problems within the scope of a particular discipline. Unlike an algorithm, a methodology is not a formula but a set of practices’. A *system* is ‘an entity, conceptual or physical, which consists of interdependent parts. Each of a system’s elements is connected to every other element, directly or indirectly, and no subset of elements is unrelated to any other subset’ (Ackoff, 1969).

Research methodology, therefore, is a way to systematically solve a research problem. The scope of research methodology is wider than that of research methods. *Research methods* concern the analytical tools and techniques which are available to perform research operations. Research methodology also considers the logic behind the methods used in the context of a research study and explains why a particular method or technique is used so that research results are capable of being evaluated either by the researcher himself or by others (Kothari, 2004).

Thus, research methodology is ‘a system of methods that is informed by philosophy, particularly *epistemology*’ and research methods are ‘the detailed approach and tools used to undertake specific research’ (Smyth and Morris, 2007).

In this chapter the conceptual framework of the research methodology is vindicated with regard to the clarification of the research context, nature and philosophy, the strategy selected, the design structuring adopted, and the research methods and appropriate commercial software applications used throughout the thesis.

3.2 Research Context

The purpose of the research is to develop a prototype integrated whole-life methodology towards more effective cost management in the built environment; thus, the thesis broadly falls into the realm of *construction management*. The type of construction products studied is narrowed to *building structures*, excluding civil engineering (infrastructure) work.

The research focuses on establishing, both deterministically and stochastically, the cost (as well as time and value) management processes throughout the *whole-life cycle* of constructed assets from inception to demolition. A *process* has been defined as a sequence of events that describes how things change over time (Van de Ven, 1992) and as a collection of activities organised to achieve some goal by transforming inputs to a desired output (Johnson and Wichern, 2013).

In order to adopt a more holistic view to building cost management, the *integration* of the time-discrete sequential phases of construction (project) production and (product) useful life is inescapable. The research is generally aimed at construction *clients*, *consultants* and *contractors*.

3.3 Nature of Research

There are two main kinds of research: *pure* (basic) and *applied* research. The former has the purpose of expanding the knowledge base and, thus, its future potential in a given area, whereas the latter is fundamentally motivated by the development of a new product or a next-generation product (McCuen, 1996). Fellows and Liu (2008) pointed out that, particularly in the context of the construction environment, the vast majority of research is a *mixture* of 'pure' (theoretical) and 'applied' (practical) research. Indeed, this thesis is directed to both researchers and practitioners in the field of construction management by combining basic theoretical and mostly practical aspects of the scientific discipline being examined, in order to contribute to the existing body of knowledge and further to assist construction managers in practical implementation issues.

According to its purpose, research can be categorised as (Bennett, 1991; Kothari, 2004):

- *Descriptive* – concerned with the collection and reporting of data related to what is (or was) the case;
- *Classifiable* – still descriptive, but easing the reporting process and highlighting similarities and clustering through grouping and classifying;
- *Exploratory* – to gain familiarity with a phenomenon or achieve insights into it;
- *Explanatory* – attempting to make sense of observations by explaining the relationships observed and attributing causality based on appropriate theory; and
- *Predictive* – going beyond the understanding and explaining of the prior stage, to model observations that allow testable predictions to be made of unknown events.

From the above categories, considering that this research aims at reaching beyond a mere description and explanation of the construction management processes being studied and attempts to *predict* outcomes and to *forecast* events and cost, time and value implications of managerial decision-making, both the *explanatory* and *predictive* types are deemed to be the most relevant to the research scope.

3.4 Research Philosophy

A fundamental question confronting researchers in social sciences is for them to construct a philosophical stance and orientation towards their enquiry (Dainty, 2007). *Epistemology* is defined in the *Merriam-Webster Dictionary* as 'the study or a theory of the nature and grounds of knowledge especially with reference to its limits and validity'. Epistemology is 'the branch of philosophy that concerns the origins, nature, methods and limits of human knowledge' whilst *ontology* concerns 'the assumptions in conceptual reality and the question of *existence* apart from specific objects and events' (Fellows and Liu, 2008). Research philosophy plays a critical role in generating knowledge on projects and their management. However, selecting an appropriate research methodology is only part of the way that knowledge is epistemologically constructed; intellectual frameworks called *paradigms* have been created which embody systems of ideas and beliefs (Smyth and Morris, 2007). The paradigm concept was largely drawn from Thomas Kuhn's classic book *The Structure of Scientific Revolutions* (Kuhn, 1970) whereas a paradigm is described as 'the entire constellation of beliefs, values, techniques, and so on shared by the members of a given community'.

Fig. 3.1 The Research Process (Source: Smyth and Morris, 2007)

The elements of the research process are schematically presented in Figure 3.1 (page 185). The two main alternative research philosophical positions (paradigms), each embodying different ideas about *conceptions of reality* (ontology) and *how we can gain acceptable knowledge of it* (epistemology), are namely *positivism* and *interpretivism* (Bryman and Bell, 2003). Positivist theory which is strongly related to *empiricism*, *objectivity* and *quantitative* approaches, asserts that there are observable facts which can be measured by an observer, who remains uninfluenced by the observation and measurement. On contrary, the interpretive paradigm is closely connected with *subjectivity* and *qualitative* methods and indicates that truth and reality are social constructs by the participants’ perspectives (Fellows and Liu, 2008).

Unlike many areas which have established practices stemming from a deeply rooted knowledge base, construction management is a relatively new domain which lies somewhere between the natural and social sciences. As such, researchers in construction draw from both traditions when designing their research projects in a way which remains sensitive to the theoretical and philosophical foundations upon which their enquiry is based (Dainty, 2007). Historically, positivism has been the dominant research approach on projects and their management. This is also reflected in the *PMBOK Guide*® (PMI, 2013) which essentially adopts an *executional* view of the discipline without, however, acknowledging the *contextual* nature of projects, especially when the transfer of models and concepts from other disciplines is investigated (Morris *et al.*, 2006). As a result, its unsuitability for addressing many project issues, ‘poses a serious dilemma for positivist methodology’ (Smyth and Morris, 2007). Nevertheless, positivism (and quantitative methods) is the dominant research paradigm within construction management research community for many years (Fellows and Liu, 2008) and it is the paradigm selected as the most suitable for conducting the herein presented research.

According to Smith (2011) two major processes of reasoning are important for theory construction and observation testing: *deductive* (theory to observation) and *inductive* (observation to theory). Deductive reasoning starts with the theory and proceeds to generate specific predictions which follow from its application (more relevant to positivism) whilst inductive reasoning starts with specific observations (data) from which theories can be generated (closer to interpretivism). The previous choice of the positivist view to the research assumes that the deductive approach is consequently selected to be applied in the thesis.

3.5 Research Strategy

Research strategies are broadly classified into *qualitative* and *quantitative*. Qualitative analysis is primarily based on the analyst's experience, judgment and intuition and is more an *art* than a *science*. On the other hand, usually when sufficiently complex problems are being studied, a quantitative approach can make an important contribution to the decision-making process. Quantitative research is 'objective' in nature. It is defined as an inquiry into a social or human problem, based on testing hypotheses or theories composed of variables, measured with numbers, and analysed with statistical procedures, in order to determine whether hypotheses or theories hold true (Creswell, 2003).

When using a quantitative approach, an analyst will concentrate on the quantitative facts or data associated with the problem and develop mathematical expressions that describe objectives, constraints, and other relationships that exist in the problem. Then, by using one or more mathematical models, the analyst will make a recommendation based on the quantitative aspects of the problem. This research project is primarily using *quantitative methods* to assist construction owners and professionals in problem solving and decision-making in the production of generally large and complex projects. *Problem solving* can be defined as the process of identifying a difference between the actual and the desired state of affairs and then taking corrective action – it involves the following seven steps:

1. Identify and define the problem;
2. Determine the set of alternative solutions;
3. Determine the criterion or criteria that will be used to evaluate the alternatives;
4. Evaluate the alternatives;
5. Choose an alternative;
6. Implement the selected alternative; and
7. Evaluate results to determine whether a satisfactory solution has been obtained.

Decision-making is the term generally associated with the above first five steps of the problem solving process (Figure 3.2) (Anderson *et al*., 2013).

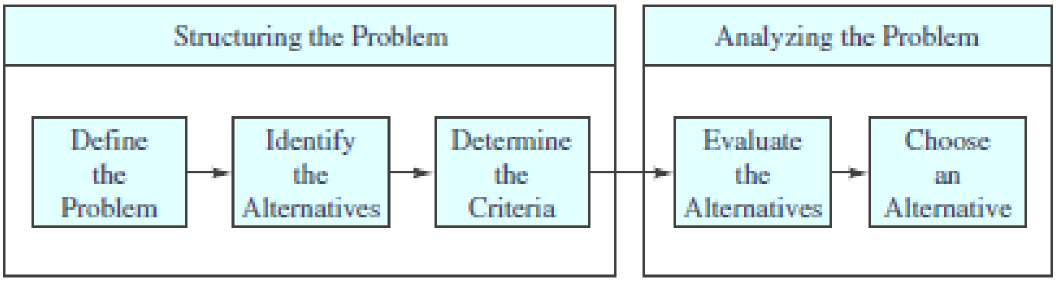


Fig. 3.2 The Decision-Making Procedure (Source: Anderson *et al*., 2013)

Some of the reasons why a quantitative approach might be used in the decision-making process include the following (Anderson *et al*., 2013):

- The problem is complex, and the manager cannot develop a good solution without the aid of quantitative analysis;
- The problem is critical (e.g., a great deal of money is involved), and the manager desires a thorough analysis before making a decision;
- The problem is new, and the manager has no previous experience from which to draw; and

- The problem is repetitive, and managers save time and effort by relying on quantitative procedures to automate routine decision recommendations.

It can be stated that project management is a mixture of *art* and *science*: the art of getting things done through (and with) people in formally organised groups; and the science of handling large amounts of data to *plan* and *control* so that project duration and cost are balanced, and excessive and disruptive demands on scarce resources are avoided (Moder *et al.*, 1983). This thesis deals primarily with the science of construction project management, with occasional excursions into the art when it has a direct relationship with the science.

3.6 Research Design

Generally, the term ‘research design’ describes the ways for data collection and analyses in order to answer the research questions posed and thus providing a framework for undertaking the research (Bryman and Bell, 2003).

Rational decisions are usually made in the light of the information available at the time of the decision. In the construction industry, cost modelling of all types is traditionally based on *past experience* projected forward. Past experience is recorded in the various forms of economic data available and also in the personal and professional judgement of the decision-makers. Whether or not sophisticated economic modelling techniques are used, reliance is based on some form of historic data for input to the decision-making process (Raftery, 1984). An absolute essential for modelling is that the data used is accurate, consistent and not distorted by personal bias (Cusack, 1984). In this research, relevant actual data is obtained from architectural and engineering drawings, contract documents and progress reports from historical completed building projects. Theoretical research models are established from the review of theory and literature which then form the bases for testing the relationships of separate processes and associated critical variables. ‘A theoretical model is a set of variables and their interrelationships designed to represent, in whole or in part, some real system or process. Common forms of theoretical modelling in construction research are graphical models and mathematical models' (Fellows and Liu, 2008). Once the structure of the models has been designed and its correctness and suitability for the research objectives is verified, appropriate values can be input for the necessary variables and the resultant outputs are calculated. *Verification* refers to the process of ensuring that the models are free from logical errors and that they do what they are intended to do (Evans and Olson, 1998). In the (next) stage of validating the models, the models' outputs are compared to realisations of reality (known outputs). *Validation* ensures that a model is a reasonable representation of the actual system or problem. These are important steps to lend credibility to models and gain acceptance from managers and other users (Evans and Olson, 1998). The consistency of the models is examined over a range of extreme and uncertain conditions for several sets of inputs and known outputs. The research modelling process is illustrated in Figure 3.3 (page 191) (Mirham, 1972 as developed by Fellows and Liu, 2008). The theoretical approach to the above modelling validation procedure is the *case study* of a typical building project. A case study explains causality and tries to show linkages among the objects of the study. In other words, the researcher collects facts and studies the relationship of one set of facts to another, with the hope of finding some causal relationship between them (Naoum, 2007). Collis and Hussey (2009) defined case study as 'a methodology that is used to explore a single phenomenon in a natural setting using a variety of methods to obtain in-depth knowledge'. According to Smith (2011) case study research is particularly useful where:

- the scenario under consideration is complex: there are many variables with unclear interrelationships in between, so that formal modelling is not feasible;
- the opportunity arises to examine actual practice and changes in practice in

response to events; and

- the interaction between events and context is critical for both processes and outcomes, providing a potentially unique situation.

Proverbs and Gameson (2008) pointed out that case study is highly relevant to an industry like construction consisting of different types of processes and organisations; nonetheless, the application of case study research in construction management domain remains low and there is significant scope for further application within the field.

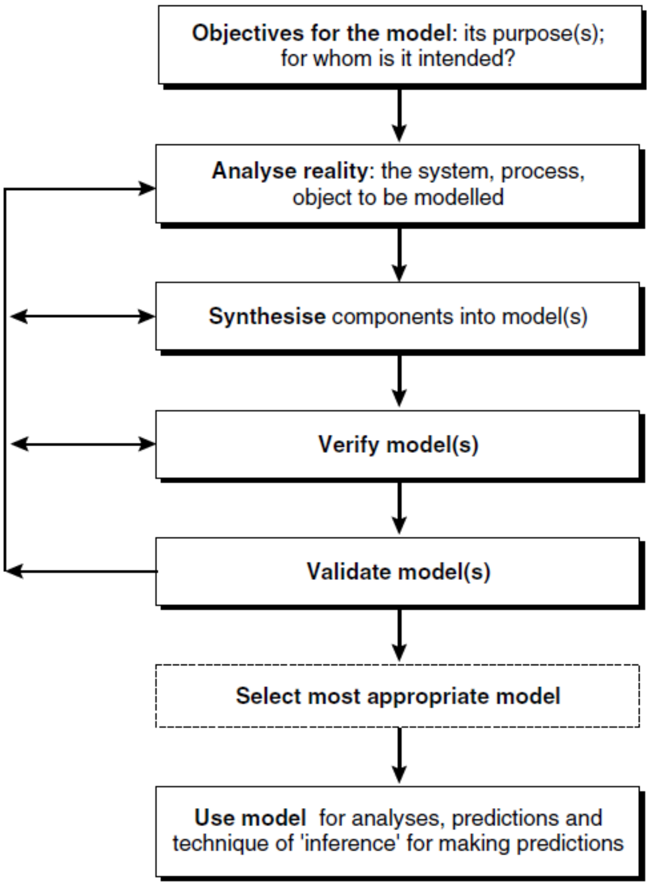


Fig. 3.3 The Modelling Process (Source: Fellows and Liu, 2008)

Furthermore, an essential part of the research involves both *analysis* and *synthesis*: analysis refers to the decomposition of elements or data to obtain the parameters of interest for understanding the underlying process; synthesis refers to the integration of concepts to produce or improve design and performance (McCuen, 1996).

3.7 Research Methods

This section describes the following dominant research methods applied to the thesis:

a) for *pre-construction* period whereas both *explanatory* and *predictive* modelling is required, *statistical* techniques such as descriptive (frequency histograms) and inferential statistics (*t*-statistic and analysis of variance), correlation and linear regression analyses;

b) for the development of *deterministic* and *stochastic* models in order to simulate the *physical construction* and *useful life* processes, *operational research* quantitative techniques such as mathematical modelling, linear/integer (optimisation) programming, network project scheduling techniques and quantitative risk analysis (simulation).

3.7.1 Statistical Techniques

Statistics is the body of methodology concerned with the *art* and *science* of collecting, classifying, summarising, organising, analysing, and interpreting data to identify and solve problems, and to make decisions. Statistical techniques should be regarded as valuable tools which do not replace; however, critical thinking and common sense; if used correctly, statistical methods enable managers to generate and assemble numerical information in a way that will help them make better decisions and create more rapid improvements in processes and products (Johnson and Wichern, 2013).

A statistical *population* is a dataset (usually large, sometimes conceptual) that is the target of interest. A *sample* is a subset of data selected from the target population. The object (an event, or a project) upon which measurements are collected is called the *experimental unit*. A population consists of data collected from experimental unit(s). A *variable* is a property or characteristic of an individual experimental unit (Mendenhall and Sincich, 2007).

3.7.1.1 Descriptive and Inferential Statistics

The first thing usually done with a given dataset is *descriptive statistics*; the application of methods that summarise and describe the data collected. While methods of descriptive statistics are used to describe data, methods of *inferential statistics*, on the other hand, are used to draw inferences from data (Levin and Rubin, 1994; Johnson and Wichern, 1997).

3.7.1.2 Correlation Analysis

Correlation is a statistical technique designed to measure how closely two variables x and y of a sample with n observations are related. Essentially, it consists of measuring the degree of association between one variable's values and those of another (or others). The usual first step is to plot the data in a *scatter diagram*, a graphic tool to portray the relationship between the variables. Originated by Karl Pearson around 1900, the statistic measure used in correlation analysis is termed the *coefficient of correlation*, or more simply, r. It has a maximum theoretical value of (+1), which means a perfect direct relationship, and a minimum theoretical value of (–1), which means a perfect inverse relationship. If $r = 0$, it means that there is no association at all between the variables. The value of r is calculated in practice from the following equation (Verma and Gross, 1978):

$$r = \frac{n\sum xy - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2]\,[n\sum y^2 - (\sum y)^2]}} \tag{3.1}$$

The r calculation is generally followed by a *statistical test of significance* to assess whether or not any detected relationship could have probabilistically occurred from a chance draw of the sample. If it is unlikely to have occurred by chance it is assumed that the association measured in the sample can be used as an *estimate* of the underlying population's association. The same form of analysis is used in *forecasting* whereas it is assumed that *historical* data are samples taken from *actual* underlying populations. The *null hypothesis* is that *no association* exists between the two underlying populations. The Student's *t-statistic* is used for a desired confidence level (say 95%) and it is calculated from the sample values and from the equation (Lind *et al.*, 2008):

$$t = r\sqrt{\frac{n-2}{1-r^2}} \tag{3.2}$$

If the computed t is in the rejection region, then the null hypothesis is rejected, therefore the correlation in the population is not zero. Otherwise, the null hypothesis is accepted and it is inferred that there is no correlation between the variables. Instead of using r to interpret the results of correlation analysis, a measure that has a more easily interpreted meaning is r^2, which is called the *coefficient of determination*. The coefficient of determination reflects the *proportion* of the total variation in one variable that may be explained, or accounted for, by the variation in the other variable(s). It is computed by squaring the coefficient of correlation and may be any value between 0 and 1. The closer r^2 is to zero, the less significant is the information derived from an attempt to associate the variables. The closer r^2 is to one, the greater is the ability to explain, or account for, the variation in values of the variables. If r is *significant* (either positive or negative), along with a relatively high value of r^2, it means that there exists a *consistent* relationship. As long as there is a significant relationship and it is consistent, the variable is a likely candidate for a relatively strong forecasting model.

3.7.1.3 Linear Regression (LR)

Regression analysis is similar to correlation analysis. However, there is one major difference. The purpose of correlation is to analyse the degree of relationship among the values of two or more variables. Regression, on the other hand, is geared towards establishing the *functional relationship* between a *dependent* variable and one or more *independent* variables. Independent means that specific values of the variable are *not* influenced by the other variables. In forecasting, the variable that is being forecast is defined as the dependent variable while the variables that are being used to make the forecast are called the independent variables. Regression analysis consists of five steps:

1. whether or not a *linear* relationship exists is determined;
2. the *regression equation* is calculated;
3. *statistical tests* are computed;
4. a *forecast* is prepared; and
5. a *confidence interval* is established.

Linear Regression (LR) builds a model that predicts *future* behaviour for a dependent variable based on the assumed linear influence of one or more independent variables. The dependent variable is the factor to be forecast; in this case, construction *cost* or *time*. The independent variables are the project parameters to base the prediction on; for example, *gross floor area, building height* or *volume above ground level*. The concept of a regression formula is relatively simple: for particular values of an independent variable, a linear relationship can be constructed that permits the forecasting of a dependent variable. *Simple* LR can be visualized on an x (independent) – y (dependent) co-ordinate system. *Multiple* LR uses more than one x to predict y. Simple LR finds the linear relationship that best fits the data by choosing a slope of the regression line, known as the *beta* (β), and a y intercept (where the line crosses the y-axis) known as the *alpha* (α). The R^2, the *co-efficient of multiple determination,* measures how well the estimated values of the regression line correspond to the actual figures and it is therefore a guide to the *'goodness of fit'* of the regression model. R^2 values range from 0 to 1, with 1 indicating perfect correspondence between the estimated value and the actual data, and with 0 indicating no systematic correspondence whatsoever (Guerrero, 2010).

The following are the key assumptions underlying the LR technique:

- The variance of the residual or error term e should not depend on the value of the independent variable x. This assumption is called *homoscedasticity*. If the variance of the error term depends on x, then we say that *heteroscedasticity* is present. To see whether the homoscedasticity assumption is satisfied, we plot the errors on the y-axis and the value of x on the x-axis. Using $\ln y$ or $y^{1/2}$ as the dependent variable will often eliminate heteroscedasticity.
- Residuals or errors are *normally distributed*.
- The residuals or errors should be *independent*. This assumption is often violated when data are collected over time. Independence of the errors implies that knowing the value of one error should tell us nothing about the value of the next (or any other) error. The validity of this assumption can be checked by plotting the errors in time-series sequence.
- The relationship between the dependent variable and each independent variable should be *linear*.

Method selection allows the specification for how independent variables are entered into the regression analysis. Using different methods, one can construct a variety of regression models from the same set of variables. The most commonly used of these methods are (Landau and Everitt, 2004):

- *Forward* selection. This method starts with a model containing none of the explanatory variables. In the first step, the procedure considers variables one by one for inclusion and selects the variable that results in the largest increase in R^2. In the second step, the procedure considers variables for inclusion in a model that only contains the variable selected in the first step. In each step, the variable with the largest increase in R^2 is selected until, according to an F-test, further additions are judged to not improve the model.

- *Backward* selection. This method starts with a model containing all the variables and eliminates variables one by one, at each step choosing the variable for exclusion as that leading to the smallest decrease in R^2. Again, the procedure is repeated until, according to an F-test, further exclusions would represent a deterioration of the model.
- *Stepwise* selection. This method is, essentially, a combination of the previous two approaches. Starting with no variables in the model, variables are added as with the forward selection method. In addition, after each inclusion step, a backward elimination process is carried out to remove variables that are no longer judged to improve the model.

3.7.2 Quantitative Methods

3.7.2.1 Operational Research (OR)

The scientific discipline that describes the body of knowledge adopting the quantitative approach to decision-making is *operational* (or *operations*) *research* (also often referred to as *management science*). Operational research (OR) is the *scientific approach to decision-making* that seeks to *best* design and operate a system, usually under conditions whereas scarce resources allocation is required (Winston, 2004). The definition adopted by the Operational Research Society is as follows: ‘Operational research (OR) is a way of using analytical methods to help make better decisions. Its methods can be used by almost all organizations, groups and individuals. It uses methods such as logic and mathematical modelling to analyse complex situations, giving decision makers of all types the power to make more effective decisions’.

Until World War II, most businesses and industries did not worry about operational problems. This was partly because no formal mathematical discipline directly handled these problems, and partly because there was no urgent need for them. During World War II, military *planners* began working with scientists and mathematicians in order to apply a scientific approach to the management of the war effort, in which they began to devise mathematical models to deal with such issues. After the war, others began to look at these techniques for industry, which brought about the beginning of OR (Rader, 2010). Since the development of computers and the establishment of OR as an academic subject in the mid-1950s, the use of formal numeric models to assist in decision-making has expanded. Many of these models use financial metrics such as profit and/or cash-flow to measure the 'correctness' of a managerial decision. Project selection decisions pose no exception, being based primarily on the degree to which the financial goals of the organization are met (Meredith and Mantel, 2012).

Urry (1991) explained that there are a number of common features to most OR problems:

- they are concerned with planning and predicting;
- they are described and analysed in numerical terms;
- there are constraints such as limitations of resources;
- the objectives are expressed as optimisations; and
- they involve uncertainties.

3.7.2.2 Mathematical Modelling

Modelling is the process of constructing a model, i.e. an abstraction or representation of a real system, idea, or object (Evans and Olson, 1998). A model must capture and represent the reality being modelled as closely as is practical; it must include the essential features of the real-world situation, in respect of the purpose of developing the model, whilst being reasonably cheap to construct and operate and easy to use (Fellows and Liu, 2008). Modelling usually involves the application of mathematics so that real-life problems are translated to a set of mathematical equations, which *mimic* reality. A solution to the mathematical problem is obtained, which is interpreted in the language of reality to *predict* future outcomes or simply to *investigate* and comprehend the actual situation better (Banerjee, 2014). A *mathematical model* is a collection of variables and the relationships needed to describe important features of a given optimisation problem. In its most general form and assuming maximisation problem, it can be expressed as (Rader, 2010):

$$\max \{f(x) : x \in S\} \tag{3.3}$$

where x is a vector of decision variables, $f(x)$ is the objective function, and the set S is the set of values for the decision variables satisfying all of the constraints.

The modelling process involves the following steps (Hillier and Lieberman, 2009):

1. Definition of the problem of interest and gathering of relevant data;
2. Formulation of a mathematical model to represent the problem;
3. Development of a computer-based procedure to derive solutions to the problem from the model formulated;
4. Testing and refinement of the model as needed;
5. Preparation for the ongoing model application as prescribed by management;
6. Implementation.

A fundamental classification for models is as either *deterministic* or *probabilistic*. A deterministic model will generally ignore, or assume away, any *uncertainty* in its relationships and variables. Unlike deterministic models, probabilistic (or stochastic, or random) models explicitly consider uncertainty by incorporating a technical description of how variables can change and thus embedding uncertainty in the model structure.

Random models are normally more complex and difficult to construct but provide great value to the modeller; after all, life is stochastic and there are many risks and uncertainties associated with any business endeavour (Guerrero, 2010). However, the potential variation in a deterministic model can be studied by using *sensitivity analysis*. This type of *what-if* analysis can be used to study uncertainty, but only through the manual change of values. The results of a sensitivity analysis are often presented graphically, on a *spider diagram*, which readily indicates the most sensitive or critical areas for management to direct its attention towards. One weakness of sensitivity analysis is that risks are treated individually and independently. Caution must therefore be exercised when using the data directly to assess the effects of combination of risks (Potts and Ankrah, 2013). Another common procedure is to calculate three scenarios, *best case*, *worst case* and *most likely*, for each key *input* in the model. Scenario analysis shows the ranges of possibilities for the *outputs*, but gives no idea of the likelihood of output values falling between the extremes. Therefore, what-if and scenario analyses are good ways to get started, but there are more sophisticated techniques for analysing and managing risk and uncertainty (Charnes, 2007). The limitations imposed by the modelling process must be identified and the variables clearly defined if the resulting outputs are to be of value. ‘It must be emphasized that a model can never be ‘true’ in the absolute sense of the word, in that at best it represents a logical deduction drawn from an imperfect set of assumptions. It is essential therefore that anyone using the model must have a sound grasp of its structure and the assumptions on which it is based’ (Cusack, 1984).

3.7.2.3 Linear Programming (LP)

Linear programming (LP) is a tool for solving *optimisation* problems. Dantzig (1963) developed an efficient method, the *simplex algorithm*, for solving linear programming problems. Since the development of the simplex algorithm, LP has been extensively used to formulate models of real-life situations in many industries, including construction. Urry (1991) explained that in the context of resource allocation optimisation problems (common in construction projects), the term *programming* means *scheduling* or *planning*, not computer programming. Computers are most often used to perform LP calculations, but the two ideas are separate.

LP is a generalisation of *linear algebra*. It is capable of handling a variety of problems, ranging from finding schedules for equipment and transportation models to distributing cements from batch plants to construction sites. The reason for this great versatility is the ease at which constraints can be incorporated into the model and, therefore, LP is a powerful technique that is often used by large corporations, and government agencies to analyse complex production, commercial, financial, and other activities when constructing large and complex programs (Haidar, 2016).

According to Winston (2004), in any LP problem the decision-maker wants to maximise (usually revenue or profit) or minimise (usually costs) some *linear* function of the *decision variables*. This function to be maximised or minimised is called the *objective function*. The values of the decision variables must satisfy a set of *constraints*. Each constraint must be a linear equation or linear inequality. A *sign restriction* is also associated with each decision variable so that any variable can be either non-negative or unrestricted in sign. The *feasible region* for a LP is the set of all points that satisfies all the LP's constraints and sign restrictions. An *optimal solution* to a LP maximization or minimization problem is a point in the feasible region with the largest or the smallest objective function value, respectively.

The general form of a LP problem can be written as follows (Rader, 2010):

$$
\begin{aligned}
&\text{max/min} \quad \sum_{j=1}^{n} c_j x_j \\
&\text{s.t.} \\
&\qquad \sum_{j=1}^{n} a_{ij} x_j \begin{pmatrix} \leq \\ \geq \\ = \end{pmatrix} b_i, \qquad i \in \{1, \ldots, m\} \\
&\qquad x_j \begin{pmatrix} \geq 0 \\ \leq 0 \\ \text{unrestricted in sign} \end{pmatrix}, \qquad j \in \{1, \ldots, n\}.
\end{aligned}
$$

Perhaps the most common mathematical program used in business and industry is *integer programming* (IP). Typically, these are linear programs where some (or all) of the variables are required to have integer values. IP is often written in the following form (Rader, 2010):

$$
\begin{aligned}
&\text{max/min} \quad \sum_{j=1}^{n} c_j x_j \\
&\text{s.t.} \\
&\qquad \sum_{j=1}^{n} a_{ij} x_j \begin{pmatrix} \leq \\ \geq \\ = \end{pmatrix} b_i, \qquad i \in \{1, \ldots, m\} \\
&\qquad x_j \begin{pmatrix} \geq 0 \\ \leq 0 \\ \text{unrestricted in sign} \end{pmatrix}, \qquad j \in \{1, \ldots, n\} \\
&\qquad x_k \text{ integer}, \qquad k \in S \subseteq \{1, \ldots, n\}.
\end{aligned}
$$

3.7.2.4 Network-Based Scheduling Techniques (PERT/CPM)

In construction contracts, time is important and delays can be costly. It is essential, therefore, to achieve the earliest possible completion and thus various techniques are used to plan and control the progress of complex projects. In such situations network models such as the *program evaluation and review technique* (PERT) and the *critical path* *method* (CPM) have proven to be extremely valuable. A network model is essentially a flow-chart showing the sequence in which various parts of a project should be performed. Construction projects are typical examples of projects where planning and scheduling through network analysis techniques is the best approach (Verma and Gross, 1978).

PERT/CPM can be used to plan, schedule, and control a wide variety of building projects in which construction managers must schedule and coordinate the various *work activities* so that the entire project is completed on time. A complicating factor in carrying out this task is the interdependence of the activities; for example, some activities depend on the completion of other activities before they can be started. Because projects may have as many as several thousand activities, project managers look for procedures that will help them answer questions such as the following:

- What is the total time to complete the project?
- What are the scheduled start and finish dates for each specific activity?
- Which activities are 'critical' and must be completed *exactly* as scheduled to keep the project on schedule?
- How long can 'non-critical' activities be delayed before they cause an increase in the total project completion time?

PERT/CPM can assist in answering the above questions (Hillier and Lieberman, 2009).

3.7.2.5 Quantitative Risk Analysis (QRA)

According to the *Oxford English Dictionary* (Brown, 2002), the term *risk analysis* means the 'systematic investigation and forecasting of risks in business and commerce'. Risk analysis is used to assess the possible consequences of business decisions. This assists managers to gain comfort that their selected course of action is the best one based on the available information at the time of decision-making. Risk analysis is the *quantification* of the consequences of uncertainty in a situation of interest (Charnes, 2007).

The information associated with project management is characterised by uncertainty and is thus appropriate for the application of risk analysis. The duration of project activities, the amounts of various resources that will be required to complete a project, the estimates made of the value of accomplishing a project, all these and many other aspects of a construction project are uncertain. While a project manager may be able to reduce uncertainty, it cannot be eliminated. Decisions must be made in the face of the ambiguity that results from uncertain information. Risk analysis does not remove the ambiguity but it simply describes the uncertainties in a way that provides the decision-maker with a useful insight into their nature (Meredith and Mantel, 2012).

To apply *quantitative risk analysis* (QRA), one must make assumptions about the *probability distributions* that characterise key parameters and variables associated with a decision and then use these to estimate the *risk profiles* or *probability distributions* of the outcomes of the decision. This can be done by *Monte Carlo simulation* (Hertz, 1964), an easy-to-use technique that is well-adapted to evaluate the risk in business decisions under uncertainty. Since its first appearance, the method has been popularized by the rapid developments in the field of information technology. Real situations rarely meet the assumptions required by standard analytical modelling approaches. In such instances, simulation can be a valuable technique to modelling and solving the problem (Law and Kelton, 1991). Simulation is 'the process of building a mathematical or logical model of a system or a decision problem, and experimenting with the model to obtain insight into the system's behaviour or to assist in solving the decision problem' (Evans and Olson, 1998). Nowadays, many practical and theoretical problems involving risk and uncertainty in the area of economics and management are solved using simulation. The simulation software allows the decision to be represented by a mathematical model and then selects samples from the assumed distributions for each input. The software then plugs these inputs into the model and finds the outcome(s) of the decision. The risk profiles are used to assess the value of the decision along with other factors that might be relevant such as strategic concerns, social and political factors, or impact on market share (Lorance and Robert, 1999). Ashworth (2004) explained that the origins of simulation are threefold. First, there is always a preference to avoid direct experimentation, where possible, since developing and testing a real system may indeed be a very costly procedure to manage. The second reason stems from the solutions given by pure mathematics. Simulation, unlike mathematical models that represent steady-state behaviour, involves observations that are subject to *experimental error*. This means that they are treated as *statistical* experiments and *inferences* regarding the performance are subject to statistical analysis testing. The third reason lies in the growth area of OR. A major difference between the subject matter of conventional scientific research and OR is the greater variability of many of the phenomena studied in the latter.

QRA should not be considered as the only means of assessing risk but as one of the several tools that the decision maker should consider. Nonetheless, it is a powerful OR technique and, providing the development of a representative and valid model with realistically quantified inputs, it should provide significant insight into problems involving uncertainty (Vose, 1996).

The use of simulation has many possible applications within the construction industry and in the field of construction cost management. The following are some examples which deserve the attention of this technique (Ashworth, 2004):

- Construction *planning*, because of the inherent risk and uncertainty associated with construction project management;

- Construction *estimating*, particularly in the area of *tender bidding* and *cost forecasting* which are indeterminate in practice; and
- *Whole-life costing*, with the variableness in data such as life of materials and components, maintenance periods, interest rates and building life.

Risk modelling may be viewed as an extension to conventional project and business forecasting and modelling (Figure 3.4, page 207). Generally, a conventional spreadsheet is the starting point, such as a simple cost estimate or a cash-flow model of the NPV of a capital investment. The main elements of the model are examined to determine what might cause the elements to vary, and the likely management responses to variations are considered. The elements of a model, risks and responses are used to develop quantitative descriptions of the variability in the model expressed as distributions that replace simple fixed values in the spreadsheet. The distributions are combined through the model structure to generate distributions of the key variables needed for decision-making, such as the distribution of capital cost, NPV or internal rate of return (Cooper *et al.*, 2005).

3.8 Research Software

In this section, the commercial software applications used in the research are briefly described.

3.8.1 IBM® SPSS® Statistics 23.0 (SPSS)

The IBM® SPSS® Statistics 23.0 (‘Statistical Package for the Social Sciences’ – SPSS) is a package of programs for manipulating, analysing, and presenting data; the package is widely used in the social and behavioural sciences (Landau and Everitt, 2004).

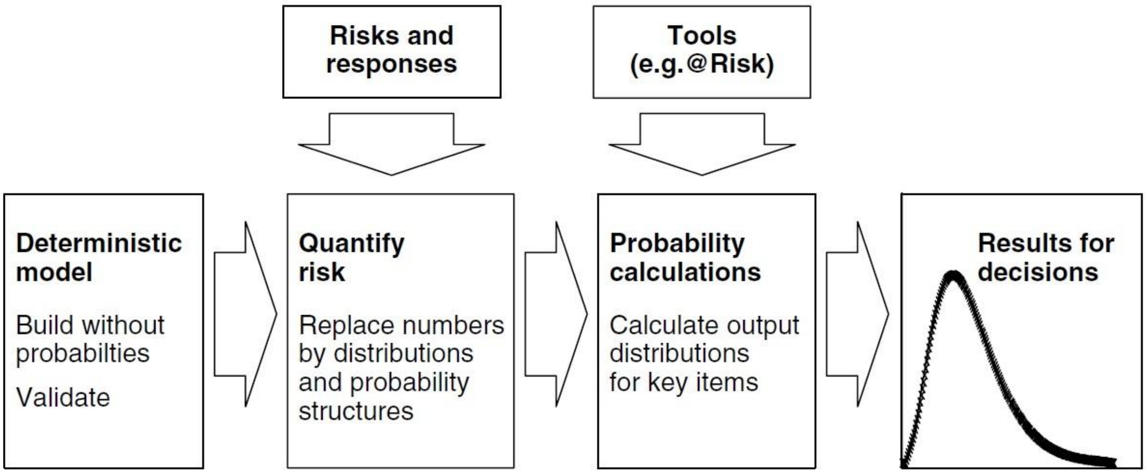


Fig. 3.4 Outline of the Quantitative Risk Analysis (QRA) Process (Source: Cooper *et al.*, 2005)

3.8.2 Microsoft® Office Excel® (Excel) and Solver Excel® add-in (Solver)

Microsoft® Office Excel® (Excel) *spreadsheet* is at the core of models development in this thesis. The use of spreadsheets has become a matter of routine for estimators and managers in construction by providing:

- ease of use;
- good presentation facilities;
- flexibility and adaptability for different tasks and different projects;
- ease of modification as new information becomes available;
- backup facilities; and
- ability to incorporate risk and uncertainty (Cooper *et al.*, 2005).

Business spreadsheets typically include some *input cells* that display key data (e.g. the various costs associated with constructing a product) and one or more *output cells* that show measures of performance (e.g. the profit earned from selling the product). The user writes Excel equations to link the inputs to the outputs so that the output cells will show the values that correspond to the values that are entered into the input cells. In some cases, there will be uncertainty about what the correct values for the input cells will turn out to be. Sensitivity analysis then can be used to check how the outputs change as the values for the input cells change. However, if there is considerable uncertainty about the values of some input cells, a more systematic approach to analyse the effect of the uncertainty would be helpful. This is where *simulation* enters the picture (Subsection 3.9.3).

Microsoft® Office Excel® Solver add-in (Solver) has the capability of tackling LP/IP problems and is used in the research to solve the project *time/cost trade-off (optimisation)* problem during the construction production phase. The key to solving a LP/IP problem with Solver is to setup a spreadsheet that tracks every decision variable of interest (time, cost, resource consumption, etc.) and to identify the *changing cells*, i.e. the cells of interest that can be varied. After defining the changing cells, the *target cell* is specified (the cell that contains the objective function). Next, the constraints are added so that Solver can calculate and place the optimal solution in the spreadsheet.

3.8.3 @RISK® for Excel 5.5 add-in by Palisade Corporation® (@RISK)

Simulation is a very powerful and widely used management science technique for the analysis and study of complex systems, which imitates the operation of a real-world system as it evolves over time. Simulation may be seen as a *sampling experiment* on the real system, with the results being sample points: to obtain the best estimate of the mean of the measure of performance, one averages the sample results; clearly, the more sample points one generates, the better their estimate will be. However, other factors, such as the starting conditions of the simulation, the length of the period being simulated, and the accuracy of the model itself, all have a bearing on how good the final estimate will be (Winston, 2004). *Stochastic* simulation generates estimates by randomly calculating a feasible value for each variable from a statistical probability distribution function which represents the range and pattern of possible outcomes. To ensure that the chosen values are representative of the pattern of possible outcomes, a quite large number of repetitive deterministic calculations (known as *iterations*) are made (Bennett and Ormerod, 1984).

The standard Excel package has some basic simulation capabilities, including the ability to generate uniform random numbers and to generate random observations from some probability distributions. The risk analysis and simulation package used in this research work is Microsoft® Office Excel® add-in @RISK® by Palisade Corporation® (@RISK). @RISK provides a convenient way of performing QRA calculations within a standard Excel spreadsheet and has several useful features:

- it allows distributions and probability trees to be specified and incorporated in an estimating spreadsheet;
- it allows simulations to be run, taking samples from the input distributions and generating output distributions for the cost totals of interest;
- it facilitates graphical display of output distributions and allows sensitivity analyses to be performed.

Risk analysis in @RISK is a quantitative method that seeks to determine the outcomes of a decision situation as a probability distribution; with @RISK you can answer questions like, 'what is the probability of profit exceeding €1 million?' or 'what are the chances of losing money on this venture?'.

In general, the techniques in @RISK analysis encompass the next four steps (@RISK Guide, 2009):

1. Developing a model by defining the problem or situation in Excel format;
2. Identifying uncertainty in variables in Excel, specifying their possible values with probability distributions, and identifying the uncertain worksheet results one wants analysed;

3. Analysing the model with simulation to determine the range and probabilities of all possible outcomes for the results of the worksheet; and
4. Making a decision based on the results provided and personal preferences.

@RISK assists in the first three steps, by providing a powerful and flexible tool that works with Excel to facilitate model building and risk analysis. The results that @RISK generates can then be used by the decision-maker to help choose a course of action (@RISK Guide, 2009).

3.9 Methodology Synopsis

The research methodology of the thesis is graphically summarised in the next Figure 3.5 (page 211).

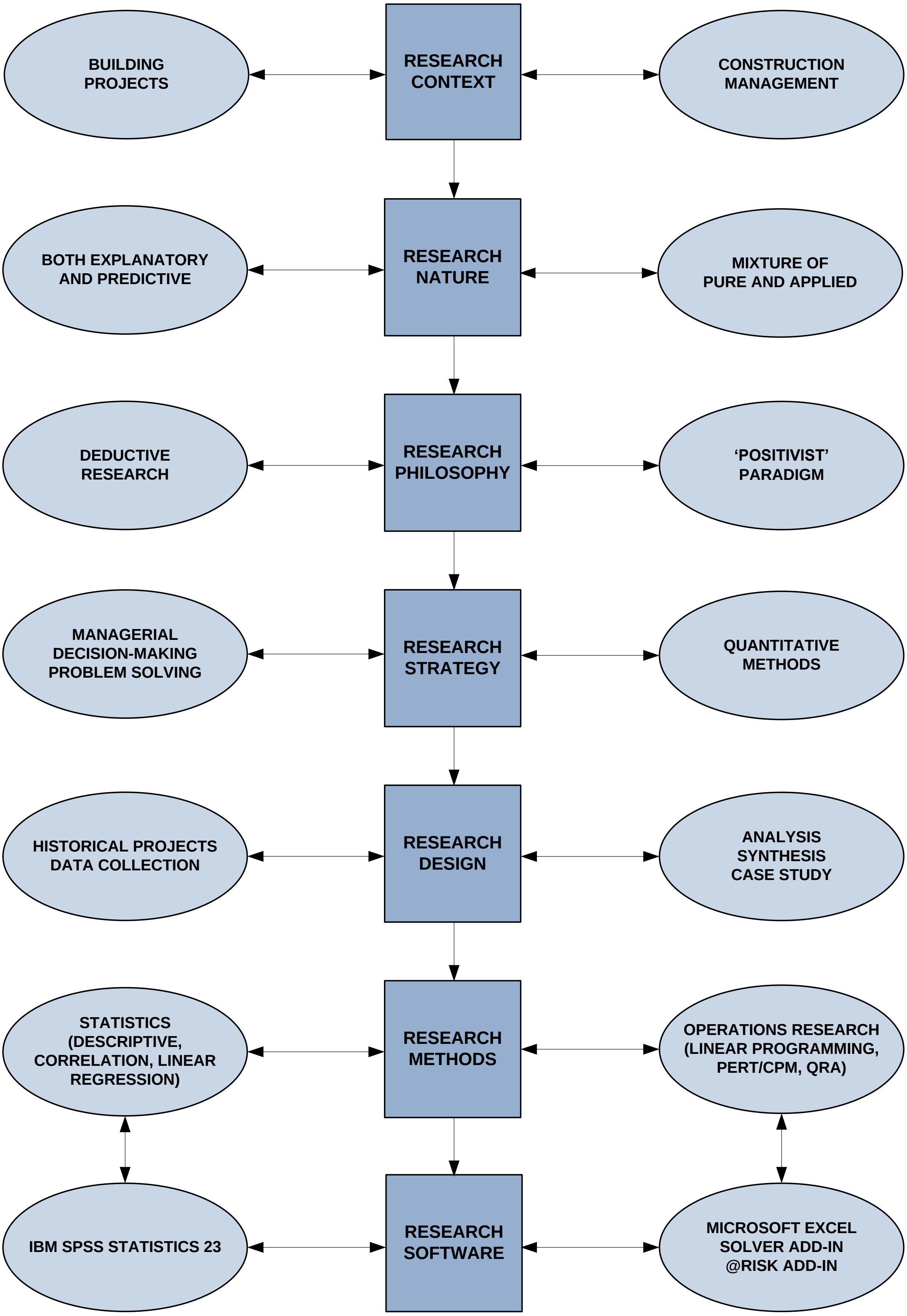


Fig. 3.5 Research Methodology Summary

This page intentionally left blank

CHAPTER 4

CONSTRUCTION PROJECT PRODUCTION

4.1 Introduction

This chapter describes the modelling methodologies and processes, both *deterministic* and *stochastic*, concerning the project overall *construction production* process which can be separated into an initial (early stage) *pre-construction* period and a subsequent *physical construction* period. Pre-construction starts with a *feasibility study* to assess project's viability with respect to client's needs and preliminary project scope requirements in relation to cost and time constraints, followed by an *evaluation and selection* of the project(s) under consideration whereas a *'go/no go'* decision is made. After the decision to proceed with the capital investment is justified, the *design* stage begins, having a significant influence on the costs incurred at subsequent project stages. To assist owners with early stage decision-making at the pre-construction period, *cost and time forecasting tools* are developed from *historical data* by using *linear regression* statistical technique, and an indication of the *building design morphology complexity* is derived from the calculation of relevant *plan shape indices* for the above sample of historical building projects. Physical construction commences after the architectural and engineering design drawings have been agreed by all parties involved. For *time and cost estimation* and *cost budgeting* (cost baseline) purposes, PERT/CPM *network analysis* technique is used together with an *activity-oriented costing* methodology based on activity resource consumption. For *cost control* reasons and in order to *monitor project performance*, the *earned-value analysis* technique is adopted and an *integer linear programming tool* is presented to tackle the *time-cost trade-off* (optimisation) problem.

4.2 Pre-Construction Stage

Construction clients require early and accurate cost advice by the QS/cost engineer, prior to site acquisition and the commitment to build, in order to assess the feasibility of the proposed project. The purpose of this early stage construction cost forecast is to assist the client in setting a conceptual budget, predicting the tender price and managing the design so that it meets the set budget (Lowe *et al.*, 2006). Therefore, accurate *cost modelling* is fundamental to the efficiency of the construction industry in general, and the stakeholders within the industry in particular; clients, consultants and contractors all have much to lose from the consequences of inaccurate cost modelling (Lawther and Edwards, 2001). Cost models are technical aids which enable management decisions to be made in the context of building design and their primary function is the provision of reliable cost forecasts (Skitmore and Marston, 1999). Moreover, because clients undertaking construction projects wish to have an understanding of their financial commitment, it is appropriate to apply cost modelling techniques as early as possible in the development process, prior to commissioning extensive design work (Ashworth and Skitmore, 1983). The goal of the building cost forecaster should be a practicable level of accuracy, in spite of the widely held assertion that a perfect initial cost prediction is not possible (Smith, 1995) due to the inherent uncertainties relating to the lack of a detailed design and even a site (Raftery, 1994). Therefore, there is a strong need to provide more accurate and robust construction cost forecasts (RICS, 1991). Moreover, it is a common occurrence that a prospective building client may not be able to give enough details about the shape of the proposed building they wish to undertake and even worse, they may not appreciate the fact that variations in the plan shape have cost implications (Ibrahim, 2007). Thus, this section essentially aims at using historical data to investigate the relationship between the total cost of a building and the shape of its design layout.

4.2.1 Data Collection and Analysis

A sample of thirty six (36) reinforced concrete-framed commercial building projects was investigated, all having identical main constructional and functional characteristics, and erected in various locations within the greater area of Athens, Greece, during the period of 2005-2015. Total cost – final account, including costs for design and construction permit issue – varied from €165.000,00 to €2.286.000,00 with a mean cost of €579.470,00. Total duration – starting from the date of contractor’s setup on site and finishing at the date of commissioning the project to the client – varied from 275 days to 732 days with a mean duration of 456 days. The complete data set for the sample of the 36 building projects is presented in Appendix (B).

Table 4.1 Descriptive Statistics for the Sample of Building Projects (*n* = 36)

	Range	Min	Max	Mean	Std. Dev.	Variance	Skewness		Kurtosis	
	Stat*	Stat	Stat	Stat	Stat	Stat	Stat	SE**	Stat	SE
cost_tot	2119	167	2286	579,47	460,84	212371,46	2,03	0,39	4,52	0,77
dur_tot	457	275	732	456,00	112,05	12555,89	0,57	0,39	-0,30	0,77
cost_m2	597,64	740,73	1338,37	939,70	168,63	28435,65	1,03	0,39	-0,01	0,77
cost_m3	239,26	181,90	421,16	280,93	58,15	3381,82	0,64	0,39	0,26	0,77
cost_day	2515,68	607,27	3122,95	1153,59	590,75	348989,04	1,68	0,39	2,60	0,77
plot_area	4465,16	102,84	4568,00	782,59	1170,55	1370196,20	2,84	0,39	7,00	0,77
cov_area	535,89	53,22	589,11	152,94	97,16	9439,83	2,97	0,39	11,35	0,77
cov_ratio	0,67	0,03	0,70	0,36	0,18	0,03	0,19	0,39	-0,28	0,77
gross_ag	1436,76	106,44	1543,20	435,28	378,85	143528,28	1,59	0,39	1,88	0,77
build_coef	4,19	0,04	4,23	1,17	1,12	1,25	1,45	0,39	1,31	0,77
gross_bg	1299,45	53,22	1352,67	218,06	228,82	52359,55	3,81	0,39	17,60	0,77
gross_tot	2736,21	159,66	2895,87	653,34	568,13	322769,21	2,20	0,39	5,93	0,77
misc_ag	249,35	10,96	260,31	80,70	72,01	5185,49	1,15	0,39	0,12	0,77
ht_ag	23,00	4,00	27,00	11,29	5,46	29,87	1,57	0,39	2,27	0,77
vol_ag	5411,12	303,35	5714,47	1566,54	1326,60	1759882,02	1,61	0,39	2,00	0,77
vol_bg	3627,82	159,66	3787,48	637,19	666,40	444091,15	3,43	0,39	14,38	0,77
vol_tot	9038,94	463,01	9501,95	2203,73	1915,29	3668339,09	2,12	0,39	5,25	0,77
st_ag	8	1	9	3,08	1,92	3,68	1,57	0,39	1,96	0,77
st_bg	2	1	3	1,08	0,37	0,14	4,71	0,39	22,88	0,77
st_tot	8	2	10	4,17	2,104	4,429	1,657	0,39	2,03	0,77
env_tot	1530,62	284,99	1815,61	799,2540	405,03290	164051,646	1,145	0,39	0,44	0,77

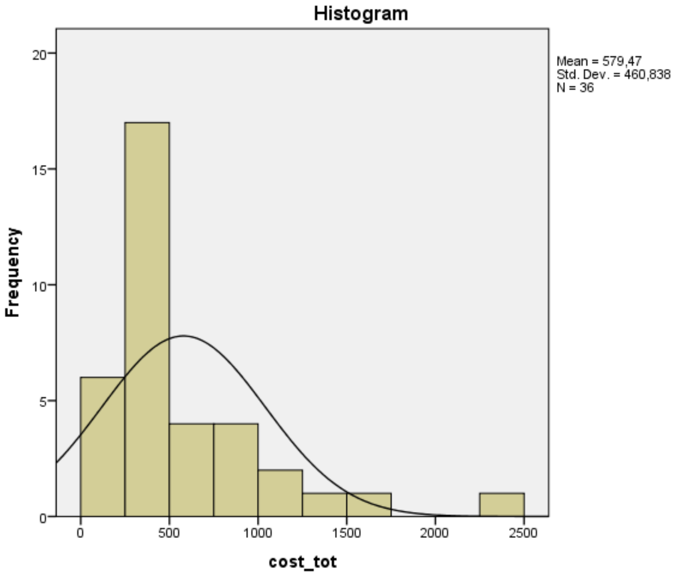
*. Stat: Statistic; **. SE: Standard Error

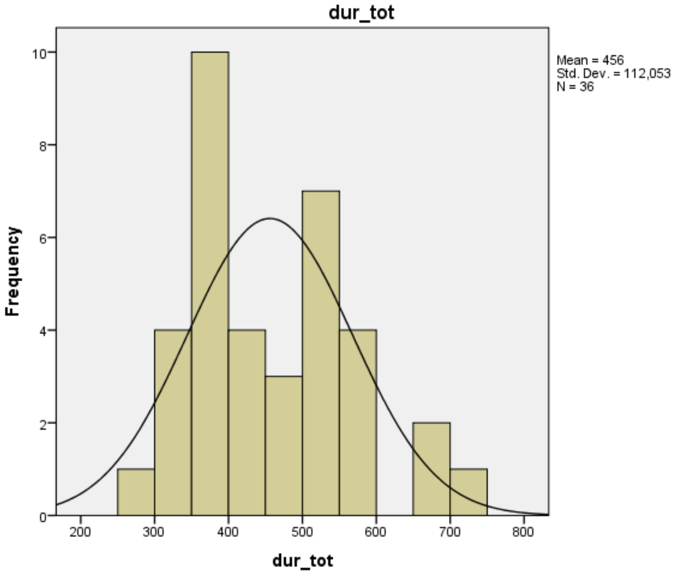
IBM® SPSS® Statistics 23.0 (SPSS) is used to perform the statistical analyses. Table 4.1 (page 215) shows *descriptive statistics* for the five (5) main *dependent* variables, i.e. total final cost in €*1000 **(cost_tot)** and total duration in days **(dur_tot)** of the sample projects, together with cost per m^2 **(cost_m2)**, cost per m^3 **(cost_m3)** and cost per day **(cost_day)**, which were calculated from the data collected to explore their relationship with the other factors selected and to assess their usefulness as output variables. Furthermore, Table 4.1 shows descriptive statistics for the sixteen (16) input variables, associated with mandatory *town planning restrictions* and *geometric characteristics* which collectively determine the final building design solution. Both output and input variables are defined as follows:

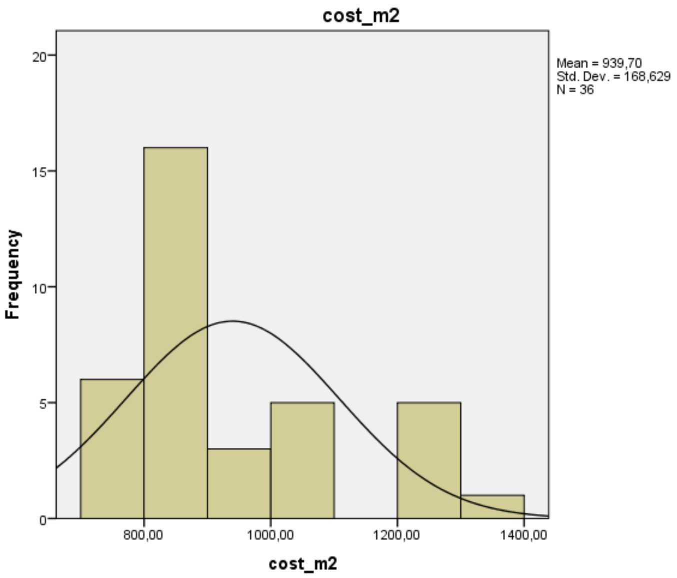
(cost_tot)	project total completion cost (final account) (in €*1000)
(dur_tot)	project total duration (in days)
(cost_m2)	project cost per m^2 of total gross floor area (in €/m^2)
(cost_m3)	project cost per m^3 of total building volume (in €/m^3)
(cost_day)	project cost per day of total project duration (in €/day)
(plot_area)	plot area (land) (m^2)
(cov_area)	coverage ratio area (m^2)
(cov_ratio)	coverage ratio = (cov_area) : (plot_area)
(gross_ag)	gross floor area above ground level, including walls (m^2)
(build_coef)	building coefficient = (gross_ag) : (plot_area)
(gross_bg)	gross floor area below ground level, including walls (m^2)
(gross_tot)	total gross floor area (m^2) = (gross_ag) + (gross_bg)
(misc_ag)	miscellaneous gross floor area above ground level (m^2)
(ht_ag)	building height above ground level, including roof (m)
(vol_ag)	building volume above ground level, including roof (m^3)
(vol_bg)	building volume below ground level (m^3)

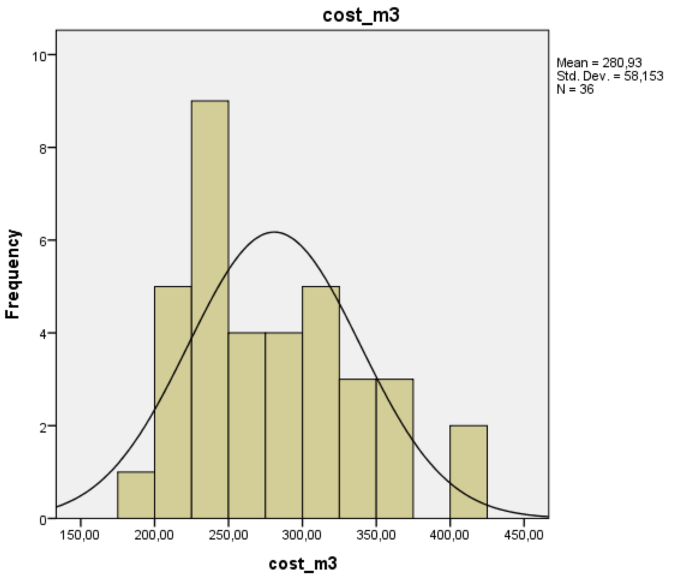
(vol_tot)	total building volume (m^3) = (vol_ag) + (vol_bg)
(st_ag)	number of storeys above ground level (no.)
(st_bg)	number of storeys below ground level (no.)
(st_tot)	total number of storeys (no.) = (st_ag) + (st_bg)
(env_tot)	total external envelope wall area (m^2)

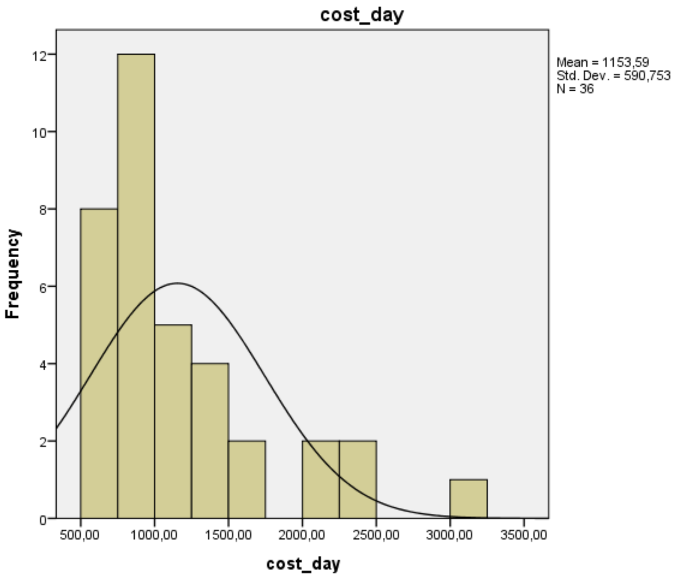
The frequency histograms (with Normal Curve) for the twenty one (21) variables in Table 4.1 are illustrated as follows:

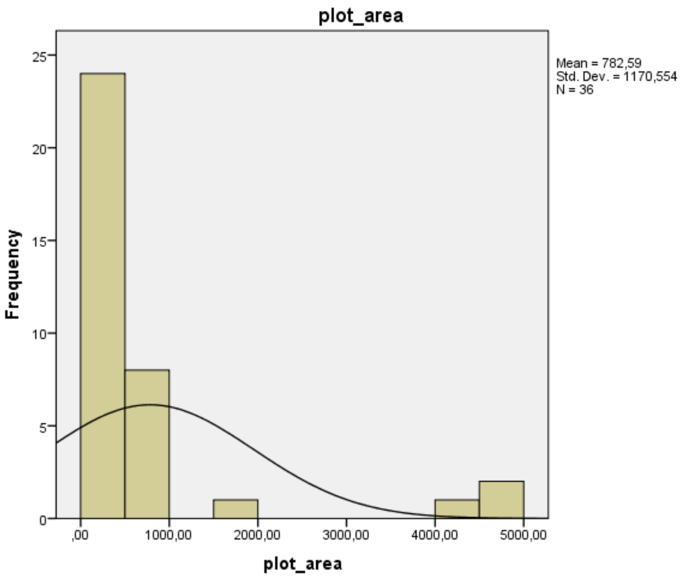


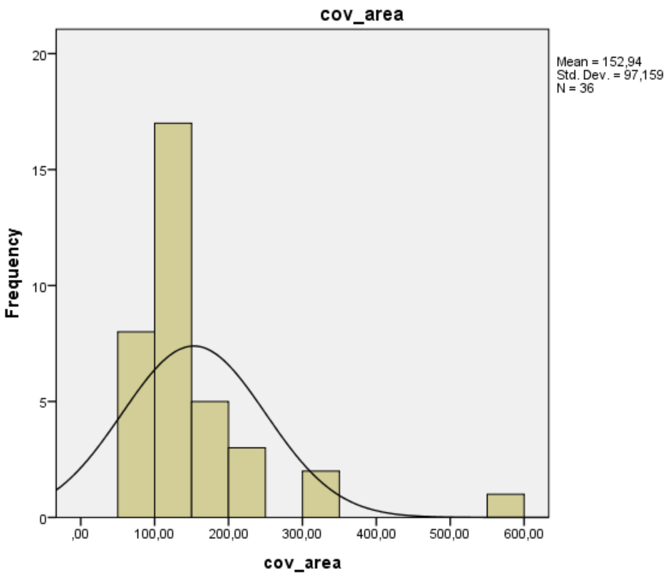


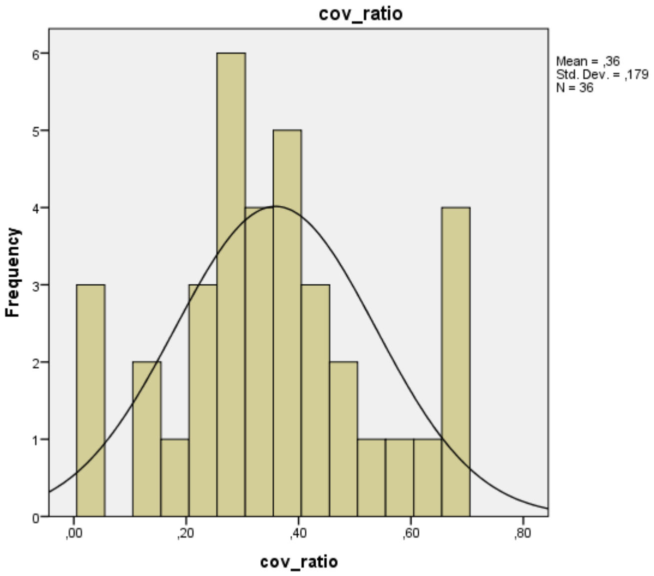

cost_m2
Mean = 939,70
Std. Dev. = 168,629
N = 36
Frequency
0
5
10
15
20
800,00
1000,00
1200,00
1400,00
cost_m2

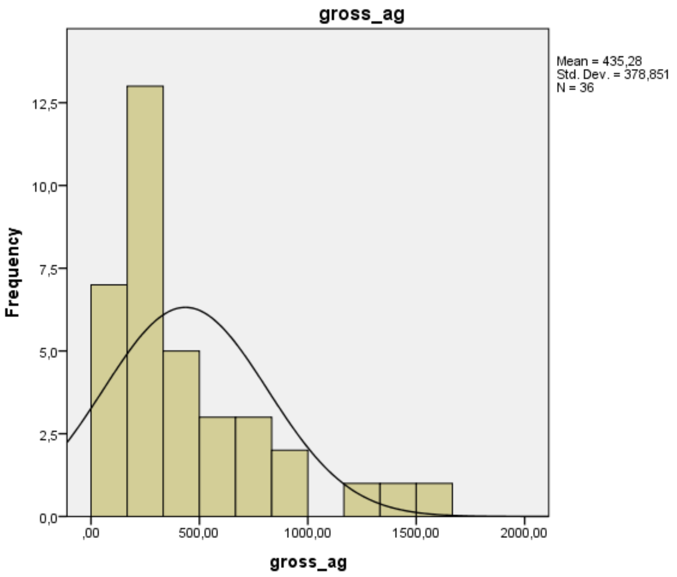

cost_m3
Mean = 280,93
Std. Dev. = 58,153
N = 36
Frequency
0
2
4
6
8
10
150,00
200,00
250,00
300,00
350,00
400,00
450,00
cost_m3

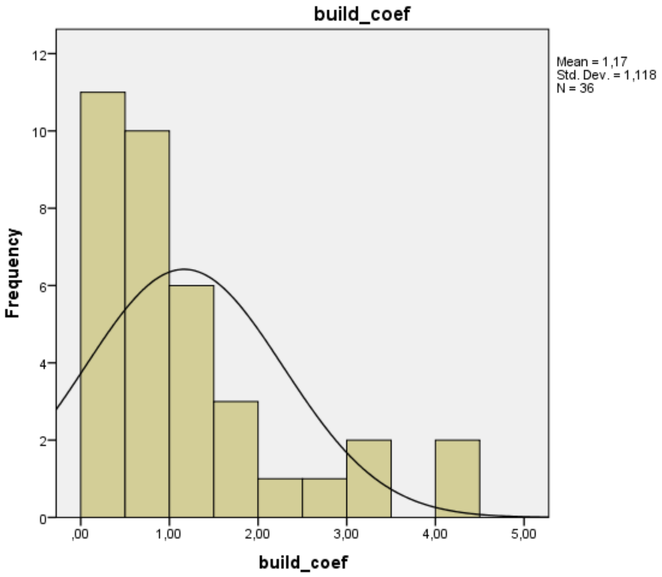

cost_day
Mean = 1153,59
Std. Dev. = 590,753
N = 36
Frequency
0
2
4
6
8
10
12
500,00
1000,00
1500,00
2000,00
2500,00
3000,00
3500,00
cost_day

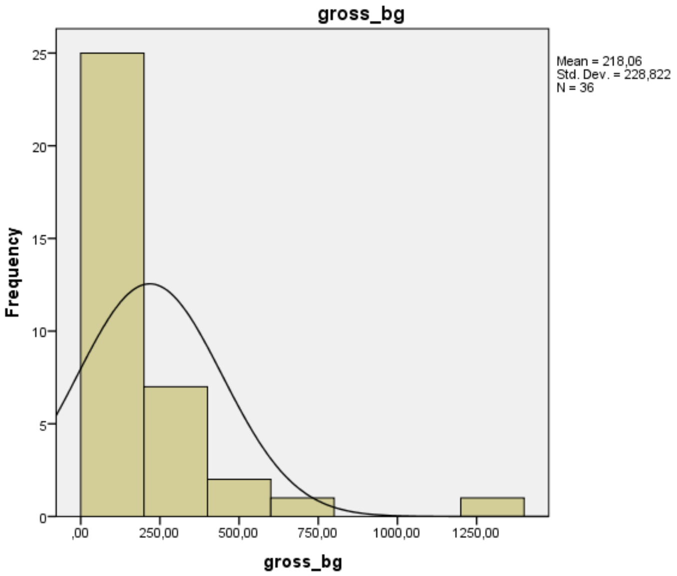

plot_area
Mean = 782,59
Std. Dev. = 1170,554
N = 36
Frequency
25
20
15
10
5
0
,00
1000,00
2000,00
3000,00
4000,00
5000,00
plot_area

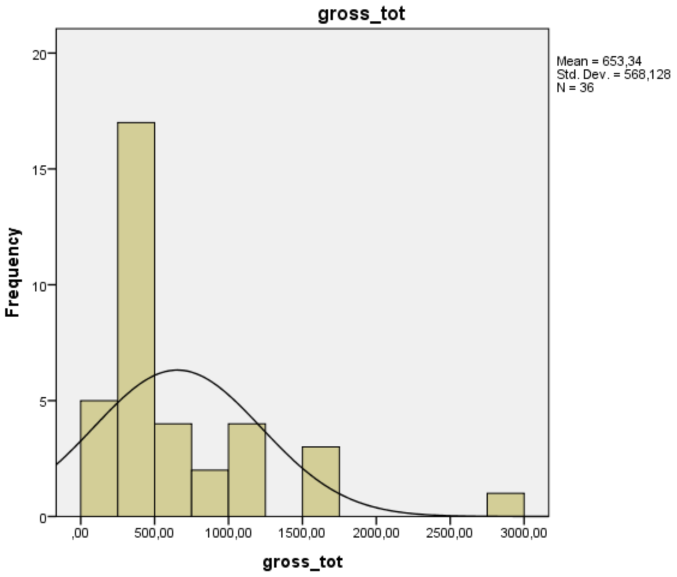

cov_area
Mean = 152,94
Std. Dev. = 97,159
N = 36
Frequency
20
15
10
5
0
,00
100,00
200,00
300,00
400,00
500,00
600,00
cov_area

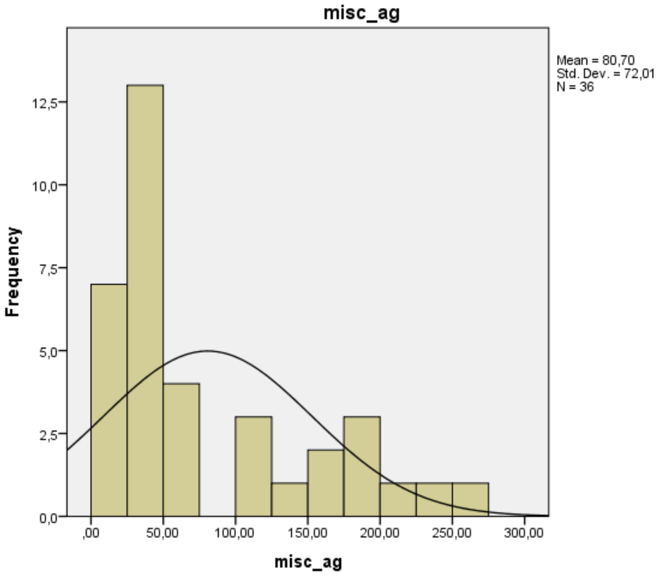

cov_ratio
Mean = ,36
Std. Dev. = ,179
N = 36
Frequency
6
5
4
3
2
1
0
,00
,20
,40
,60
,80
cov_ratio

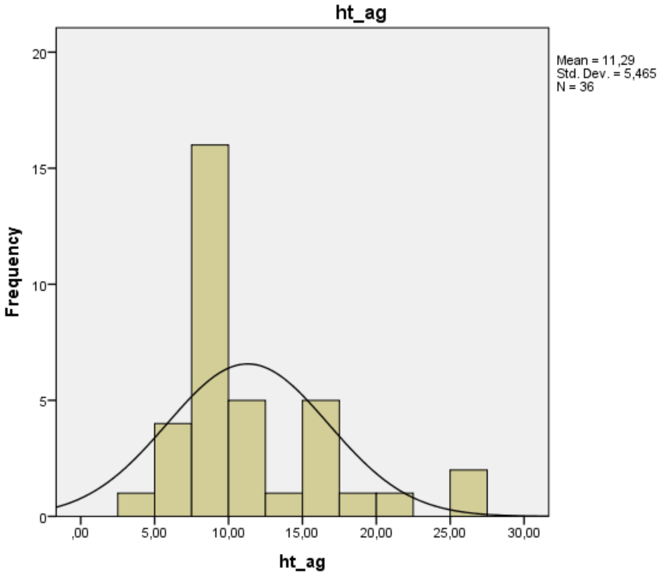

gross_ag
Mean = 435,28
Std. Dev. = 378,851
N = 36
Frequency
12,5
10,0
7,5
5,0
2,5
0,0
,00
500,00
1000,00
1500,00
2000,00
gross_ag

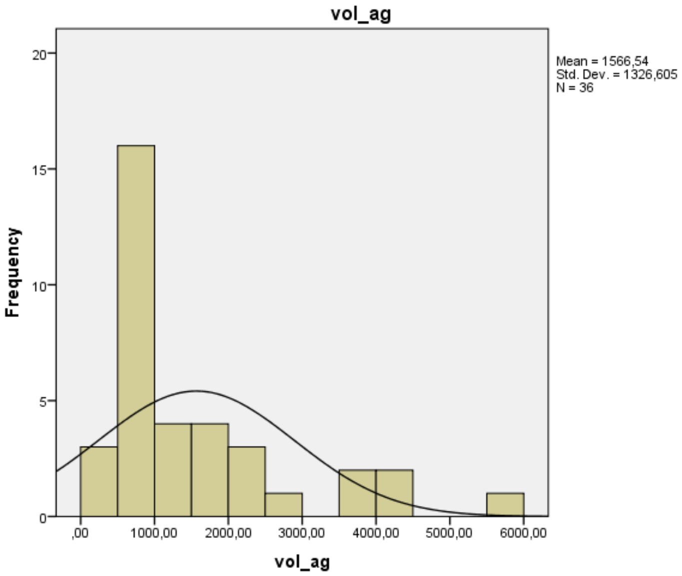

build_coef
Mean = 1,17
Std. Dev. = 1,118
N = 36
Frequency
12
10
8
6
4
2
0
,00
1,00
2,00
3,00
4,00
5,00
build_coef

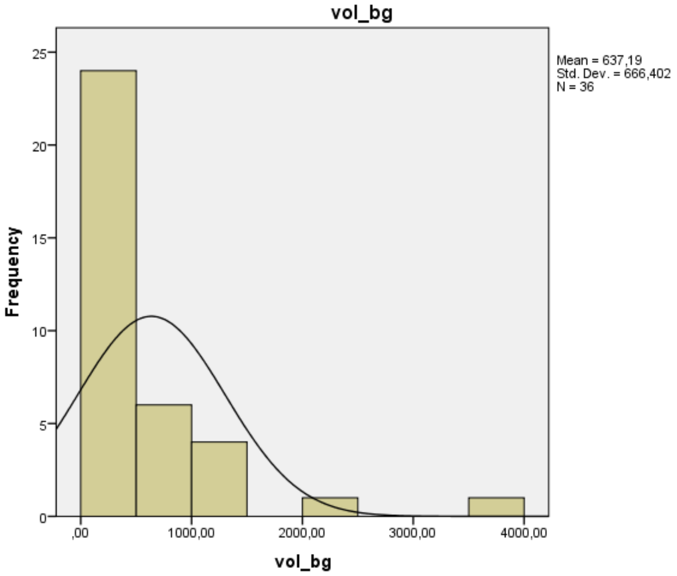

gross_bg
Mean = 218,06
Std. Dev. = 228,822
N = 36
Frequency
25
20
15
10
5
0
,00
250,00
500,00
750,00
1000,00
1250,00
gross_bg

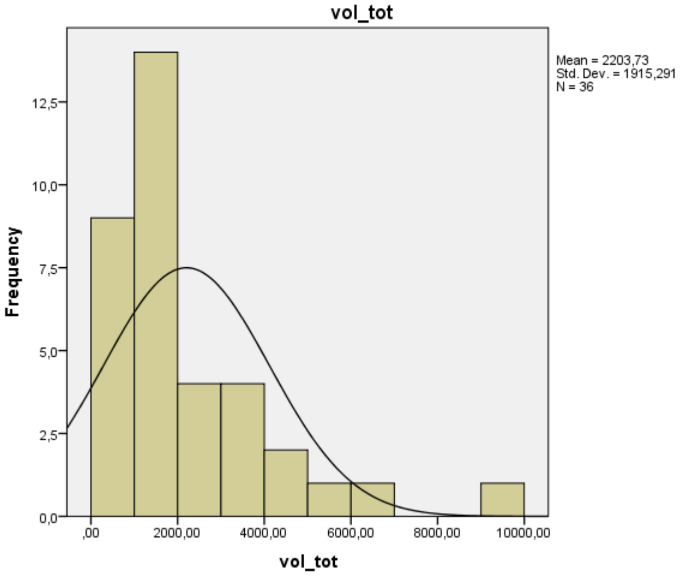

gross_tot
Mean = 653,34
Std. Dev. = 568,128
N = 36
Frequency
0
5
10
15
20
,00
500,00
1000,00
1500,00
2000,00
2500,00
3000,00
gross_tot

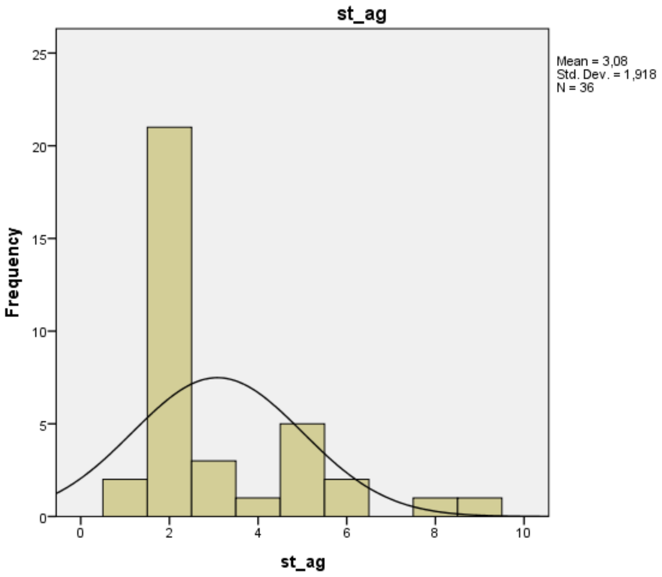

misc_ag
Mean = 80,70
Std. Dev. = 72,01
N = 36
Frequency
0,0
2,5
5,0
7,5
10,0
12,5
,00
50,00
100,00
150,00
200,00
250,00
300,00
misc_ag

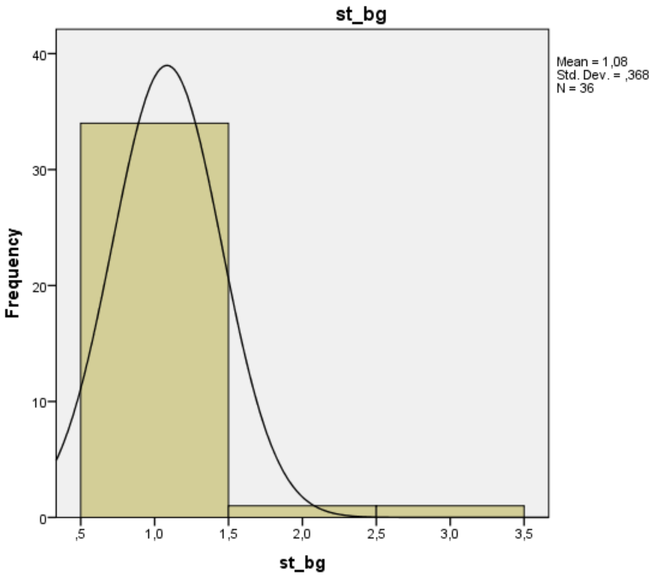

ht_ag
Mean = 11,29
Std. Dev. = 5,465
N = 36
Frequency
0
5
10
15
20
,00
5,00
10,00
15,00
20,00
25,00
30,00
ht_ag

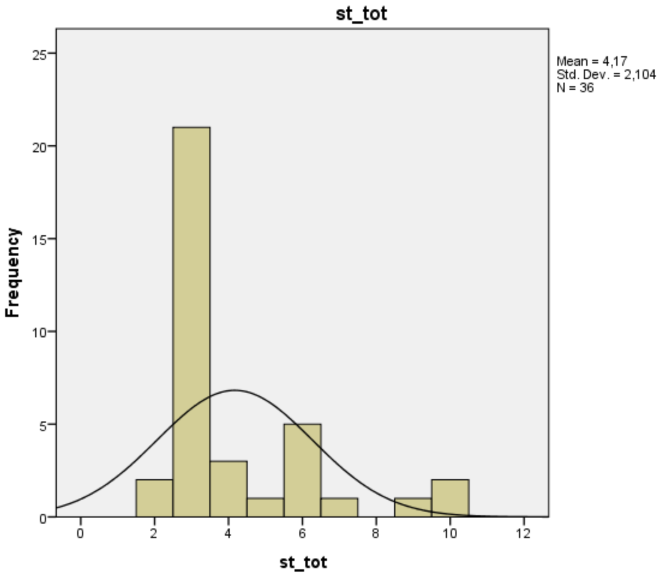

vol_ag
Mean = 1566,54
Std. Dev. = 1326,605
N = 36
Frequency
20
15
10
5
0
,00
1000,00
2000,00
3000,00
4000,00
5000,00
6000,00
vol_ag

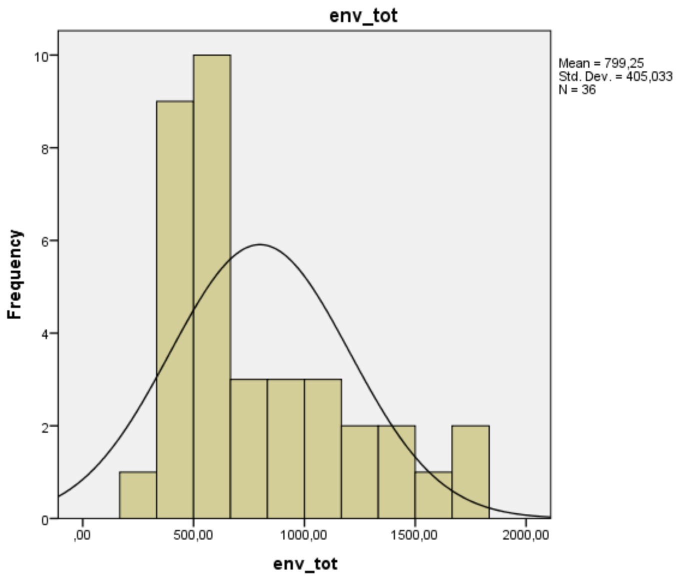

vol_bg
Mean = 637,19
Std. Dev. = 666,402
N = 36
Frequency
25
20
15
10
5
0
,00
1000,00
2000,00
3000,00
4000,00
vol_bg


vol_tot
Mean = 2203,73
Std. Dev. = 1915,291
N = 36
Frequency
12,5
10,0
7,5
5,0
2,5
0,0
,00
2000,00
4000,00
6000,00
8000,00
10000,00
vol_tot


st_ag
Mean = 3,08
Std. Dev. = 1,918
N = 36
Frequency
0
5
10
15
20
25
0
2
4
6
8
10
st_ag


st_bg
Mean = 1,08
Std. Dev. = ,368
N = 36
Frequency
0
10
20
30
40
,5
1,0
1,5
2,0
2,5
3,0
3,5
st_bg


st_tot
Mean = 4,17
Std. Dev. = 2,104
N = 36
Frequency
0
5
10
15
20
25
0
2
4
6
8
10
12
st_tot



The building *morphology* significant design parameters which are used in Subsection 4.2.2 (page 225) to calculate the *design complexity coefficients* were also derived from the collected data of the sample projects and are described as follows:

F ground floor plan area (m^2) = coverage ratio area (cov_area)

P perimeter (m) of ground floor plan area (F)

V total volume (m^3) of building (vol_tot)

G sum of perimeters (m) of floor plans divided by total no. of storeys, where:

$$G = (\text{per\_tot}) : (\text{st\_tot}) \qquad (4.1)$$

R total gross floor area (m^2) divided by total no. of storeys, where:

$$R = (\text{gross\_tot}) : (\text{st\_tot}) \qquad (4.2)$$

W external envelope (wall) area (m^2) for perimeter (P), including doors, windows etc. and assuming an equal ground floor height of h = 3,50m for all projects, where:

$$W = (P * h) \qquad (4.3)$$

H total height of building (m)

The calculated values of these parameters and the floor plan shapes of sample projects can also be seen in Appendix (B) where the complete sample data set is presented.

4.2.2 Building Morphology Complexity

4.2.2.1 Coefficients of Building Geometry

The design parameters as described in the literature review (Subsection 2.5.3.2, pages 82-83) are used to calculate the following coefficients of *building shape complexity*:

WF *Wall to Floor* area ratio (Seeley, 1996):

$$WF = (P * h) : (cov\_area) \tag{4.4}$$

JCSE J. Cook's *Shape Effectiveness* index (Ferry *et al.*, 1999):

$$JCSE = [P : (4 * \sqrt{F})] - 1 \tag{4.5}$$

POP *Plan Compactness* or *Perimeter over Plan* (POP) ratio (Strathclyde University) (Ashworth, 2004):

$$POP = [2 * \sqrt{(\pi * F)}] : P \tag{4.6}$$

VOLM *Mass Compactness* or VOLM ratio (Strathclyde University) (Ashworth, 2004):

$$VOLM = \{2 * [(3V : 2\pi)^{1/3}]^2\} : F \tag{4.7}$$

LBI *Length/Breadth* index (Banks, 1974):

$$LBI = [P + \sqrt{(P^2 - 16F)}] : [P - \sqrt{(P^2 - 16F)}] \tag{4.8}$$

PSI *Plan/Shape* index (Banks, 1974):

$$PSI = [G + \sqrt{(G^2 - 16R)}] : [G - \sqrt{(G^2 - 16R)}] \tag{4.9}$$

m *Building Planning* ‘m’ index (in Zima and Plebankiewicz, 2012):

$$m = P : \sqrt{F} \tag{4.10}$$

Tables 4.2 and 4.3 (page 226) show descriptive statistics and results from calculations for the seven (7) building geometry indices of the thirty six (36) projects. **Bold** figures indicate projects that meet the optimal values for the building morphology coefficients. It can be seen that only **seven (7)** out of 252 coefficient calculations and **five (5)** out of the 36 building projects are within the acceptable limits (optimal values in parentheses).

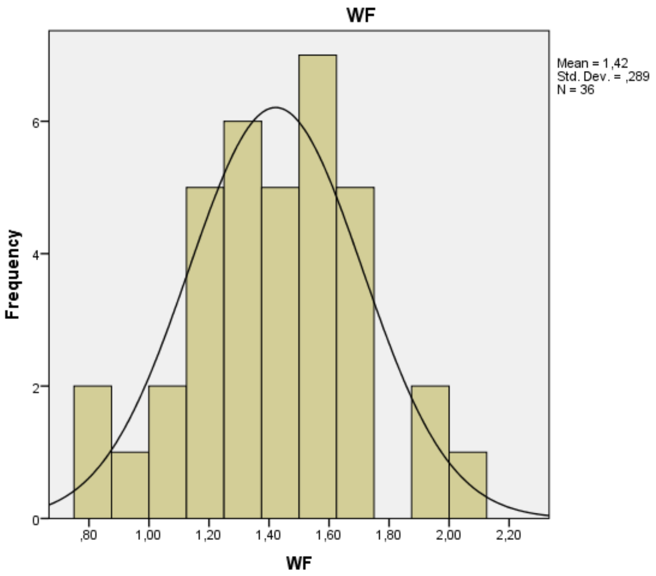
Table 4.2 Building Morphology Coefficients for the Sample of Building Projects (*n* = 36)

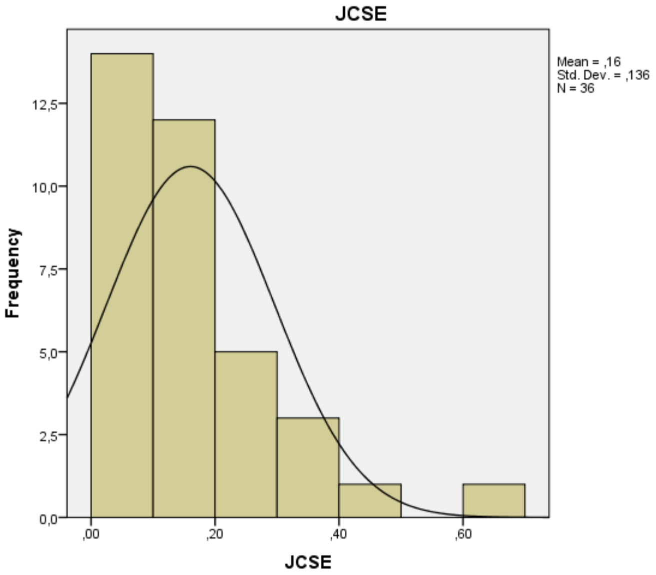
No.	F	P	V	G	R	W	H	W/F	JCSE	POP	VOLM	LBI	PSI	m
								(<1)	(0)	(1)	(3,84)	(1)	(1)	(4)
1	158,06	54,70	1424,33	51,97	144,39	191,45	12,10	1,21	0,09	0,81	0,98	2,30	2,23	4,35
2	67,47	36,27	683,28	36,27	67,47	126,95	12,90	1,88	0,10	0,80	1,40	2,47	2,47	4,42
3	100,71	47,75	857,59	45,42	95,86	167,13	9,60	1,66	0,19	0,75	1,10	3,36	3,05	4,76
4	123,20	47,69	1476,78	47,69	123,20	166,92	13,35	1,35	0,07	0,83	1,29	2,15	2,15	4,30
5	144,80	68,25	1062,04	68,25	144,80	238,88	7,00	1,65	0,42	0,63	0,88	5,87	5,87	5,67
6	89,93	41,80	728,58	38,00	75,56	146,30	10,30	1,63	0,10	0,80	1,10	2,45	2,35	4,41
7	123,39	51,00	1319,98	48,37	120,15	178,50	12,00	1,45	0,15	0,77	1,19	2,93	2,46	4,59
8	74,02	37,00	849,15	39,53	88,75	129,50	10,80	1,75	0,08	0,82	1,48	2,16	1,87	4,30
9	237,83	76,20	3243,37	77,91	261,44	266,70	15,30	1,12	0,24	0,72	1,13	3,84	3,52	4,94
10	91,45	40,90	1063,88	44,37	109,91	143,15	11,40	1,57	0,07	0,83	1,39	2,10	1,97	4,28
11	199,86	71,60	1236,19	60,90	161,39	250,60	8,00	1,25	0,27	0,70	0,70	4,17	3,46	5,06
12	187,87	61,25	2297,08	67,48	221,51	214,38	12,30	1,14	0,12	0,79	1,13	2,61	2,78	4,47
13	84,18	36,70	974,35	38,75	94,62	128,45	14,00	1,53	**0,00**	0,89	1,43	**1,01**	N/A	**4,00**
14	131,27	49,10	1665,09	55,97	166,43	171,85	12,00	1,31	0,07	0,83	1,31	2,12	2,26	4,29
15	130,16	55,05	1100,52	54,60	123,16	192,68	11,00	1,48	0,21	0,73	1,00	3,54	3,79	4,83
16	53,22	29,38	463,01	29,38	53,22	102,83	9,70	1,93	0,01	0,88	1,37	1,26	1,26	**4,03**
17	102,65	47,50	975,18	46,17	100,32	166,25	10,50	1,62	0,17	0,76	1,17	3,18	2,98	4,69
18	76,59	37,30	861,63	37,30	76,59	130,55	12,00	1,70	0,07	0,83	1,44	2,05	2,05	4,26
19	157,57	55,33	5071,23	56,90	164,25	193,66	30,40	1,23	0,10	0,80	2,29	2,45	2,53	4,41
20	127,40	74,78	1390,78	80,16	143,07	261,73	11,70	2,05	0,66	0,54	1,19	8,86	9,12	6,63
21	133,73	60,97	1224,24	60,97	133,73	213,40	10,50	1,60	0,32	0,67	1,05	4,74	4,74	5,27
22	100,20	45,83	913,81	45,83	96,67	160,41	10,50	1,60	0,14	0,77	1,15	2,90	3,11	4,58
23	217,51	79,47	4629,48	78,70	220,45	278,15	21,00	1,28	0,35	0,66	1,56	5,06	4,82	5,39
24	101,76	43,60	1024,94	42,40	96,79	152,60	11,80	1,50	0,08	0,82	1,22	2,22	2,19	4,32
25	151,87	53,70	2224,33	53,13	148,88	187,95	14,80	1,24	0,09	0,81	1,37	2,32	2,31	4,36
26	147,55	60,20	1466,74	60,20	136,76	210,70	10,30	1,43	0,24	0,72	1,07	3,88	4,40	4,96
27	310,49	72,57	9501,95	73,21	321,76	254,00	24,80	**0,82**	0,03	0,86	1,77	1,63	1,50	4,12
28	138,15	49,52	4750,00	49,60	146,13	173,32	29,80	1,25	0,05	0,84	2,50	1,92	1,57	4,21
29	338,87	94,84	3415,32	88,52	301,21	331,94	11,40	**0,98**	0,29	0,69	0,82	4,41	4,27	5,15
30	589,11	133,73	6466,31	120,70	531,01	468,06	11,10	**0,79**	0,38	0,64	0,72	5,40	4,64	5,51
31	103,78	47,77	1893,01	47,77	103,78	167,20	17,90	1,61	0,17	0,76	1,80	3,18	3,18	4,69
32	94,52	43,47	1179,11	43,47	94,52	152,15	14,50	1,61	0,12	0,79	1,44	2,62	2,62	4,47
33	204,37	64,30	3905,92	65,37	219,86	225,05	19,20	1,10	0,12	0,79	1,48	2,69	2,45	4,50
34	134,43	53,50	2536,15	53,53	140,28	187,25	19,20	1,39	0,15	0,77	1,69	2,99	2,74	4,61
35	133,36	48,20	2317,98	48,20	133,36	168,70	18,80	1,26	0,04	0,85	1,60	1,80	1,80	4,17
36	139,77	48,50	3201,65	53,40	175,32	169,75	19,00	1,21	0,03	0,86	1,90	1,57	1,29	4,10

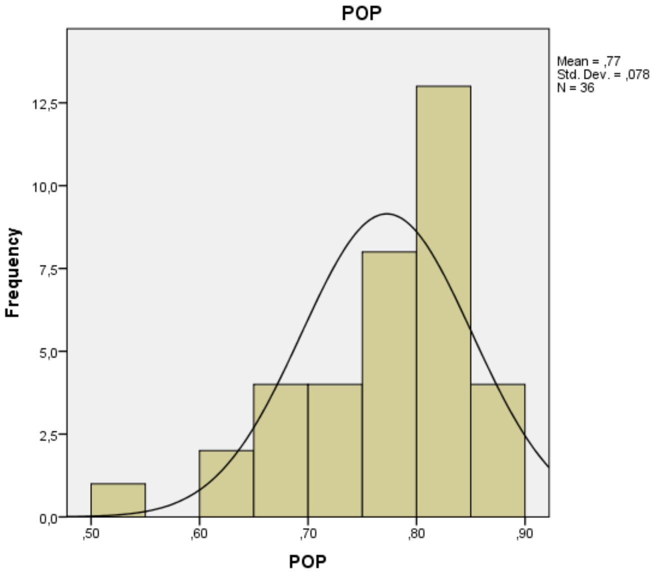
Table 4.3 Descriptive Statistics for Building Morphology Coefficients

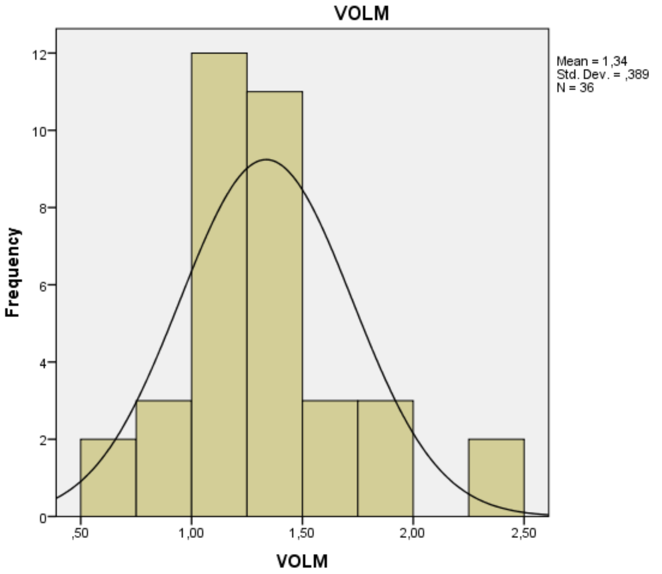
	N	Range	Min	Max	Mean	Std. Dev.	Variance	Skewness		Kurtosis	
	Stat	Stat	Stat	Stat	Stat	Stat	Stat	Stat	S.E.	Stat	S.E.
WF	36	1,26	0,79	2,05	1,42	0,29	0,08	-0,10	0,39	-0,05	0,77
JCSE	36	0,66	0,00	0,66	0,16	0,14	0,02	1,74	0,39	3,96	0,77
POP	36	0,35	0,54	0,89	0,77	0,08	0,01	-1,04	0,39	1,07	0,77
VOLM	36	1,79	0,70	2,50	1,34	0,39	0,15	1,01	0,39	1,68	0,77
LBI	36	7,86	1,01	8,86	3,06	1,52	2,32	1,86	0,39	4,93	0,77
PSI	35	7,86	1,26	9,12	3,02	1,52	2,33	2,14	0,39	6,55	0,77
m	36	2,63	4,00	6,63	4,64	0,54	0,29	1,74	0,39	3,96	0,77

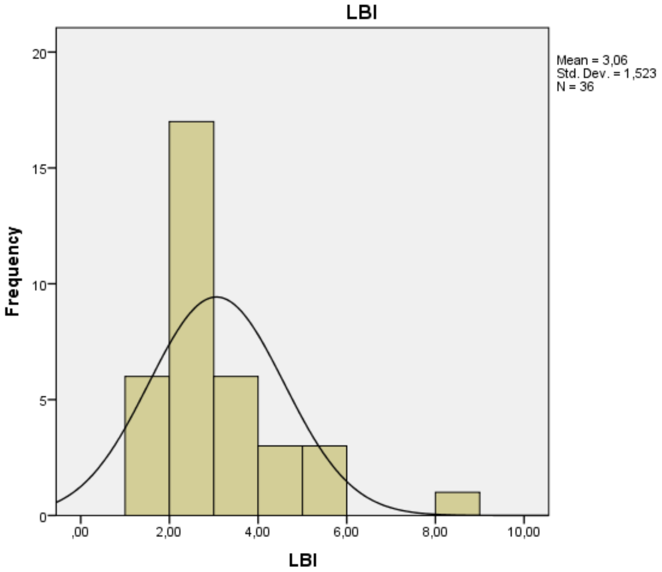
The frequency histograms (with Normal Curve) for the seven (7) building morphology indices of Table 4.3 are the following:

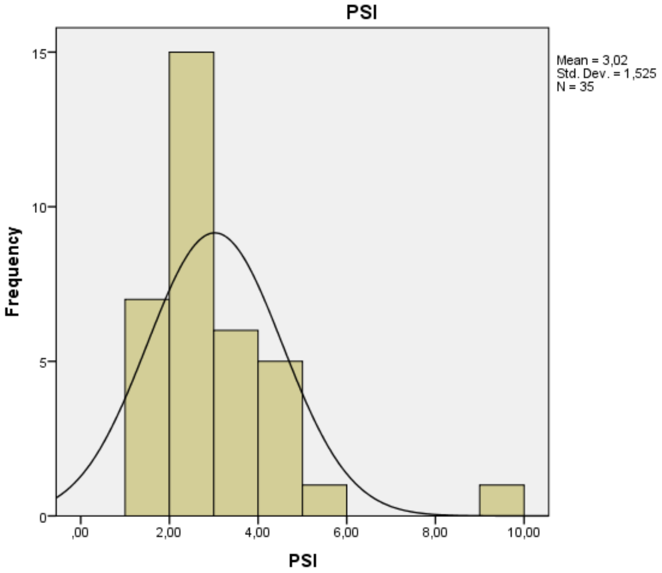

WF
Mean = 1,42
Std. Dev. = ,289
N = 36
Frequency
0
2
4
6
,80
1,00
1,20
1,40
1,60
1,80
2,00
2,20
WF

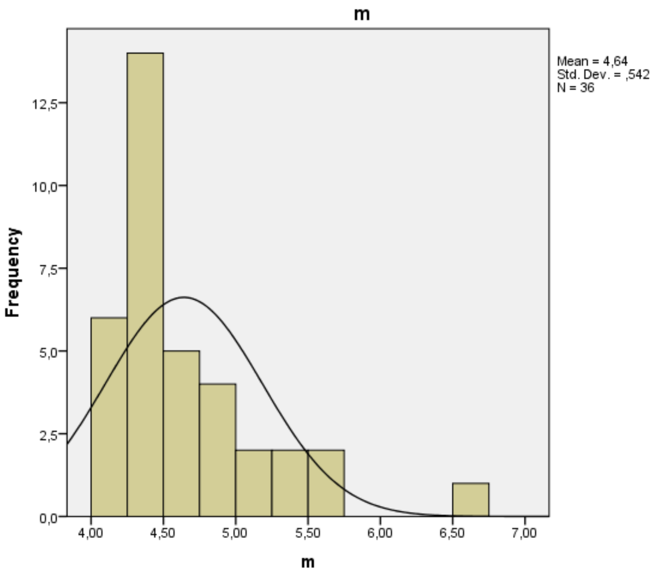

JCSE
Mean = ,16
Std. Dev. = ,136
N = 36
Frequency
0,0
2,5
5,0
7,5
10,0
12,5
,00
,20
,40
,60
JCSE


POP
Mean = ,77
Std. Dev. = ,078
N = 36
Frequency
0,0
2,5
5,0
7,5
10,0
12,5
,50
,60
,70
,80
,90
POP


VOLM
Mean = 1,34
Std. Dev. = ,389
N = 36
Frequency
0
2
4
6
8
10
12
,50
1,00
1,50
2,00
2,50
VOLM


LBI
Mean = 3,06
Std. Dev. = 1,523
N = 36
Frequency
0
5
10
15
20
,00
2,00
4,00
6,00
8,00
10,00
LBI


PSI
Mean = 3,02
Std. Dev. = 1,525
N = 35
Frequency
0
5
10
15
,00
2,00
4,00
6,00
8,00
10,00
PSI



4.2.2.2 Design Complexity *vs.* Project Cost and Time

The correlations between project total cost (cost_tot) and complexity coefficients (WF, JCSE, POP, VOLM, LBI, PSI and m) are presented in the correlation matrix of Table 4.4. It appears that WF and VOLM indices are significantly correlated at the 0.01 level (2-tailed).

Table 4.4 Correlations between Total Cost and Building Morphology Coefficients

		cost_tot	WF	JCSE	POP	VOLM	LBI	PSI	m
cost_tot	Pearson Correlation	1	**-,716****	-,025	,026	**,463****	-,028	-,088	-,025
	Sig. (2-tailed)		,000	,885	,881	,004	,873	,614	,885
	N	36	36	36	36	36	36	35	36
WF	Pearson Correlation	-,716**	1	,116	-,069	-,042	,126	,205	,116
	Sig. (2-tailed)	,000		,500	,687	,810	,463	,237	,500
	N	36	36	36	36	36	36	35	36
JCSE	Pearson Correlation	-,025	,116	1	-,988**	-,464**	,999**	,982**	1,000**
	Sig. (2-tailed)	,885	,500		,000	,004	,000	,000	,000
	N	36	36	36	36	36	36	35	36
POP	Pearson Correlation	,026	-,069	-,988**	1	,502**	-,984**	-,961**	-,988**
	Sig. (2-tailed)	,881	,687	,000		,002	,000	,000	,000
	N	36	36	36	36	36	36	35	36
VOLM	Pearson Correlation	,463**	-,042	-,464**	,502**	1	-,449**	-,436**	-,464**
	Sig. (2-tailed)	,004	,810	,004	,002		,006	,009	,004
	N	36	36	36	36	36	36	35	36
LBI	Pearson Correlation	-,028	,126	,999**	-,984**	-,449**	1	,986**	,999**
	Sig. (2-tailed)	,873	,463	,000	,000	,006		,000	,000
	N	36	36	36	36	36	36	35	36
PSI	Pearson Correlation	-,088	,205	,982**	-,961**	-,436**	,986**	1	,982**
	Sig. (2-tailed)	,614	,237	,000	,000	,009	,000		,000
	N	35	35	35	35	35	35	35	35
m	Pearson Correlation	-,025	,116	1,000**	-,988**	-,464**	,999**	,982**	1
	Sig. (2-tailed)	,885	,500	,000	,000	,004	,000	,000	
	N	36	36	36	36	36	36	35	36

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4.5 shows the correlations of building morphology indices with project total duration (dur_tot). The same indices, WF and VOLM, are significantly correlated at the 0.01 and 0.05 levels (2-tailed) respectively (in **bold** figures).

Table 4.5 Correlations between Total Duration and Building Morphology Coefficients

		dur_tot	WF	JCSE	POP	VOLM	LBI	PSI	m
dur_tot	Pearson Correlation	1	**-,768****	-,040	,029	**,362***	-,042	-,110	-,040
	Sig. (2-tailed)		,000	,815	,865	,030	,806	,531	,815
	N	36	36	36	36	36	36	35	36
WF	Pearson Correlation	-,768**	1	,116	-,069	-,042	,126	,205	,116
	Sig. (2-tailed)	,000		,500	,687	,810	,463	,237	,500
	N	36	36	36	36	36	36	35	36
JCSE	Pearson Correlation	-,040	,116	1	-,988**	-,464**	,999**	,982**	1,000**
	Sig. (2-tailed)	,815	,500		,000	,004	,000	,000	,000
	N	36	36	36	36	36	36	35	36
POP	Pearson Correlation	,029	-,069	-,988**	1	,502**	-,984**	-,961**	-,988**
	Sig. (2-tailed)	,865	,687	,000		,002	,000	,000	,000
	N	36	36	36	36	36	36	35	36
VOLM	Pearson Correlation	,362*	-,042	-,464**	,502**	1	-,449**	-,436**	-,464**
	Sig. (2-tailed)	,030	,810	,004	,002		,006	,009	,004
	N	36	36	36	36	36	36	35	36
LBI	Pearson Correlation	-,042	,126	,999**	-,984**	-,449**	1	,986**	,999**
	Sig. (2-tailed)	,806	,463	,000	,000	,006		,000	,000
	N	36	36	36	36	36	36	35	36
PSI	Pearson Correlation	-,110	,205	,982**	-,961**	-,436**	,986**	1	,982**
	Sig. (2-tailed)	,531	,237	,000	,000	,009	,000		,000
	N	35	35	35	35	35	35	35	35
m	Pearson Correlation	-,040	,116	1,000**	-,988**	-,464**	,999**	,982**	1
	Sig. (2-tailed)	,815	,500	,000	,000	,004	,000	,000	
	N	36	36	36	36	36	36	35	36

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

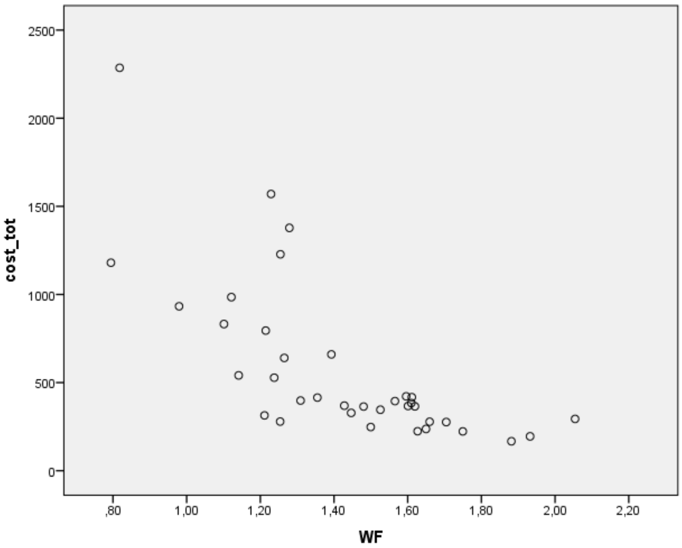


Fig. 4.1 Relationship between Total Cost and WF ratio

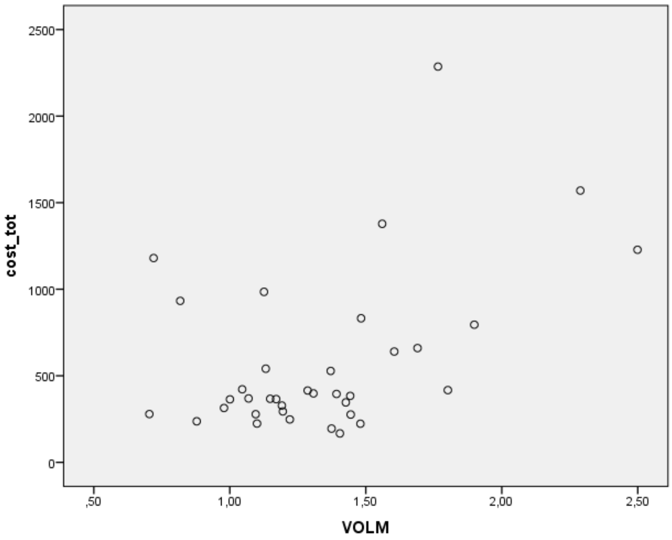


Fig. 4.2 Relationship between Total Cost and VOLM ratio

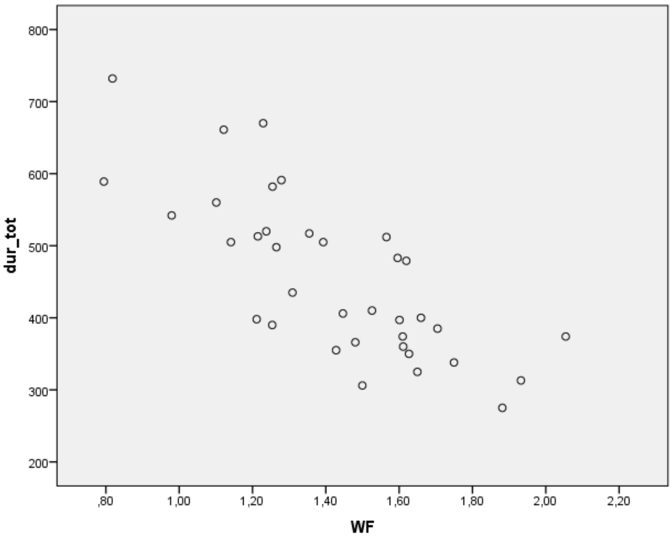


Fig. 4.3 Relationship between Total Duration and WF ratio

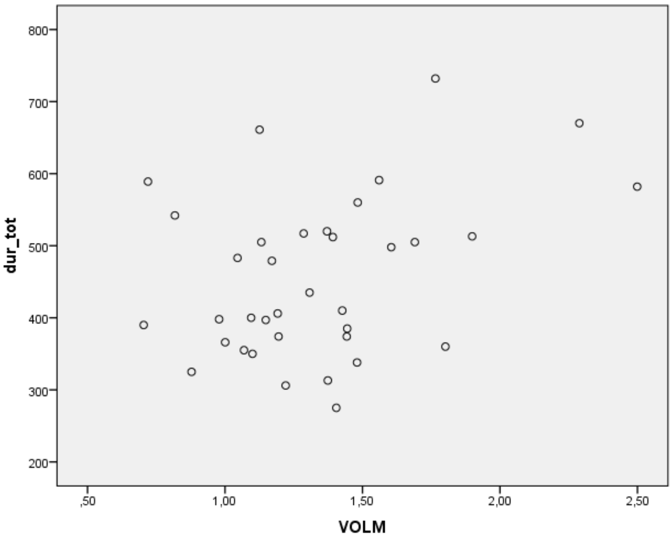


Fig. 4.4 Relationship between Total Duration and VOLM ratio

Figures 4.1 (page 230) and 4.2 (page 231) illustrate the scatter graphs for (cost_tot), WF and VOLM and Figures 4.3 and 4.4 (page 231) present the scatter plots for (dur_tot), WF and VOLM. Therefore, WF and VOLM could be used as potential regression predictors. The correlations between each one of the other three (3) output variables, namely project cost per m^2 (cost_m2), project cost per m^3 (cost_m3) and project cost per day (cost_day), and complexity coefficients (WF, JCSE, POP, VOLM, LBI, PSI and m) are presented in the correlation matrices of Tables 4.6, 4.7 and 4.8.

Table 4.6 Correlations between Cost per m^2 and Building Morphology Coefficients

		cost_m2	WF	JCSE	POP	VOLM	LBI	PSI	m
cost_m2	Pearson Correlation	1	**,372***	-,154	,133	-,106	-,164	-,119	-,154
	Sig. (2-tailed)		,025	,369	,438	,540	,338	,495	,369
	N	36	36	36	36	36	36	35	36
WF	Pearson Correlation	,372*	1	,116	-,069	-,042	,126	,205	,116
	Sig. (2-tailed)	,025		,500	,687	,810	,463	,237	,500
	N	36	36	36	36	36	36	35	36
JCSE	Pearson Correlation	-,154	,116	1	-,988**	-,464**	,999**	,982**	1,000**
	Sig. (2-tailed)	,369	,500		,000	,004	,000	,000	,000
	N	36	36	36	36	36	36	35	36
POP	Pearson Correlation	,133	-,069	-,988**	1	,502**	-,984**	-,961**	-,988**
	Sig. (2-tailed)	,438	,687	,000		,002	,000	,000	,000
	N	36	36	36	36	36	36	35	36
VOLM	Pearson Correlation	-,106	-,042	-,464**	,502**	1	-,449**	-,436**	-,464**
	Sig. (2-tailed)	,540	,810	,004	,002		,006	,009	,004
	N	36	36	36	36	36	36	35	36
LBI	Pearson Correlation	-,164	,126	,999**	-,984**	-,449**	1	,986**	,999**
	Sig. (2-tailed)	,338	,463	,000	,000	,006		,000	,000
	N	36	36	36	36	36	36	35	36
PSI	Pearson Correlation	-,119	,205	,982**	-,961**	-,436**	,986**	1	,982**
	Sig. (2-tailed)	,495	,237	,000	,000	,009	,000		,000
	N	35	35	35	35	35	35	35	35
m	Pearson Correlation	-,154	,116	1,000**	-,988**	-,464**	,999**	,982**	1
	Sig. (2-tailed)	,369	,500	,000	,000	,004	,000	,000	
	N	36	36	36	36	36	36	35	36

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Again, WF and VOLM indices appear to be significantly correlated at the 0.05 level (2-tailed) and at the 0.01 level (2-tailed) (in **bold** figures). Figures 4.5, 4.6 and 4.7 (page 233) present the relevant scatter plot graphs. Therefore, WF and VOLM coefficients could be used as potential predictors in the regression analyses.

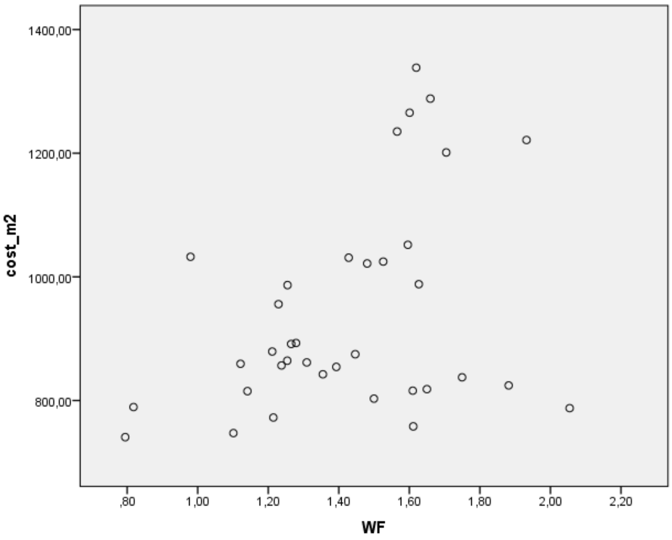


Fig. 4.5 Relationship between Cost per m^2 and WF ratio

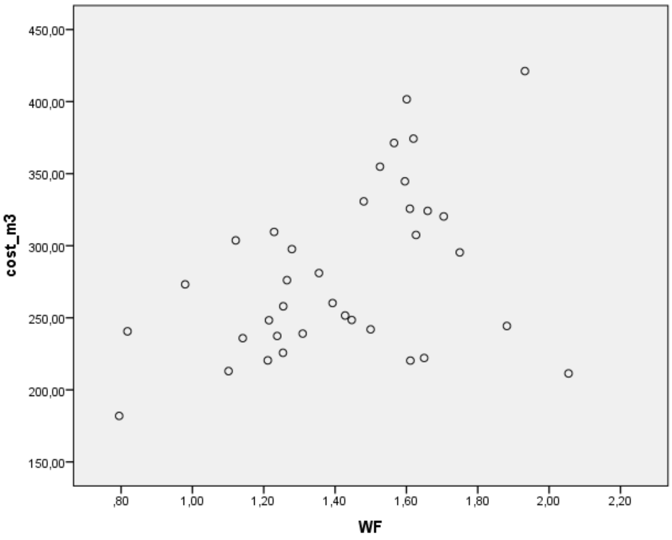


Fig. 4.6 Relationship between Cost per m^3 and WF ratio

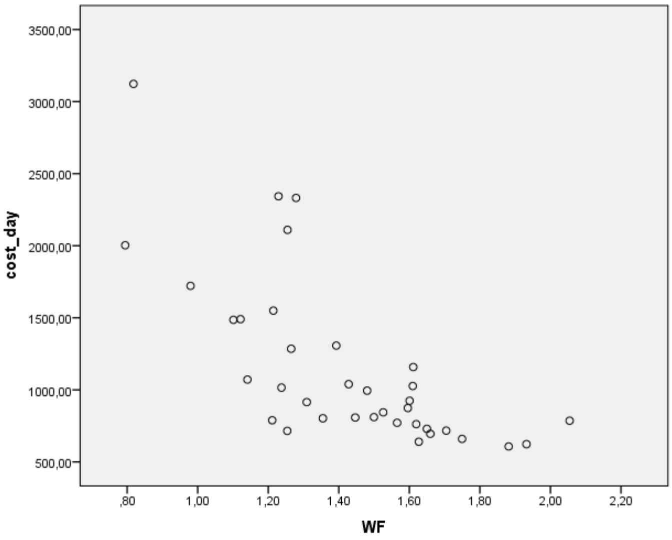


Fig. 4.7 Relationship between Cost per day and WF ratio

Table 4.7 Correlations between Cost per m^3 and Building Morphology Coefficients

		cost_m3	WF	JCSE	POP	VOLM	LBI	PSI	m
cost_m3	Pearson Correlation	1	,430**	-,294	,286	,047	-,307	-,231	-,294
	Sig. (2-tailed)		,009	,082	,091	,787	,068	,181	,082
	N	36	36	36	36	36	36	35	36
WF	Pearson Correlation	,430**	1	,116	-,069	-,042	,126	,205	,116
	Sig. (2-tailed)	,009		,500	,687	,810	,463	,237	,500
	N	36	36	36	36	36	36	35	36
JCSE	Pearson Correlation	-,294	,116	1	-,988**	-,464**	,999**	,982**	1,000**
	Sig. (2-tailed)	,082	,500		,000	,004	,000	,000	,000
	N	36	36	36	36	36	36	35	36
POP	Pearson Correlation	,286	-,069	-,988**	1	,502**	-,984**	-,961**	-,988**
	Sig. (2-tailed)	,091	,687	,000		,002	,000	,000	,000
	N	36	36	36	36	36	36	35	36
VOLM	Pearson Correlation	,047	-,042	-,464**	,502**	1	-,449**	-,436**	-,464**
	Sig. (2-tailed)	,787	,810	,004	,002		,006	,009	,004
	N	36	36	36	36	36	36	35	36
LBI	Pearson Correlation	-,307	,126	,999**	-,984**	-,449**	1	,986**	,999**
	Sig. (2-tailed)	,068	,463	,000	,000	,006		,000	,000
	N	36	36	36	36	36	36	35	36
PSI	Pearson Correlation	-,231	,205	,982**	-,961**	-,436**	,986**	1	,982**
	Sig. (2-tailed)	,181	,237	,000	,000	,009	,000		,000
	N	35	35	35	35	35	35	35	35
m	Pearson Correlation	-,294	,116	1,000**	-,988**	-,464**	,999**	,982**	1
	Sig. (2-tailed)	,082	,500	,000	,000	,004	,000	,000	
	N	36	36	36	36	36	36	35	36

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4.8 Correlations between Cost per day and Building Morphology Coefficients

		cost_day	WF	JCSE	POP	VOLM	LBI	PSI	m
cost_day	Pearson Correlation	1	-,714**	,006	-,008	,482**	,002	-,055	,006
	Sig. (2-tailed)		,000	,972	,962	,003	,990	,754	,972
	N	36	36	36	36	36	36	35	36
WF	Pearson Correlation	-,714**	1	,116	-,069	-,042	,126	,205	,116
	Sig. (2-tailed)	,000		,500	,687	,810	,463	,237	,500
	N	36	36	36	36	36	36	35	36
JCSE	Pearson Correlation	,006	,116	1	-,988**	-,464**	,999**	,982**	1,000**
	Sig. (2-tailed)	,972	,500		,000	,004	,000	,000	,000
	N	36	36	36	36	36	36	35	36
POP	Pearson Correlation	-,008	-,069	-,988**	1	,502**	-,984**	-,961**	-,988**
	Sig. (2-tailed)	,962	,687	,000		,002	,000	,000	,000
	N	36	36	36	36	36	36	35	36
VOLM	Pearson Correlation	,482**	-,042	-,464**	,502**	1	-,449**	-,436**	-,464**
	Sig. (2-tailed)	,003	,810	,004	,002		,006	,009	,004
	N	36	36	36	36	36	36	35	36
LBI	Pearson Correlation	,002	,126	,999**	-,984**	-,449**	1	,986**	,999**
	Sig. (2-tailed)	,990	,463	,000	,000	,006		,000	,000
	N	36	36	36	36	36	36	35	36
PSI	Pearson Correlation	-,055	,205	,982**	-,961**	-,436**	,986**	1	,982**
	Sig. (2-tailed)	,754	,237	,000	,000	,009	,000		,000
	N	35	35	35	35	35	35	35	35
m	Pearson Correlation	,006	,116	1,000**	-,988**	-,464**	,999**	,982**	1
	Sig. (2-tailed)	,972	,500	,000	,000	,004	,000	,000	
	N	36	36	36	36	36	36	35	36

**. Correlation is significant at the 0.01 level (2-tailed).

4.2.3 Parametric Building Project Cost and Time Prognostic Tools

Estimating based on statistical methods has the appeal of condensing historical records into useable form. Regression analysis is a powerful statistical technique for applications that seek to analyse industrial processes (Draper and Smith, 1998).

The first stage in developing a *multiple* linear regression forecasting model which best describes the data collected would be to find the one independent variable that explains most of the variation in the dependent variable. This is likely to be the variable which has the highest correlation with the dependent variable. A *simple* regression model is derived, by finding a straight line that ‘best fits’ the data. By examining the residuals, one can determine how well the regression line fits the data. A residual is the difference between the value predicted by the model (i.e. a point on the line) and the actual cost recorded in the data (one of the plotted points). Examining the residuals is in effect examining the model’s inaccuracy; the greater the residuals, the less accurate the regression model. The second stage in finding the best model is to determine the second independent variable that explains most of the variation in the dependent variable after taking account of the first variable. The process can be extended to include any number of variables until the best model possible is found, that is until the residuals are made as small as possible. However, the more variables included in the model, the greater is the amount of data required to construct the model. A rough guide is that the minimum number of past schemes required for model building is two or three times the number of variables included in the final model (McCaffer, 1975).

The technique is only applicable for the same type of buildings used in the analysis and not for other building types. It also enables the cost estimator to assess how accurate the estimate is, in numerical rather than subjective terms. Obviously, it is much quicker to calculate likely costs in this way rather than by approximate design, quantities and rates.

In practice, it is valuable to update the models periodically by including recent data and discarding the oldest data. The accuracy of the model is judged by the scatter of the residuals, the difference between the model's predicted cost and the actual cost. The scatter of these residuals can be examined in two ways: one is to plot them; the other way is to calculate the *coefficient of variation* (CV). The CV is expressed as a percentage of the standard deviation of the residuals divided by the mean cost of all schemes. A model with as small a CV as possible is desired. Nevertheless, the real test is how accurately does the model forecast cases that are not included in its own database. Experience indicates that the CV is increased by 25% to 50% when the derived model is applied to data outside its own database; that is a model with a CV of 10% will deteriorate to 15-20% when used on other cases of similar type (McCaffer, 1975).

4.2.3.1 The Relationship between Project Cost and Duration

SPSS is used to perform the regression analyses. The following scatter graph (Figure 4.8) for (cost_tot) and (dur_tot) shows the relationship between project total cost and duration. The results from regression analysis using SPSS are summarised in page 237:

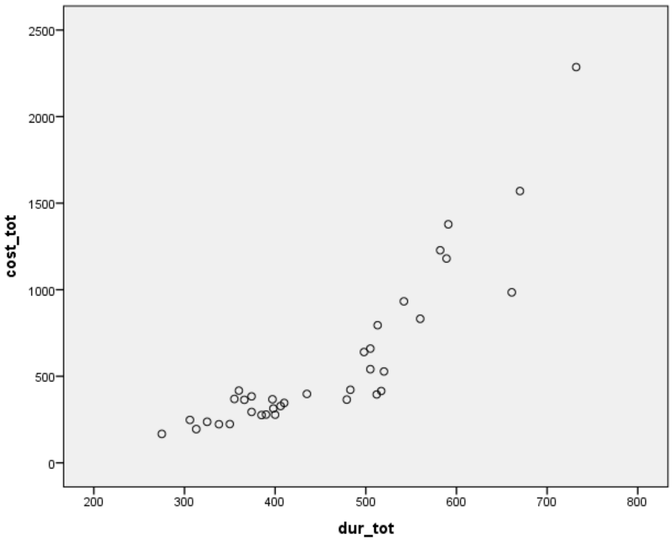


Fig. 4.8 Relationship between Total Cost and Total Duration

Correlations

		cost_tot	dur_tot
cost_tot	Pearson Correlation	1	**,879******
	Sig. (2-tailed)		,000
	N	36	36
dur_tot	Pearson Correlation	,879**	1
	Sig. (2-tailed)	,000	
	N	36	36

**. Correlation is significant at the 0.01 level (2-tailed).

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,879[a]	,773	,766	222,696

a. Predictors: (Constant), dur_tot

b. Dependent Variable: cost_tot

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5746818,799	1	5746818,799	115,878	,000[b]
	Residual	1686182,173	34	49593,593		
	Total	7433000,972	35			

a. Dependent Variable: cost_tot

b. Predictors: (Constant), dur_tot

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95,0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	-1069,529	157,619		-6,786	,000	-1389,848	-749,209
	dur_tot	3,616	,336	,879	10,765	,000	2,934	4,299

a. Dependent Variable: cost_tot

Regression Equation (1): **(cost_tot) = – 1069,529 + 3,616 * (dur_tot)** (4.11)

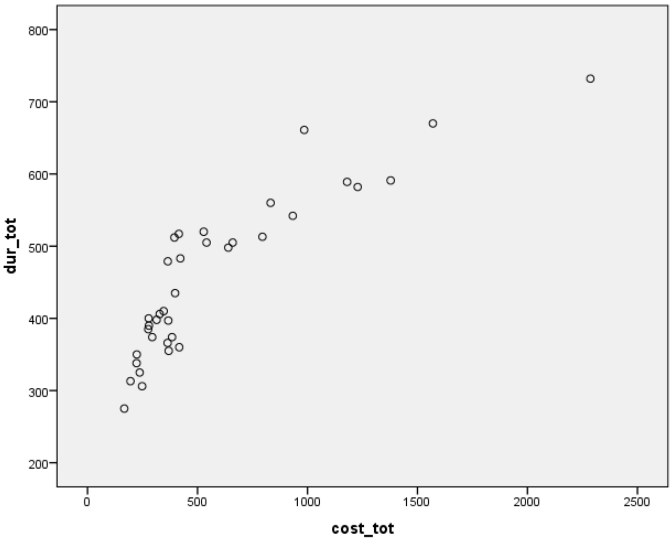


Fig. 4.9 Relationship between Total Duration and Total Cost

Figure 4.9 (page 237) describes the relationship between project total duration (dur_tot) and cost (cost_tot). SPSS regression analysis results are as follows:

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,879[a]	,773	,766	54,149

a. Predictors: (Constant), cost_tot
b. Dependent Variable: dur_tot

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	339765,057	1	339765,057	115,878	,000[b]
	Residual	99690,943	34	2932,087		
	Total	439456,000	35			

a. Dependent Variable: dur_tot
b. Predictors: (Constant), cost_tot

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			95,0% Confidence Interval for B	
		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound
1	(Constant)	332,109	14,625		22,708	,000	302,386	361,832
	cost_tot	,214	,020	,879	10,765	,000	,173	,254

a. Dependent Variable: dur_tot

Regression Equation (2): **(dur_tot) = 332,109 + 0,214 * (cost_tot)** (4.12)

4.2.3.2 Forecasting Models Construction

Output Variable: **(cost_tot)**

Predictors from Stepwise Regression Method: **(gross_tot)**; **(st_ag)**

SPSS regression analysis summary results:

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,986[a]	,971	,971	79,030
2	,988[b]	,976	,975	72,991

a. Predictors: (Constant), gross_tot
b. Predictors: (Constant), gross_tot, st_ag

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7220648,215	1	7220648,215	1156,105	,000[b]
	Residual	212352,757	34	6245,669		
	Total	7433000,972	35			
2	Regression	7257188,069	2	3628594,034	681,085	,000[c]
	Residual	175812,903	33	5327,664		
	Total	7433000,972	35			

a. Dependent Variable: cost_tot
b. Predictors: (Constant), gross_tot
c. Predictors: (Constant), gross_tot, st_ag

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			95,0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	57,143	20,236		2,824	,008	16,019	98,267		
	gross_tot	,799	,024	,986	34,002	,000	,752	,847	1,000	1,000
2	(Constant)	20,778	23,283		,892	,379	-26,591	68,148		
	gross_tot	,746	,030	,920	25,055	,000	,686	,807	,532	1,880
	st_ag	23,101	8,821	,096	2,619	,013	5,155	41,048	,532	1,880

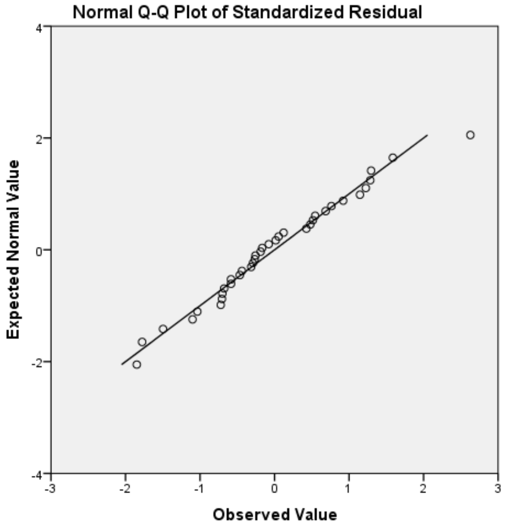
a. Dependent Variable: cost_tot

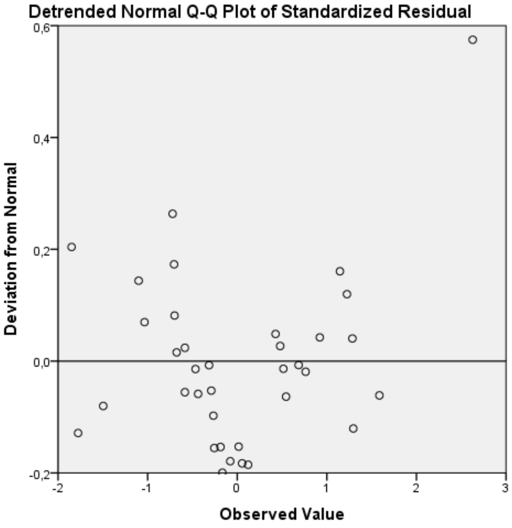
Regression Equation (3):

(cost_tot) = 20,778 + 0,746 * (gross_tot) + 23,101 * (st_ag) (4.13)

SPSS regression assumptions testing:

Linearity and Homoscedasticity:





Normality of Residuals:

Residuals Statistics[a]

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	186,11	2320,05	579,47	455,355	36
Residual	-134,959	191,812	,000	70,875	36
Std. Predicted Value	-,864	3,822	,000	1,000	36
Std. Residual	-1,849	2,628	,000	,971	36

a. Dependent Variable: cost_tot

One-Sample Kolmogorov-Smirnov Test

			Standardized Residual
N			36
Normal Parameters[a,b]	Mean		,0000000
	Std. Deviation		,97100831
Most Extreme Differences	Absolute		,096
	Positive		,096
	Negative		-,090
Test Statistic			,096
Asymp. Sig. (2-tailed)			,200[c,d]
Monte Carlo Sig. (2-tailed)	Sig.		,868[e]
	99% Confidence Interval	Lower Bound	,859
		Upper Bound	,877

a. Test distribution is Normal.

b. Calculated from data.

c. Lilliefors Significance Correction.

d. This is a lower bound of the true significance.

e. Based on 10000 sampled tables with starting seed 2000000.

Output Variable: **(dur_tot)**

Predictors from Stepwise Regression Method: **(gross_tot)**

SPSS regression analysis summary results:

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,852[a]	,726	,718	59,467

a. Predictors: (Constant), gross_tot

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	319221,863	1	319221,863	90,270	,000[b]
	Residual	120234,137	34	3536,298		
	Total	439456,000	35			

a. Dependent Variable: dur_tot

b. Predictors: (Constant), gross_tot

Coefficients[a]

		Unstandardized Coefficients		Standardized Coefficients			95,0% Confidence Interval for B		Collinearity Statistics	
Model		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	346,175	15,227		22,735	,000	315,231	377,119		
	gross_tot	,168	,018	,852	9,501	,000	,132	,204	1,000	1,000

a. Dependent Variable: dur_tot

Regression Equation (4):

(dur_tot) = 346,175 + 0,168 * (gross_tot) (4.14)

Output Variable: **(cost_m2)**

Predictors from Stepwise Regression Method: **(env_tot)**

SPSS regression analysis summary results:

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,405[a]	,164	,139	156,43619

a. Predictors: (Constant), env_tot

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	163190,157	1	163190,157	6,668	,014[b]
	Residual	832057,549	34	24472,281		
	Total	995247,705	35			

a. Dependent Variable: cost_m2

b. Predictors: (Constant), env_tot

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95,0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	1074,448	58,331		18,420	,000	955,906	1192,990		
	env_tot	-,169	,065	-,405	-2,582	,014	-,301	-,036	1,000	1,000

a. Dependent Variable: cost_m2

Regression Equation (5):

(cost_m2) = 1074,448 – 0,169 * (env_tot) (4.15)

Output Variable: **(cost_m3)**

Predictors from Stepwise Regression Method: **(cov_area)**

SPSS regression analysis summary results:

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,461[a]	,212	,189	52,37177

a. Predictors: (Constant), cov_area

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	25108,505	1	25108,505	9,154	,005[b]
	Residual	93255,264	34	2742,802		
	Total	118363,769	35			

a. Dependent Variable: cost_m3

b. Predictors: (Constant), cov_area

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95,0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	323,091	16,443		19,649	,000	289,675	356,507		
	cov_area	-,276	,091	-,461	-3,026	,005	-,461	-,091	1,000	1,000

a. Dependent Variable: cost_m3

Regression Equation (6):

(cost_m3) = 323,091 – 0,276 * (cov_area) (4.16)

Output Variable: **(cost_day)**

Predictors from Stepwise Regression Method: **(gross_tot)**; **(env_tot)**

SPSS summary regression analysis results:

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,971[a]	,943	,942	142,79161
2	,980[b]	,961	,958	120,53443

a. Predictors: (Constant), gross_tot

b. Predictors: (Constant), gross_tot, env_tot

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	11521375,235	1	11521375,235	565,066	,000[b]
	Residual	693241,083	34	20389,444		
	Total	12214616,318	35			
2	Regression	11735174,209	2	5867587,105	403,866	,000[c]
	Residual	479442,109	33	14528,549		
	Total	12214616,318	35			

a. Dependent Variable: cost_day

b. Predictors: (Constant), gross_tot

c. Predictors: (Constant), gross_tot, env_tot

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95,0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	493,792	36,562		13,506	,000	419,490	568,095		
	gross_tot	1,010	,042	,971	23,771	,000	,924	1,096	1,000	1,000
2	(Constant)	299,317	59,352		5,043	,000	178,565	420,068		
	gross_tot	,656	,099	,631	6,626	,000	,455	,857	,131	7,619
	env_tot	,533	,139	,365	3,836	,001	,250	,815	,131	7,619

a. Dependent Variable: cost_day

Regression Equation (7):

(cost_day) = 299,317 + 0,656 * (gross_tot) + 0,533 * (env_tot) (4.17)

4.3 Physical Construction Stage

In the construction industry, previous experience is mainly used to estimate building project duration and cost. Typically, a project is broken down into work packages or elements with required work activities to which resources are assigned and durations and costs can be estimated. The work packages or elements are linked together according to their precedence relationships to form the project network. Scheduling techniques are then used to analyse the network to identify critical path(s) and project duration and cost (Burns *et al*., 1996).

In this section an integrated linear programming mathematical modelling methodology is proposed for simulating the process of project physical construction. The developed *deterministic* model, which is founded on the *activity-on-node* (AoN) network analysis, incorporates the *activity-based costing* (ABC) methodology into the PERT/CPM *time-cost trade-off* (TCT) scheduling analysis for building projects. The proposed methodology generates *minimum*, *optimum* and *maximum* envelopes for project time-cost profiles based on different levels of activity resource consumption and time requirements (*normal* as opposed to *crashing*). After the verification of the deterministic model through its application to an actual commercial building project, *probabilistic* (stochastic) time and cost analyses are further conducted in order to enhance the model's capability of capturing real-life uncertain project conditions as close as possible to assist in more effective decision-making in construction.

4.3.1 Development of Physical Construction Deterministic Model

The physical construction process *deterministic* model development includes a total number of twenty sequential steps covering all three project cost management interactive processes, i.e. cost estimating, cost budgeting and cost control.

4.3.1.1 Activity-on-Node (AoN) Network Construction

The starting point is to construct a reliable and transparent project network involving:

1. the decomposition of the project *work packages* or *elements* into a set of interrelated *work activities*;
2. the further analysis of the above work activities in the *resources* required for their completion, i.e. *materials*, *equipment*, *labour*, and *subcontractors*;
3. the assignment of (fixed) *single-point estimates* for *duration* and *direct cost* (based on resource consumption) for *normal* completion of each work package or element;
4. the *activity-on-node* (AoN) network construction for the project, considering the necessary *precedence relationships* between the work packages or elements;
5. the identification of the *critical path* to complete the project after calculating at first the *total float* for each work package or element by performing *forward* and *backward* calculations through the network corresponding to the *earliest* and *latest* times for completing the work packages or elements respectively;

4.3.1.2 Project Scheduling and Activity-Based Budgeting

Based on the previously developed AoN network, the second process is the scheduling and cost budgeting of the project engaging:

6. the calculation of *normal duration* (from the above critical path) and *normal direct cost* of the entire project based on an *activity-based costing* (ABC) methodology, as will be described later in Subsection 4.3.1.5 (pages 250-251);
7. the determination of the *normal total budget* for the project by adding *site field* (project-level) plus *head-office* (company-level) *overhead costs* to the normal direct costs for executing the work packages or elements;

8. the generation of the *normal* project *time-cost envelopes* (*S*-curve budget profiles) from both the earliest start and the latest start completion of project work packages or elements.

4.3.1.3 Time-Cost Trade-off (TCT)

The next stage in constructing the model considers the time-cost trade-off (TCT) or time-cost optimisation problem. The TCT procedure entails the following steps:

9. the assignment of (fixed) *single-point estimates* for *duration* and *direct cost* for *compressed* completion ('crashing') of each work package or element;
10. the calculation of the *marginal crashing cost* for each critical work package or element (i.e. the additional cost for shortening the work package or element duration by one time unit);
11. the *reduction by one time unit* of the *critical* work package or element with the lowest marginal cost of crashing;
12. the calculation of the resulting project *total crashed duration* and *total direct crashed cost*;
13. the repetition of steps 11 and 12 until another network path becomes critical and until all critical work activities are fully crashed;
14. the determination of the *optimum* crashing point, i.e. the project duration which corresponds to the minimum total project cost (including total overhead costs, bonuses, and/or penalties);
15. the generation of the *optimum* project *time-cost profile* (baseline *S*-curve) from the *optimum* project critical path.

4.3.1.4 Earned Value Analysis (EVA)

The fourth (and last) phase of the model development considers the monitoring and control of the time and cost performance of the project. The *S*-curve time-cost baseline which has been established during the previous stage (or any other generated time-cost profile depending on management's strategic decision on how to execute the project, e.g. the fully crashed time-cost relationship with the minimum possible duration at the maximum project cost) provides the basis for monitoring and controlling the project by using the *earned value analysis* (EVA). The required steps are presented herein:

16. the determination of how much work has been accomplished and how much work should have been accomplished according to the plan;
17. the determination of how much money have been earned and how much money have been spent;
18. the calculation of the time (schedule) and money (budget) variances at the time of the analysis;
19. the analysis of the causes for the major variances and the determination of possible remedial actions; and
20. the extrapolation of these variances to the end of the entire project.

4.3.1.5 Mathematical Formulation

In *activity-on-node* (AoN) networks, or Metra Potential Method (MPM) (Roy, 1959) or Precedence Diagramming Method (PDM) (Fondahl, 1961), the activities are assigned to *nodes* instead of *arcs*. A project can be considered to be a set of interacting *work packages* or *elements* consisting of *work activities* with required *time* and *resources* for their completion. The structural analysis of the project provides a decomposition of the work packages or elements into a set N of *nodes* and a set P of *precedence relationships* among them. Set N consists of n work packages or elements $i = 1, \ldots, n$ to be scheduled and two auxiliary (dummy) work packages or elements 0 and $n+1$, representing project *start* and *finish*, respectively. The precedence relationships can be represented as work packages or elements pairs (a, b) where $a \neq b$, denoting that the beginning time of work package or element a affects the earliest start time of work package or element b. A duration d_a is given to each work package or element $a \in N$ and a time lag δ_{ab} to each pair $(a, b) \in P$ where:

$$\delta_{ab} \leq s_b - s_a \tag{4.18}$$

being the *temporal constraint* with s_a and s_b the start times of work packages or elements a and b, respectively. If $(a, b) \in P$, work package or element b cannot start earlier than δ_{ab} units of time after the start of work package or element a. If $\delta_{ab} = d_a$ constraint (4.18) is referred to as *precedence constraint* between work packages or elements a and b.

The network analysis then consists of (Oxley and Poskitt, 1996):

- calculating the earliest times by working *forwards* through the network and selecting the longest path (the final earliest time gives the project duration);
- calculating the latest times by working *backwards* through the network and selecting the longest path (the final latest time is the same as its earliest time and gives the same project duration);
- calculating the *total float* of work packages, which is either the latest start time minus the earliest start time or the latest finish time minus the earliest finish time (both methods give the same result); and
- identifying the critical work packages or elements, i.e. the ones with zero total float, to determine the *critical path*.

The **project network definition** is presented as follows:

G an acyclic and directed graph, where $G = (N, P)$

N set of nodes in project network, each node representing a work package or element

P	set of arcs in project network, representing the immediate precedence relationships between work packages or elements, with each work package or element pair $(x, y) \in P$ with $x \neq y$, denoting that the beginning time of work package or element x affects the earliest start time of work package or element y
i	work package or element to be scheduled, where $i = \{0, 1, \ldots, n, n+1\} \in N$ and the two auxiliary (dummy) work packages or elements 0 and n+1, representing project start and finish, respectively
d_i	normal duration assigned to each work package or element i ($d_i \geq 0$)
c_i	crash duration assigned to each work package or element i ($0 \leq c_i \leq d_i$)
r_i^{max}	maximum time reduction in duration of work package or element i, where: $r_i^{max} = d_i - c_i \quad (4.19)$
r_i	time reduction in duration of work package or element i when crashing the project ($0 \leq r_i \leq r_i^{max}$)
s_i	start time of work package or element i when crashing the project ($s_i \geq 0$)
e_i	end time of work package or element i when crashing the project, where: $e_i = s_i + d_i - c_i \quad (4.20)$
es_i	earliest start time of work package or element i
ef_i	earliest finish time of work package or element i
ls_i	latest start time of work package or element i
lf_i	latest finish time of work package or element i
tf_i	total float (slack) of work package or element i where: $tf_i = lf_i - ef_i = ls_i - es_i \quad (4.21)$
δ	time lag to each arc $(x, y) \in P$, where: $\delta_{xy} + s_x \leq s_y \quad (4.22)$ being the temporal constraint with s_x and s_y the start times of work packages or

	elements x and y, respectively. If $(x, y) \in P$, work package or element y cannot start earlier than δ_{xy} units of time after the start of work package or element x. If $\delta_{xy} = d_x$ the above constraint (4.22) is referred to as the precedence constraint (finish-to-start relationship) between work packages or elements x and y
T_p	project completion time
$T_p^{\,n}$	project normal completion time
$T_p^{\,max}$	project completion deadline according to contract
$T_p^{\,min}$	project crash completion time
$T_p^{\,opt}$	project optimal completion time
$T_p^{\,(+)}$	project bonus time for early completion
$T_p^{\,(-)}$	project penalty time for late completion
t	time units of construction period, where:
	$t = \{1, 2, \ldots, T_p^{\,min}, \ldots, T_p^{\,opt}, \ldots, T_p^{\,(+)}, \ldots, T_p^{\,\mathrm{max}}, T_p^{\,(-)}, \ldots, T_p\}$
D_i^n	direct cost for normal completion (d_i) of work package or element i
D_i^{nt}	direct cost per week for normal completion (d_i) of work package or element i
$D_p^{\,n}$	total project direct cost for normal completion ($T_p^{\,n}$), where:
	$D_p^{\,n} = \Sigma\,(D_i^n)$ (4.23)
D_i^c	direct cost for crash completion (c_i) of work package or element i
$D_p^{\,c}$	total project direct cost for crash completion ($T_p^{\,min}$)
	$D_p^{\,c} = \Sigma\,(D_i^c)$ (4.24)
A_i	additional direct cost for crash completion of work package or element i, where:
	$A_i = (D_i^c - D_i^n)$ (4.25)
A_i^t	additional direct cost per time unit for compressing work package or element i
b_i	crash cost slope for compressing work package or element i, where:
	$b_i = (D_i^c - D_i^n) : (c_i - d_i) = -(A_i : r_i^{\,max}) = A_i^{\,t}$ (4.26)

C_i^c crash cost for work package or element i when crashing the project, where:

$$C_i^c = A_i^t * r_i \tag{4.27}$$

C_p^c total project crash cost, where:

$$C_p^c = \Sigma\,(C_i^c) = \Sigma\,(A_i^t * r_i),\ i = \{0, 1, \ldots, n, n{+}1\} \in N \tag{4.28}$$

O_p total project overhead cost

C_p total project cost after crashing, where:

$$C_p = D_p^n + C_p^c + O_p \tag{4.29}$$

F_p field (site) overhead (indirect) project cost, where:

$$F_p = \varepsilon_f(\text{fixed amount per week}) * T_p \tag{4.30}$$

H_p head-office (company) overhead (indirect) project cost, where:

$$H_p = \varepsilon_h\ (\text{fixed amount per week, as a \% of contract sum}) * T_p \tag{4.31}$$

$B_p^{(+)}$ bonus fee per time unit of early completion

$B_p^{(-)}$ penalty clause per time unit of late completion.

This research project adopts an **ABC-oriented methodology** for *direct cost* estimation. In building projects, an ABC system can be implemented assuming that project *work elements* or *packages,* such as the reinforced concrete building frame, represent the *cost objects* that create the demand for *work activities,* e.g. placing formwork and steel rebars, pouring of concrete etc., which in turn causes *resources* to be consumed, e.g. concrete and reinforcement delivery, labour hours etc., and therefore *causing costs*. Thus, work packages or elements (cost objects) are the reason for performing work activities (cost centers) and work activities are the cause for cost creation through resource consumption.

Suppose that a building project is decomposed into $i = \{0, 1, \ldots, n, n{+}1\} \in N$ work packages or elements (cost objects) and that to produce these work packages or elements, $j = \{1, \ldots, k\}$ work activities (cost centres) are required. Then, total direct (field) cost D_i of each work package or element is the sum of the direct (site field) costs incurred by the resources required for the completion of its constituent work activities with direct cost D_{ij} of each work activity being the sum of the costs of all resources required for the execution of that work activity. Direct costs of *labour*, *material*, *equipment,* and *subcontractors* are assigned to all project work activities. For a work package or element i, let Q_{ij} be the quantity of work activity j, M_{ij} be the unit material cost of work activity j, E_{ij} be the unit equipment rate for work activity j, L_{ij} be the units of labour required per unit of Q_{ij}, W_{ij} be the wage rate associated with L_{ij} and S_{ij} be the subcontracting cost (if any) for work activity j. Therefore, the total direct cost D_p for the project could be mathematically formulated as:

$$D_p = \sum_{i=1}^{n} D_i = \sum_{i=1}^{n}\sum_{j=1}^{k} D_{ij} = \sum_{i=1}^{n}\sum_{j=1}^{k} Q_{ij}\left(M_{ij} + E_{ij} + W_{ij}L_{ij}\right) + S_{ij} \tag{4.32}$$

$i = 1, \ldots, n$ work packages or elements (cost objects) and $j = 1, \ldots, k$ work activities (cost centres). The units of all terms in Equation (4.32) are consistent, since $W_{ij} * L_{ij}$ yields the labour cost per unit of Q_{ij}, therefore, the labour unit cost of cost centre j. The allocation of company overheads to work packages or elements is prorated in fixed proportion to the contract sum. Field (site) overheads are allocated to the project as a fixed sum per week.

The linear programming **time-cost optimisation problem** is formulated as follows:

Objective Function:

minimise Z where: Z = total crashing cost = $\Sigma\ (A_i^t * r_i)$, for $i = \{0, 1, \ldots, n, n+1\}$

A_i^t = additional crash cost per time unit saved in duration of work package or element i due to crashing this work package or element, for $i = \{0, 1, \ldots, n, n+1\}$

r_i = reduction in normal duration of work package or element i due to crashing this work package or element, for $i = \{0, 1, \ldots, n, n+1\}$

Subject to (Constraints):

$r_i \leq r_i^{max}$ for $i = \{0, 1, \ldots, n, n+1\}$ (maximum time reduction)

$r_i \geq 0$ for $i = \{0, 1, \ldots, n, n+1\}$ (non-negativity for reduction)

$s_i \geq 0$ for $i = \{0, 1, \ldots, n, n+1\}$ (non-negativity for start times)

$T_p \geq 0$ where: T_p the project duration (non-negativity for project duration)

$T_p \leq T_p^{max}$ where: T_p^{max} the contract deadline (maximum project duration)

$s_{i+1} \geq s_i + d_i - r_i$ for $i = \{0, 1, \ldots, n, n+1\}$ (general start time constraint)

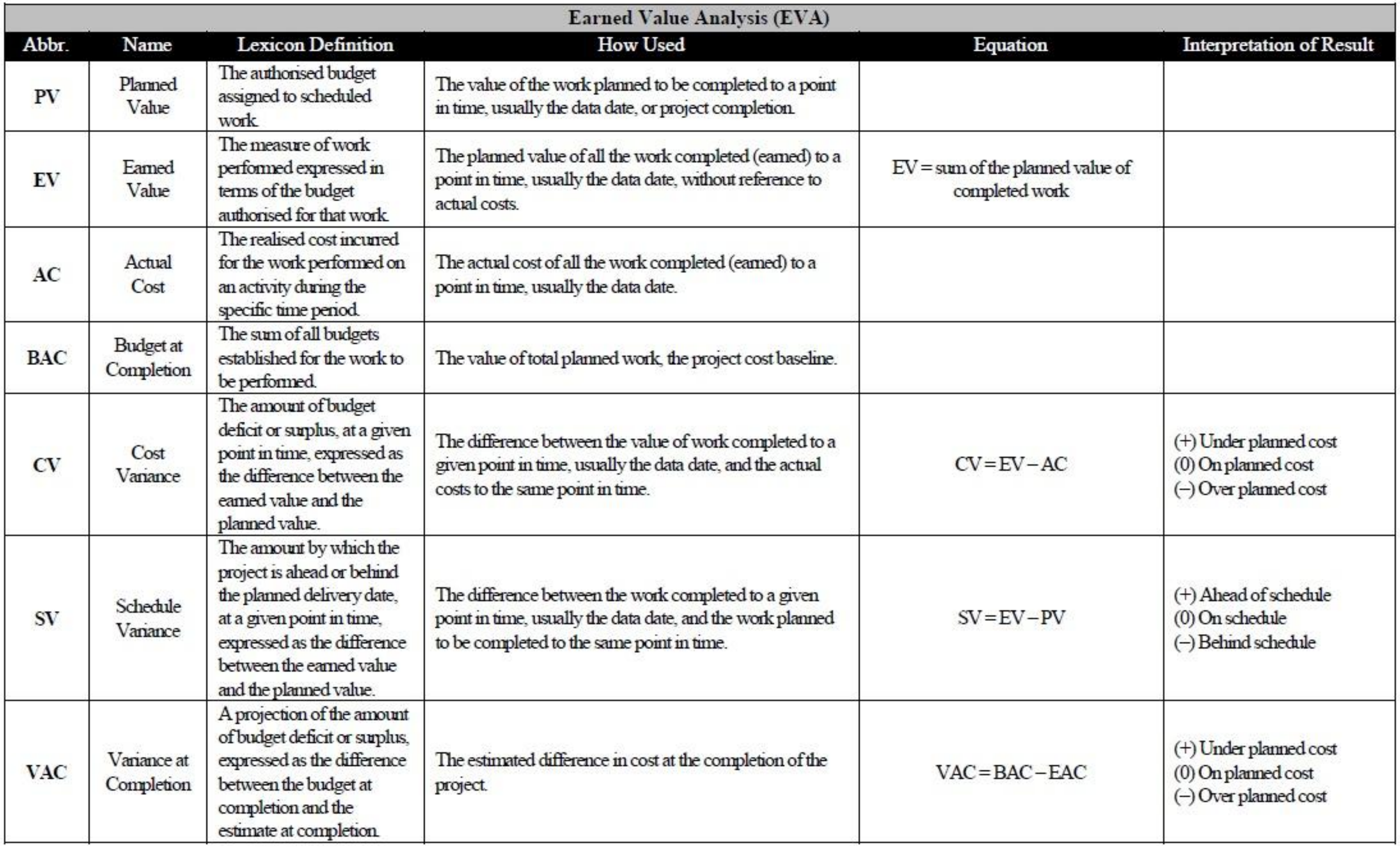
$T_p \geq s_{n+1} + d_{n+1} - r_{n+1}$ (project duration constraint)

The complete set of **earned value analysis (EVA)** definitions, formulas and results interpretation are presented in Table 4.9 (pages 253-254) (PMI, 2013).

4.3.2 Data Collection and Analysis

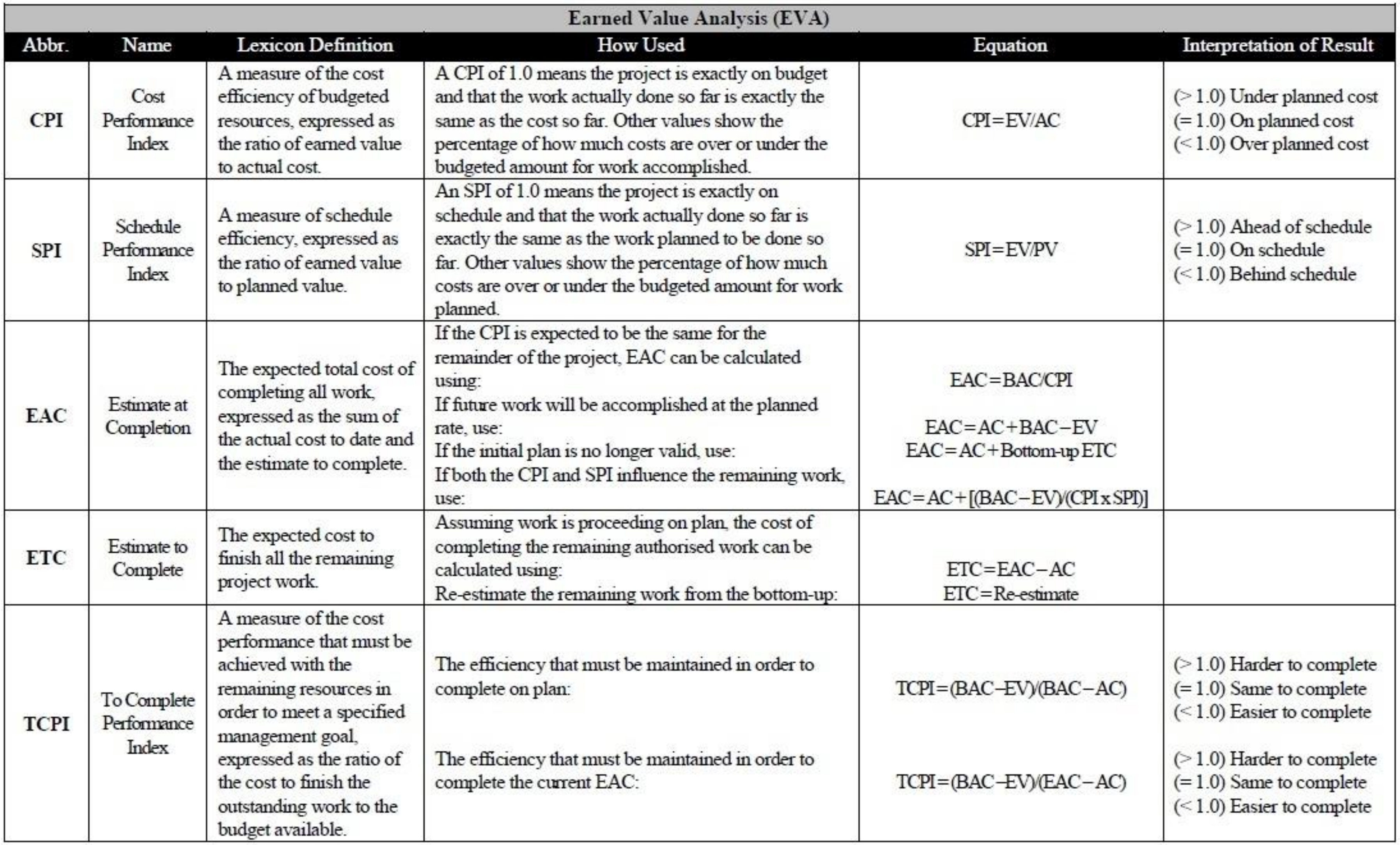
Historical cost and time data were collected from the construction records of a 3-storey reinforced concrete-framed commercial building project with a total gross floor area (TGFA) of 903,62 m^2, erected in Athens, Greece, in 2014. The total contract sum for the project was €1.200.000,00 (contractor's winning bid) and the associated contract duration (deadline), from the date of contractor's setup on site to the date of commissioning the project to the client, was 82 weeks. The owner included in the contract: a *penalty clause* of €2.500,00 per week for late completion beyond the contract deadline; and a *bonus fee* of €1.500,00 per week saved if the project is handed-over to be operated by the client earlier than 82 weeks. The cost data collected involved actual resource consumption quantities for work activities per work package or element together with *site* and *head-office* overhead (indirect) costs. Furthermore, the approved construction execution program (in the form of a Gantt chart) was carefully examined in order to be able to develop the AoN project network assuming the finish-to-start (*FS*) immediate precedence relationship.

Table 4.9 Earned Value Analysis (EVA) Typology (Source: PMI, 2013)



Earned Value Analysis (EVA)					
Abbr.	**Name**	**Lexicon Definition**	**How Used**	**Equation**	**Interpretation of Result**
PV	Planned Value	The authorised budget assigned to scheduled work.	The value of the work planned to be completed to a point in time, usually the data date, or project completion.		
EV	Earned Value	The measure of work performed expressed in terms of the budget authorised for that work.	The planned value of all the work completed (earned) to a point in time, usually the data date, without reference to actual costs.	EV = sum of the planned value of completed work	
AC	Actual Cost	The realised cost incurred for the work performed on an activity during the specific time period.	The actual cost of all the work completed (earned) to a point in time, usually the data date.		
BAC	Budget at Completion	The sum of all budgets established for the work to be performed.	The value of total planned work, the project cost baseline.		
CV	Cost Variance	The amount of budget deficit or surplus, at a given point in time, expressed as the difference between the earned value and the planned value.	The difference between the value of work completed to a given point in time, usually the data date, and the actual costs to the same point in time.	$CV = EV - AC$	(+) Under planned cost (0) On planned cost (–) Over planned cost
SV	Schedule Variance	The amount by which the project is ahead or behind the planned delivery date, at a given point in time, expressed as the difference between the earned value and the planned value.	The difference between the work completed to a given point in time, usually the data date, and the work planned to be completed to the same point in time.	$SV = EV - PV$	(+) Ahead of schedule (0) On schedule (–) Behind schedule
VAC	Variance at Completion	A projection of the amount of budget deficit or surplus, expressed as the difference between the budget at completion and the estimate at completion.	The estimated difference in cost at the completion of the project.	$VAC = BAC - EAC$	(+) Under planned cost (0) On planned cost (–) Over planned cost

Table 4.9 Earned Value Analysis (EVA) Typology – *cont'd.* (Source: PMI, 2013)



Earned Value Analysis (EVA)					
Abbr.	**Name**	**Lexicon Definition**	**How Used**	**Equation**	**Interpretation of Result**
CPI	Cost Performance Index	A measure of the cost efficiency of budgeted resources, expressed as the ratio of earned value to actual cost.	A CPI of 1.0 means the project is exactly on budget and that the work actually done so far is exactly the same as the cost so far. Other values show the percentage of how much costs are over or under the budgeted amount for work accomplished.	CPI=EV/AC	(> 1.0) Under planned cost (= 1.0) On planned cost (< 1.0) Over planned cost
SPI	Schedule Performance Index	A measure of schedule efficiency, expressed as the ratio of earned value to planned value.	An SPI of 1.0 means the project is exactly on schedule and that the work actually done so far is exactly the same as the work planned to be done so far. Other values show the percentage of how much costs are over or under the budgeted amount for work planned.	SPI=EV/PV	(> 1.0) Ahead of schedule (= 1.0) On schedule (< 1.0) Behind schedule
EAC	Estimate at Completion	The expected total cost of completing all work, expressed as the sum of the actual cost to date and the estimate to complete.	If the CPI is expected to be the same for the remainder of the project, EAC can be calculated using: If future work will be accomplished at the planned rate, use: If the initial plan is no longer valid, use: If both the CPI and SPI influence the remaining work, use:	EAC=BAC/CPI EAC=AC+BAC−EV EAC=AC+Bottom-up ETC EAC=AC+[(BAC−EV)/(CPI x SPI)]	
ETC	Estimate to Complete	The expected cost to finish all the remaining project work.	Assuming work is proceeding on plan, the cost of completing the remaining authorised work can be calculated using: Re-estimate the remaining work from the bottom-up:	ETC=EAC−AC ETC=Re-estimate	
TCPI	To Complete Performance Index	A measure of the cost performance that must be achieved with the remaining resources in order to meet a specified management goal, expressed as the ratio of the cost to finish the outstanding work to the budget available.	The efficiency that must be maintained in order to complete on plan: The efficiency that must be maintained in order to complete the current EAC:	TCPI=(BAC−EV)/(BAC−AC) TCPI=(BAC−EV)/(EAC−AC)	(> 1.0) Harder to complete (= 1.0) Same to complete (< 1.0) Easier to complete (> 1.0) Harder to complete (= 1.0) Same to complete (< 1.0) Easier to complete

4.3.3 Case Study (I): *Cost Management of a Commercial Building Project at Physical Construction Stage*

The presented in the thesis physical construction cost management approach is applied to the above actual commercial building project. At first, a *deterministic* CPM base-case calculation is conducted to establish the project *normal* duration and direct cost. Then, the time/cost trade-off (TCT) problem is analysed in order to explore minimum and optimum project total duration with respect to the associated costs.

4.3.3.1 Critical Path Method (CPM) Scheduling and Budgeting

The interdependence of the work packages or elements of the project means that some parts of the building construction cannot be initiated until some other parts are finalised. For example, some of the essential starting tasks include foundations excavation, placement of formwork and steel rebars, casting with concrete for foundations construction, erection of the main building frame consisting of columns, beams and plates, and so forth. These operations cannot be performed in any random sequence: the foundations must be dug first, followed by formwork, steelwork and concrete pours for foundations, followed by the building of the framework etc. At some point, some of the activities can be performed simultaneously because they are not dependent upon each other, but normally most of the operations cannot. Therefore, any delay in digging the foundations will delay pouring the concrete, which in turn will probably delay the completion of the entire building. In short, the *timing* and *interdependent nature* of construction production operations are critical.

The definition of the project work packages or elements, the establishment of the proper precedence interrelationships, and the estimated normal time (in weeks) to complete the work together with the associated estimated direct cost (in €) are shown in Table 4.10 (page 256).

Most network schedules are not adjusted for uncertainty but, rather, are developed as if there were ‘one right answer’ for the schedule’s numerical data. Generally, activity durations are established by calculating the quantity of work represented by an activity, divided by the production rate, or by a sheer ‘gut feeling’ of the project manager or crew leader. This production rate is normally established by the contractor’s historical records or an estimating system, such as RS Means Cost Data by the Gordian Group, which provides an accurate database of average production rate (Mubarak, 2015).

Table 4.10 Work Start-up List with Expected *Normal* Duration and Direct Cost

Work Package or Element (WP/E) **($i = 0, 1, \ldots, n, n+1$)**	**WP/E id no.**	**Immediate Predecessors*** **($FS = 0$)**	**Normal Time** **(d_i)**	**Normal Direct Cost** **(D_i^n)**
Project Start (Dummy)	0		0	0
Site Setup/Demolitions	1	0	3	8200
Excavations	2	1	4	18500
RC Structural Frame	3	2	14	145800
Brickwork	4	3	8	16100
Metal Casing Pseudoframes	5	4	2	2300
Electrical 1st Fix (conduits)	6	4	3	31900
Plumbing (piping)	7	4	4	42500
Marble Sills	8	4	2	2000
Waterproofing/Roofs	9	3	4	13700
Plasterings	10	5; 6; 7; 8; 9	9	16700
Steelworks/Railings	11	10	2	12000
Electrical 2nd Fix (wiring)	12	10	3	20100
Walls Tiling	13	11	2	4600
Heating/Cooling/Gas/Solar (ducts)	14	12	3	17200
Floorings (marble, wooden, tiles)	15	11; 13; 14	6	13400
Doors/Windows	16	15	5	39200
Joinery	17	15	3	10400
Bathrooms/WC Fixtures	18	15	2	3500
Boiler/Panels/Fan-coils Installation	19	15	4	43200
Elevator	20	12; 14	2	12000
Plasterboard Ceilings	21	19; 20	2	7700
Colourings	22	21	10	18900
Lighting/Electrical Finishings/Minor Works	23	16; 17; 18	3	17600
Surrounding Area Works	24	22; 23	6	24700
Operational Testing/Clean-up/Handover	25	24	3	3300
Project Finish (Dummy)	26	25	0	0

* Finish-to-Start ($FS = 0$) relationship is assumed.

Table 4.11 Activity-Based Costing (ABC) Template for Direct Cost Calculations

Work Package or Element/Cost Object ($i = 0, 1, \ldots, n, n+1$)	Cost Object no.	Work Activity/ Cost Center ($j = 1, \ldots, k$)	Unit Rate/ Cost Driver	Work Activity Quantity (Q_{ij})	Material Unit Cost (M_{ij})	Equipment Unit Cost (E_{ij})	Labour Wage Rate (W_{ij})	Labour Input (L_{ij})	Labour Unit Cost ($W_{ij}*L_{ij}$)	Sub-contract Cost (S_{ij})	Work Activity (Normal) Direct Cost (D_{ij})	Work Package (Normal) Direct Cost (D_i)
1	2	3	4	5	6	7	8	9	10 = 8*9	11	12	13
Project Start (Dummy)	0											
Site Set-up/Demolitions	1											
Excavations	2											
RC Structural Frame	3											
Brickwork	4											
Metal Casing Pseudoframes	5											
Electrical 1st Fix (conduits)	6											
Plumbing (piping)	7											
Marble Sills	8											
Waterproofing/Roofs	9											
Plasterings	10											
Steelworks/Railings	11											
Electrical 2nd Fix (wiring)	12											
Walls Tiling	13											
Heating/Cooling/Gas/Solar (ducts)	14											
Floorings (marble, wooden, tiles)	15											
Doors/Windows	16											
Joinery	17											
Bathrooms/WC Fixtures	18											
Boiler/Panels/Fan-coils Installation	19											
Elevator	20											
Plasterboard Ceilings	21											
Colourings	22											
Lighting/Electrical Finishings/Minor Works	23											
Surrounding Area Works	24											
Operational Testing/Clean-up/Handover	25											
Project Finish (Dummy)	26											
Totals												

Once work activities are defined for the WBS work packages or elements, resources are allocated to each work activity and, therefore, costs are estimated. Then, it is possible to plot the network and perform the CPM to estimate *normal* time and cost over the whole project. The total direct cost estimate is €545.500,00. Table 4.11 (page 257) shows the template used to calculate the direct cost of each work package or element, following Equation (4.32) as introduced in Subsection 4.3.1.5 (page 251, Mathematical Formulation).

Table 4.12 CPM Basic Calculations for *Earliest Start* and *Latest Start* Durations

Work Package or Element ($i = 0, 1, \ldots, n, n+1$)	**Early Start Time (es_i)**	**Early Finish Time (ef_i)**	**Late Start Time (ls_i)**	**Late Finish Time (lf_i)**	**Total Float (tf_i)**	**Critical Path* ($tf_i = 0$)**
Project Start (Dummy)	**0**	**0**	**0**	**0**	**0**	**1**
Site Setup/Demolitions	**0**	**3**	**0**	**3**	**0**	**1**
Excavations	**3**	**7**	**3**	**7**	**0**	**1**
RC Structural Frame	**7**	**21**	**7**	**21**	**0**	**1**
Brickwork	**21**	**29**	**21**	**29**	**0**	**1**
Metal Casing Pseudoframes	29	31	31	33	2	0
Electrical 1st Fix (conduits)	29	32	30	33	1	0
Plumbing (piping)	**29**	**33**	**29**	**33**	**0**	**1**
Marble Sills	29	31	31	33	2	0
Waterproofing/Roofs	21	25	29	33	8	0
Plasterings	**33**	**42**	**33**	**42**	**0**	**1**
Steelworks/Railings	42	44	44	46	2	0
Electrical 2nd Fix (wiring)	**42**	**45**	**42**	**45**	**0**	**1**
Walls Tiling	44	46	46	48	2	0
Heating/Cooling/Gas/Solar (ducts)	**45**	**48**	**45**	**48**	**0**	**1**
Floorings (marble, wooden, tiles)	**48**	**54**	**48**	**54**	**0**	**1**
Doors/Windows	54	59	62	67	8	0
Joinery	54	57	64	67	10	0
Bathrooms/WC Fixtures	54	56	65	67	11	0
Boiler/Panels/Fan-coils Installation	**54**	**58**	**54**	**58**	**0**	**1**
Elevator	48	50	56	58	8	0
Plasterboard Ceilings	**58**	**60**	**58**	**60**	**0**	**1**
Colourings	**60**	**70**	**60**	**70**	**0**	**1**
Lighting/Electrical Finishings/Minor Works	59	62	67	70	8	0
Surrounding Area Works	**70**	**76**	**70**	**76**	**0**	**1**
Operational Testing/Clean-up/Handover	**76**	**79**	**76**	**79**	**0**	**1**
Project Finish (Dummy)	**79**	**79**	**79**	**79**	**0**	**1**

* **Bold** figures indicate ***critical*** work packages or elements.

Table 4.12 (page 258) presents the required *earliest start* and *latest start* forward and backward calculations to construct the project network; it can be seen that the estimated *normal* duration of the project is 79 weeks while the contract deadline is 82 weeks. Following the above calculations, the project AoN network for *normal* scheduling can be constructed (Figure 4.10, page 260). **Critical** work packages or elements are with **bold** boxes whilst the *critical path* of the project is illustrated with dashed connecting lines. The critical path is the *longest path* from start to finish and determines the overall project duration. If work on this longest path is delayed, then, the entire project will be delayed. For this reason, the subset of work packages or elements on the critical path, which are called the *critical* work packages or elements of the project, must be kept on schedule to avoid time overruns. Critical work packages or elements are those with *zero float* (slack). Therefore, it could be argued that the deterministic initial scheduling CPM procedure described above, can be used to answer the following early stage key questions:

- *What is the expected duration for project completion?*

  The expected project (normal) duration is 79 weeks, 3 weeks earlier than the contract deadline of 82 weeks.

- *What is the expected direct cost for project completion?*

  The expected project (normal) direct cost is €545.000,00.

- *Which are the critical work packages or elements of the project that they must be completed exactly as scheduled so that the overall project finish target is met?*

  The critical work packages or elements of the project are: Site Setup/Demolitions; Excavations; RC Structural Frame; Brickwork; Plumbing (piping); Plasterings; Electrical 2nd Fix (wiring); Heating/Cooling/Gas/Solar (ducts); Floorings (marble, wooden, tiles); Boiler/Panels/Fan-coils Installation; Plasterboard Ceilings; Colourings; Surrounding Area Works; Operational Testing/Clean-up/Handover.

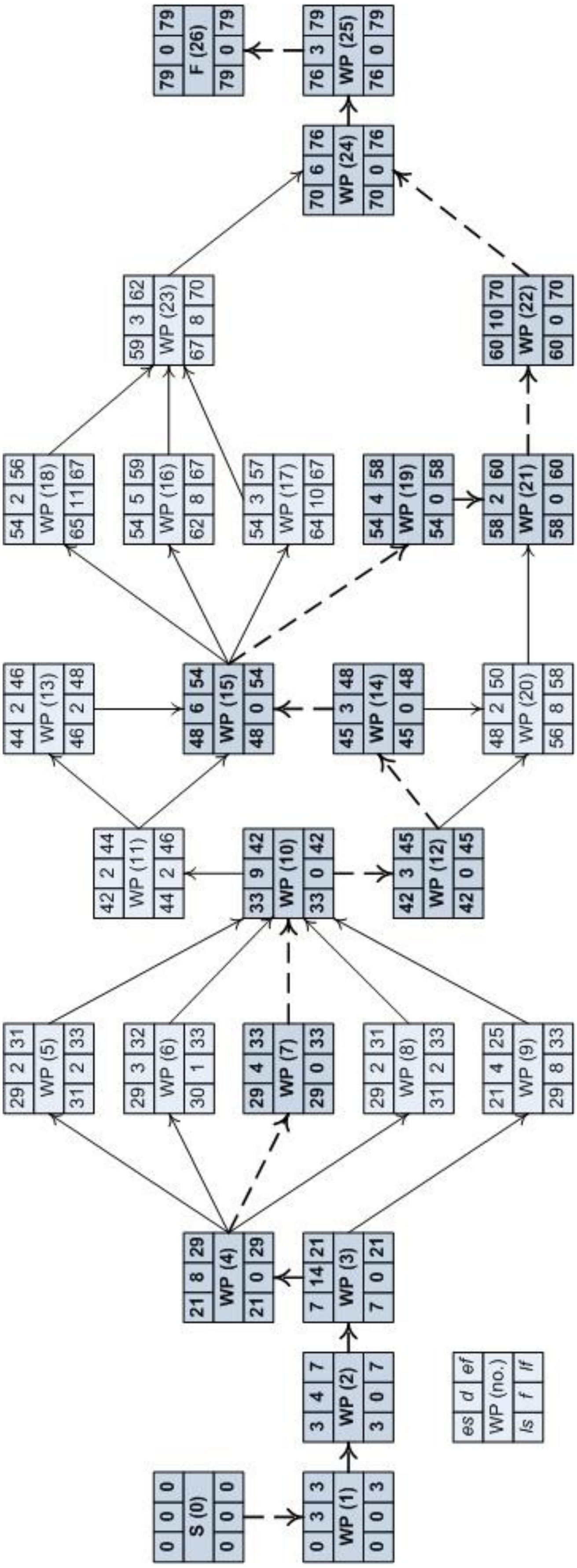


Fig. 4.10 AoN Network for *Normal* Scheduling (**Critical Path** with **bold** and dashed lines)

- *How long can non-critical work packages or elements be delayed without affecting the overall project completion duration?*

  The non-critical work packages or elements are the ones with total slack (total free time) greater than zero and their maximum potential delay equals their calculated total float (see latest start times column in Table 4.12, page 258).

Table 4.13 *Normal* Duration, Direct Cost and Direct Cost per Week

Work Package or Element (WP/E) ($i = 0, 1, \ldots, n, n+1$)	**WP/E id no.**	**Normal Time (d_i)**	**Normal Direct Cost (D_i^n)**	**Normal Direct Cost per Week (D_i^{nt})**
Project Start (Dummy)	0	0	0	0
Site Setup/Demolitions	1	3	8200	2733
Excavations	2	4	18500	4625
RC Structural Frame	3	14	145800	10414
Brickwork	4	8	16100	2013
Metal Casing Pseudoframes	5	2	2300	1150
Electrical 1st Fix (conduits)	6	3	31900	10633
Plumbing (piping)	7	4	42500	10625
Marble Sills	8	2	2000	1000
Waterproofing/Roofs	9	4	13700	3425
Plasterings	10	9	16700	1856
Steelworks/Railings	11	2	12000	6000
Electrical 2nd Fix (wiring)	12	3	20100	6700
Walls Tiling	13	2	4600	2300
Heating/Cooling/Gas/Solar (ducts)	14	3	17200	5733
Floorings (marble, wooden, tiles)	15	6	13400	2233
Doors/Windows	16	5	39200	7840
Joinery	17	3	10400	3467
Bathrooms/WC Fixtures	18	2	3500	1750
Boiler/Panels/Fan-coils Installation	19	4	43200	10800
Elevator	20	2	12000	6000
Plasterboard Ceilings	21	2	7700	3850
Colourings	22	10	18900	1890
Lighting/Electrical Finishings/Minor Works	23	3	17600	5867
Surrounding Area Works	24	6	24700	4117
Operational Testing/Clean-up/Handover	25	3	3300	1100
Project Finish (Dummy)	26	0	0	0

In construction, projects can strongly influence both client's and contractor's financial position; the need to cover daily operations affects the overall project budget and cash-flow. The way in which work packages or elements (cost objects) and their associated work activities (cost centers) are scheduled, determines the project funding requirements. From earliest and latest start times of project work packages or elements and their associated costs, a *project accounting system* can be developed to assist in effective cost management of the commercial building project; this system is based on the construction of a *direct cost* (or *budget*) *graph* for work packages or elements against project time. The assumption is made that expenditures are incurred *uniformly* (at a constant rate) throughout work package or element duration (Table 4.13, page 261). Therefore, the weekly cost for each work package or element and the cumulative project cost per week can be calculated. Site (project) overheads are charged with a fixed fee of €3.000,00 per week whilst head-office (company) overheads are allocated to the project as a constant amount of €2.000,00 per week. The graphs for direct cost, total overhead cost and total cost (budget) for earliest start and latest start execution of project work packages or elements are presented in Figures 4.11 and 4.12 (page 263) respectively. Figure 4.13 (page 264) illustrates the time-cost envelope (for earliest and latest start times) which represents the feasible budgeting region in order to monitor the project progress.

Burke (2003) explained that: 'Project planners normally schedule activities *early start* to ensure that all the float time is available. However, the accountant may see things differently and feel that activities should begin *late start*. The advantage with activities starting *late start* is that the payments will be delayed and finance charges reduced. This approach, however, could backfire on the accountant in the later stages of the project if there are delays, because now there is no float available to accommodate these delays, so the activities must be crashed if the project is to finish on time. This means the float that was freely given away in the early stages of the project may now be expensive to buy back.' However, this single 'best guess' CPM deterministic scheduling and budgeting approach cannot provide any estimates of the potential variability in the expected duration and cost.

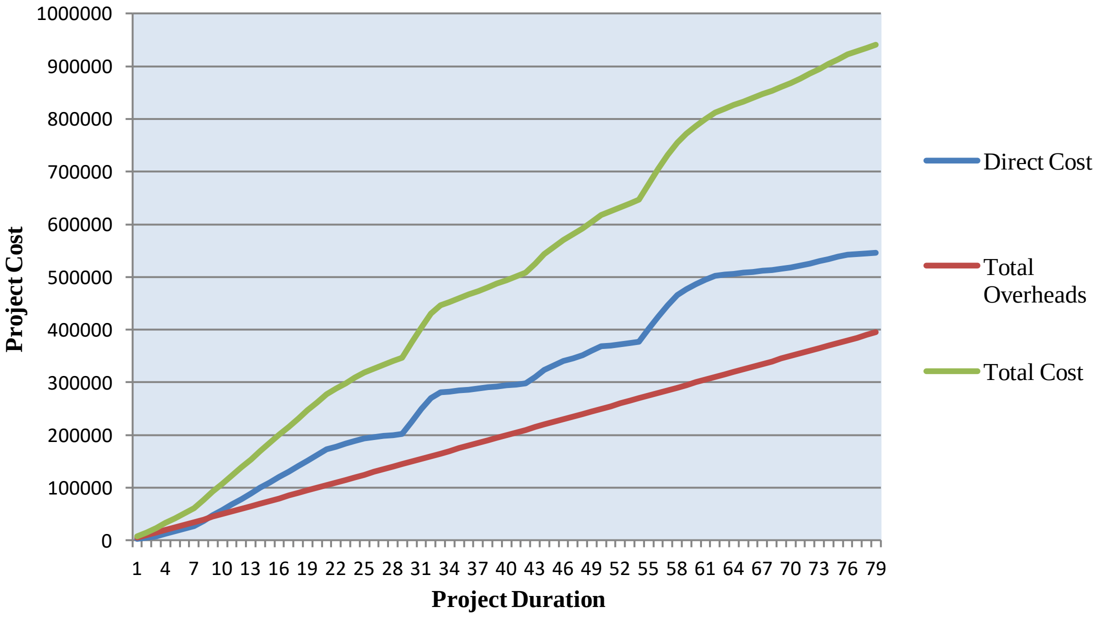


Fig. 4.11 Project Cost Budgeting for *Earliest Start* Times

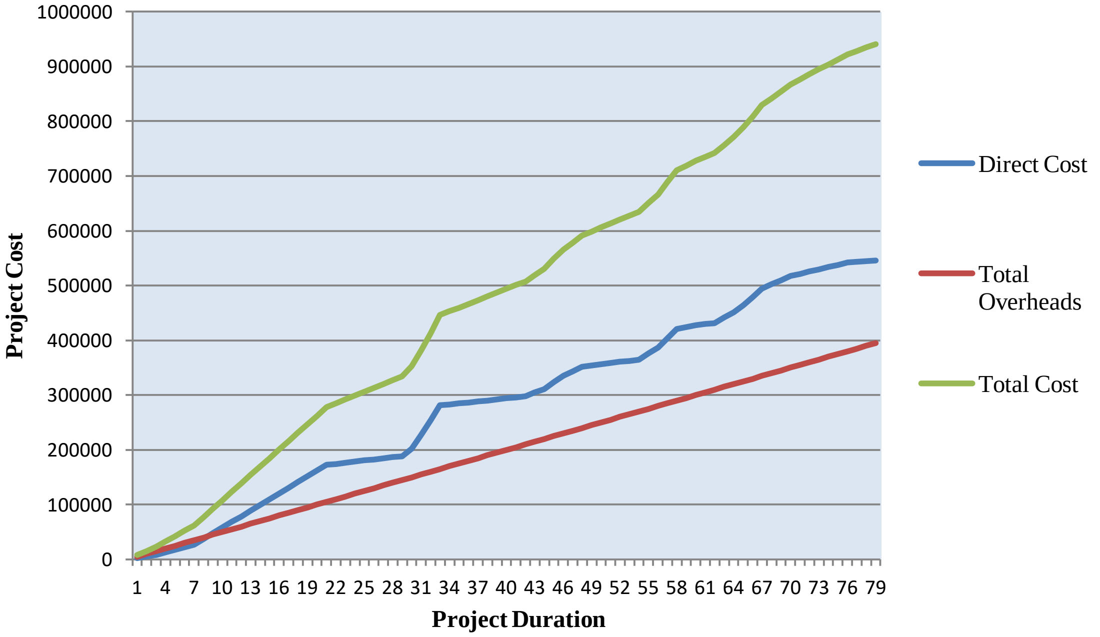


Fig. 4.12 Project Cost Budgeting for *Latest Start* Times

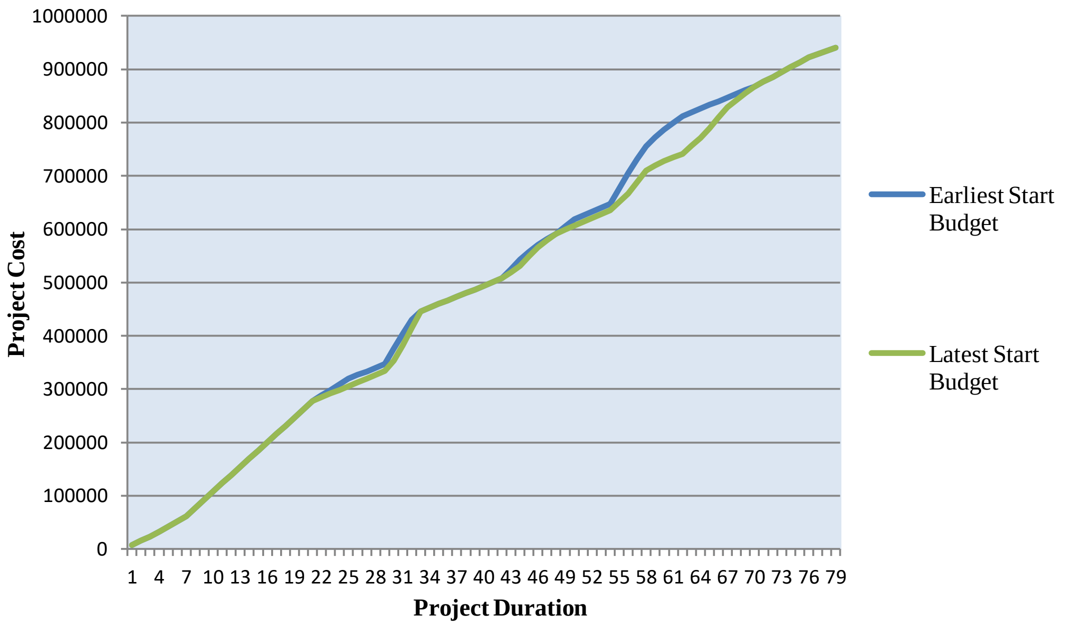


Fig. 4.13 Time-Cost Envelope for *Earliest Start* and *Latest Start* Budgeting

4.3.3.2 Traditional Program Evaluation and Review Technique (PERT)

In the previous subsection, the durations of work packages or elements and the derived values for earliest and latest start times were all assumed to be *deterministic*. However, real-life durations are often not known in advance with certainty. The potential variability in the expected project completion time can be estimated using the traditional PERT analysis. PERT method can also be used to calculate the probability that the project will be completed by any particular time. The estimation of the expected time value of a work package or element is based on the assumption that duration is a *random variable* following a *beta distribution*. Thus, the formula used to find the expected duration of a work package or element *i* is:

$$\mu_i = (o_i + 4m_i + p_i) : 6 \tag{4.33}$$

The above duration estimate is a *weighted average* of the *optimistic* (o), *most likely* (m) and *pessimistic* (p) values; the weights ($^1/_6$, $^4/_6$, $^1/_6$) sum to unity and this means that the estimate will always lie between o and p. The optimistic time is the minimum expected duration if everything goes perfect. The most likely time is the most probable duration under normal circumstances (and equals the single figure used in the CPM calculation). The pessimistic time is the maximum expected duration when *Murphy's Law* is in effect. To estimate the *variance* of the duration of work package or element *i*, the assumption is made that there are six (6) *standard deviations* between optimistic and pessimistic times:

$$\sigma_i^2 = [(p_i - o_i) : 6]^2 \qquad (4.34)$$

The assumed randomness of the work packages or elements durations implies that the completion time for the entire project is also a random variable. The commercial building project studied thus far has a (normal) mean μ_p duration of 79 weeks as calculated through the traditional CPM method. The contract deadline for the project is 82 weeks. In order to calculate the probability that the project will be completed in 82 weeks (or any other specified time of interest to management), the following analysis is carried out:

If T_p is the total project duration (Subsection 4.3.1.5, page 249), i.e. the sum of the durations of work packages or elements on the *critical path*, then the probability that $T_p \leq 82$ can be calculated if it is further assumed that: a). the work packages or elements times are *statistically independent* random variables and b). the random variable T_p follows approx. the *normal distribution*, i.e. the *central limit theorem* (CLT) can be used. CLT broadly states that *the sum of independent random variables is approx. normally distributed*. Thus, T_p can be converted to a standard normal random variable:

$$z = (T_p - \mu_p) : \sigma_p \qquad (4.35)$$

and the values for one-tail areas under the normal curve, as can be found in any standard statistics textbook, can be consulted to calculate an approx. probability of 87,5% that the project will be completed within 82 weeks:

$$P[T_p \leq 82] = P[\{(T_p - \mu_p) : \sigma_p\} \leq \{(82 - 79) : 2{,}604\}] = P[z \leq 1{,}152] = 1 - P[z > 1{,}152] =$$
$$= 1 - 0{,}1255 = 0{,}8745.$$

Table 4.14 presents optimistic, most likely, and pessimistic values for each work package or element in order to conduct the PERT analysis, their mean times and variances, the estimated mean duration and total variance for the whole project, and the calculated approx. probability of delivering the building no later than the contract deadline.

Table 4.14 Traditional PERT Analysis for the Commercial Building Project

Work Element or Package ($i = 0, 1, \ldots, n, n+1$)	**Optimistic Time (o_i)**	**Most Likely Time (m_i)**	**Pessimistic Time (p_i)**	**Mean Time* (μ_i)**	**Variance* (σ_i^2)**
Project Start (Dummy)	0	0	0	0	0
Site Set-up/Demolitions	2	3	4	3	0,111
Excavations	2	4	6	4	0,444
RC Structural Frame	11	14	17	14	1
Brickwork	7	8	9	8	0,111
Metal Casing Pseudoframes	1	2	3	2	0,111
Electrical 1st Fix (conduits)	1	3	5	3	0,444
Plumbing (piping)	3	4	5	4	0,111
Marble Sills	1	2	3	2	0,111
Waterproofing/Roofs	2	4	6	4	0,444
Plasterings	6	9	12	9	1
Steelworks/Railings	1	2	3	2	0,111
Electrical 2nd Fix (wiring)	1	3	5	3	0,444
Walls Tiling	1	2	3	2	0,111
Heating/Cooling/Gas/Solar (ducts)	1	3	5	3	0,444
Floorings (marble, wooden, tiles)	4	6	8	6	0,444
Doors/Windows	2	5	8	5	1
Joinery	1	3	3	3	0,111
Bathrooms/WC Fixtures	1	2	3	2	0,111
Boiler/Panels/Fan-coils Installation	2	4	6	4	0,444
Elevator	1	2	3	2	0,111
Plasterboard Ceilings	1	2	3	2	0,111
Colourings	7	10	13	10	1
Lighting/Electrical Finishings/Minor Works	1	3	5	3	0,444
Surrounding Area Works	3	6	9	6	1
Operational Testing/Clean-up/Handover	2	3	4	3	0,111
Project Finish (Dummy)	0	0	0	0	0
Central Limit Theorem (CLT): Mean Critical Path (μ_p, σ_p^2) =				**79**	**6,780**
P($T_p \leq 82$) =				**0,8745 (~87,5%)**	

* Mean time $\mu_i = (o_i + 4m_i + p_i) : 6$ and Variance $\sigma_i^2 = [(p_i - o_i) : 6]^2$

4.3.3.3 Monte Carlo Simulation (MCS) Stochastic Approach

As an alternative to the PERT method, the use of Monte Carlo Simulation (MCS) has long been suggested to override PERT's problematic assumptions (Van Slyke, 1963). The duration of an activity is a *random variable* for most of the cases in the real world, and obviously, the project completion time turns out to be another random variable. Facing such a challenge, serious attention must be paid to monitoring the uncertainty involved in *stochastic networks*. Project managers are highly interested in obtaining the *probability density function* (pdf) of the project's completion time because it provides full insight into the randomness of project completion and the basis for many subsequent decisions such as bidding, budgeting and scheduling (Yao and Chu, 2007). Using @RISK, it is possible to calculate different sets of artificial but realistic work package or element duration times and then to apply a deterministic scheduling procedure to each set of durations. From the results of MCS, a number of project schedule indicators can be obtained:

- estimates of the expected time and variance of the project completion;
- an estimate of the distribution of completion times, so that the probability of meeting a particular project deadline can be estimated; and
- the probability that a particular work package or element will lie on the critical path.

4.3.3.3.1 Uncertain Project Duration

Four (4) different probability distributions are assigned to the work package or element durations: the *PERT* distribution (to test the traditional PERT assumptions); the *triangular* distribution; the *uniform* distribution; and the *Poisson* distribution. The MCS results (10.000 iterations) in the form of histograms with cumulative distribution (*S*-curve) for the estimated project duration, with the most significant work (according to Spearman's rank correlation coefficients) are demonstrated in the following Figures 4.14-

4.21 (pages 268-271) and are summarised in Table 4.15 (page 272):

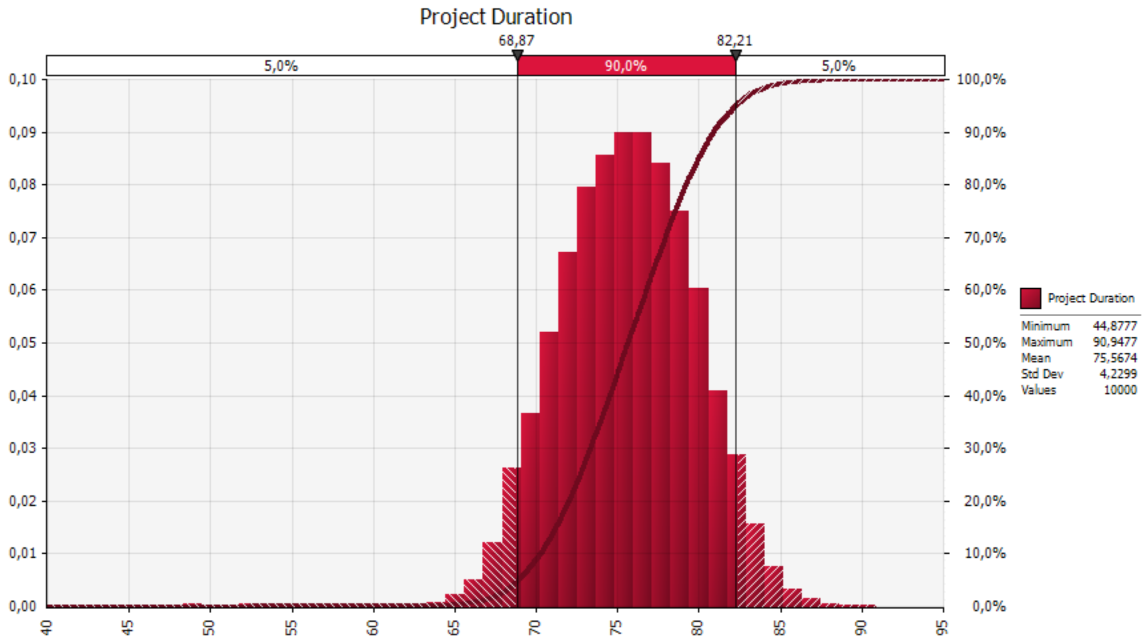


Fig. 4.14 Estimated Project Duration – *PERT* distribution

Mean estimated project duration: 75,57 weeks

Standard deviation: 4,23 weeks

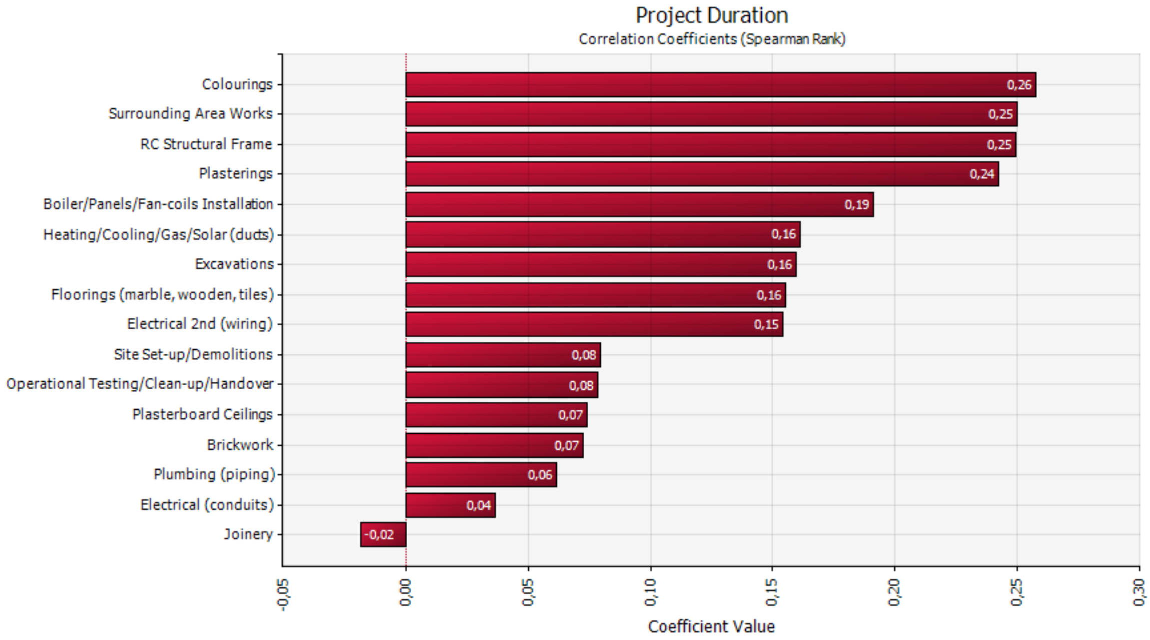


Fig. 4.15 Critical Work Packages for Project Duration – *PERT* distribution

Most critical work package/element (coefficient value): Colourings (0,26)

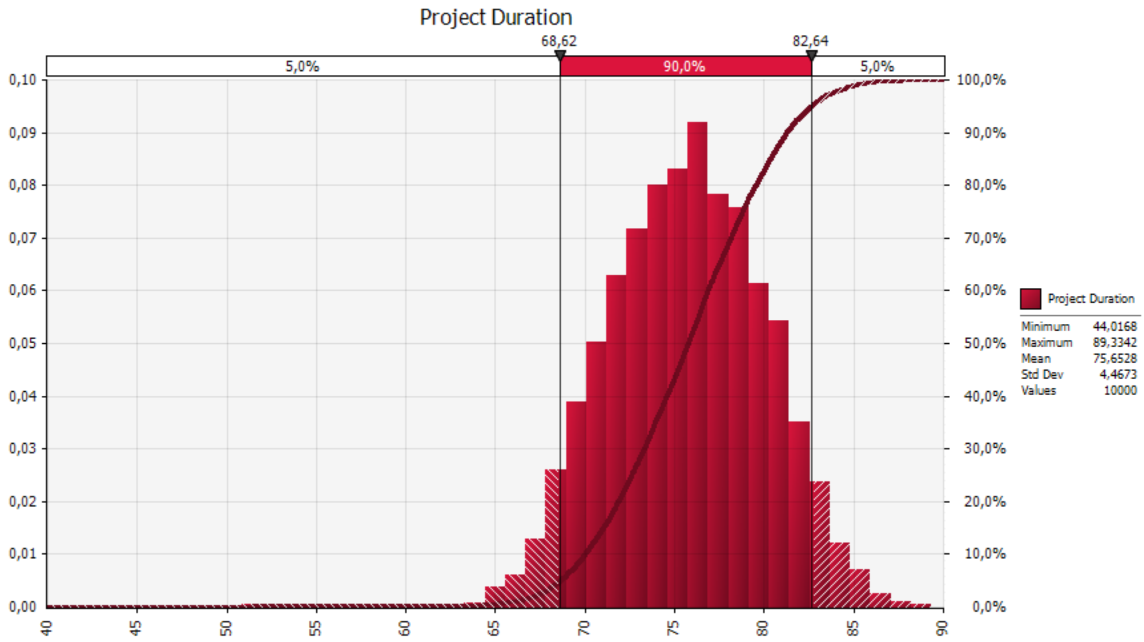


Fig. 4.16 Estimated Project Duration – *triangular* distribution

Mean estimated project duration: 75,65 weeks

Standard deviation: 4,47 weeks

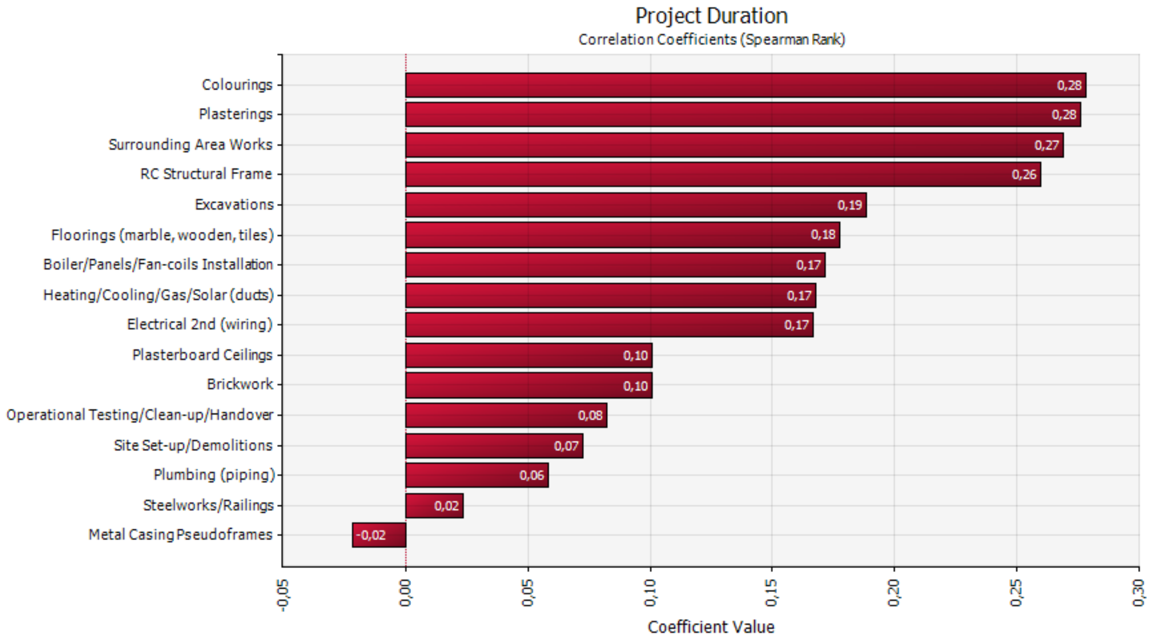


Fig. 4.17 Critical Work Packages for Project Duration – *triangular* distribution

Most critical work package/element (coefficient value): Colourings (0,28)

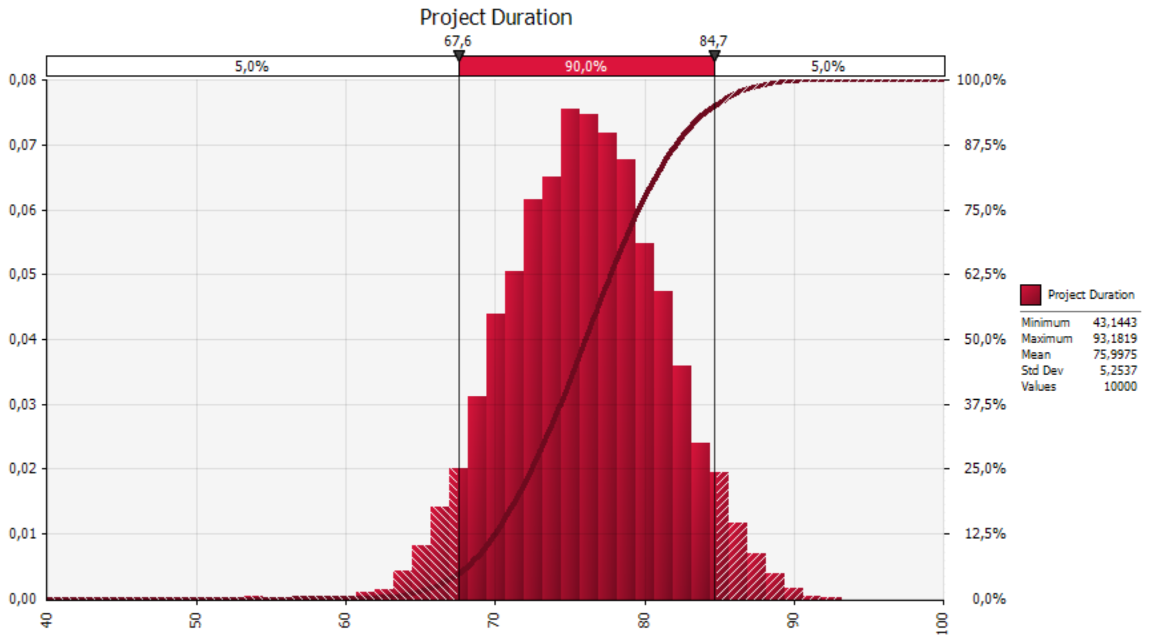


Fig. 4.18 Estimated Project Duration – *uniform* distribution

Mean estimated project duration: 76,00 weeks

Standard deviation: 5,25 weeks

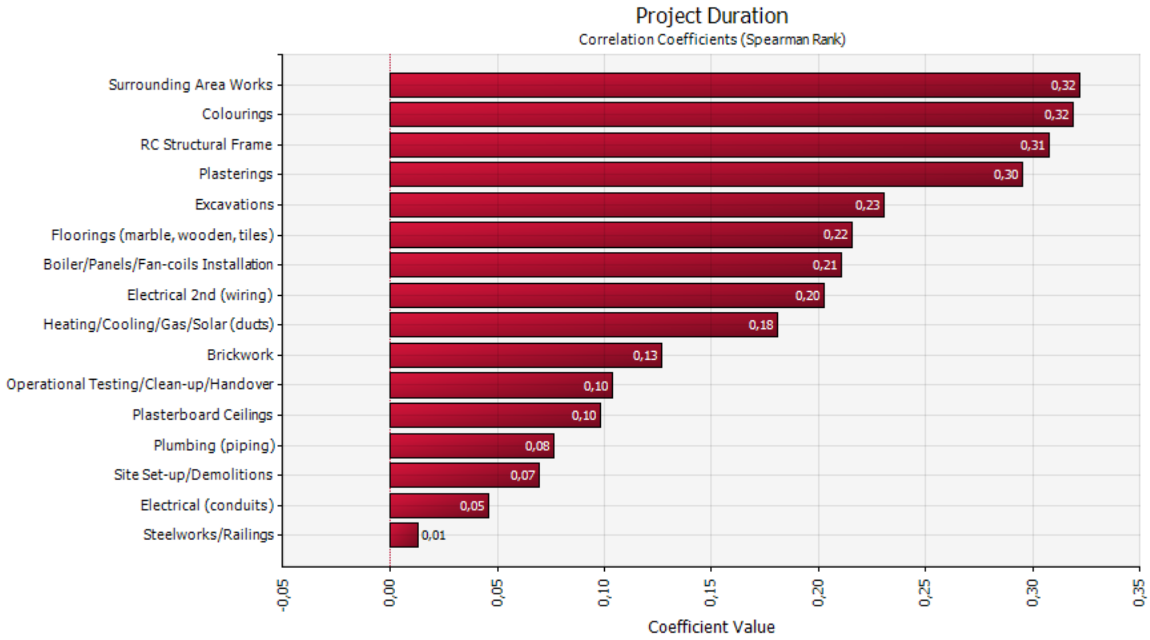


Fig. 4.19 Critical Work Packages for Project Duration – *uniform* distribution

Most critical work package/element (coefficient value): Surrounding Area Works (0,32)

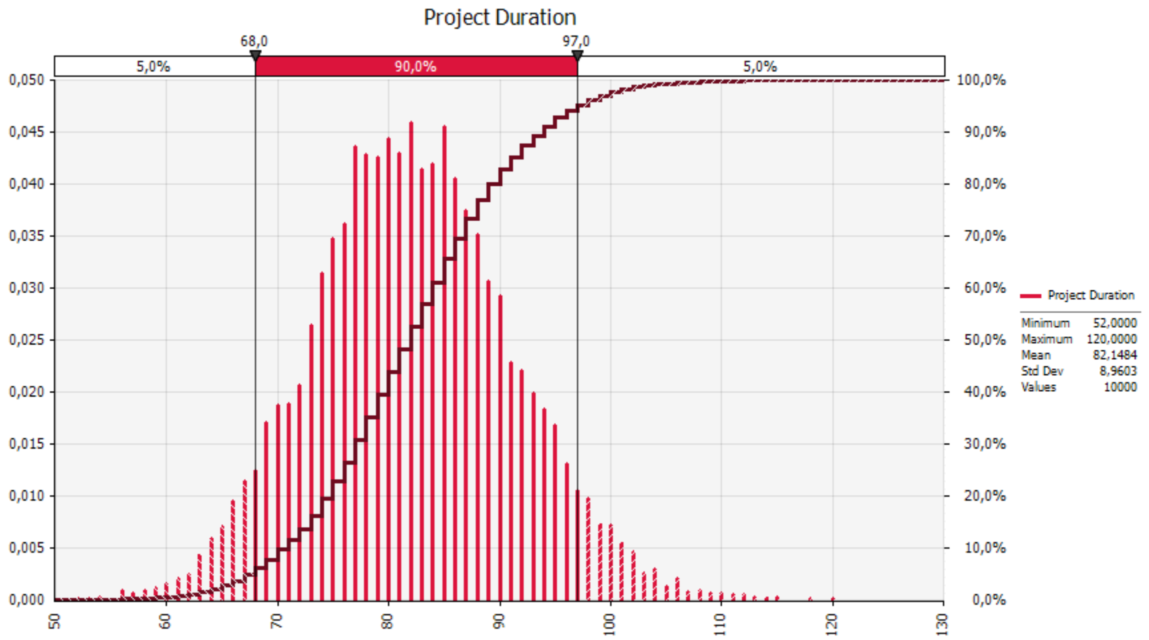


Fig. 4.20 Estimated Project Duration – *Poisson* distribution

Mean estimated project duration: 82,15 weeks

Standard deviation: 8,96 weeks

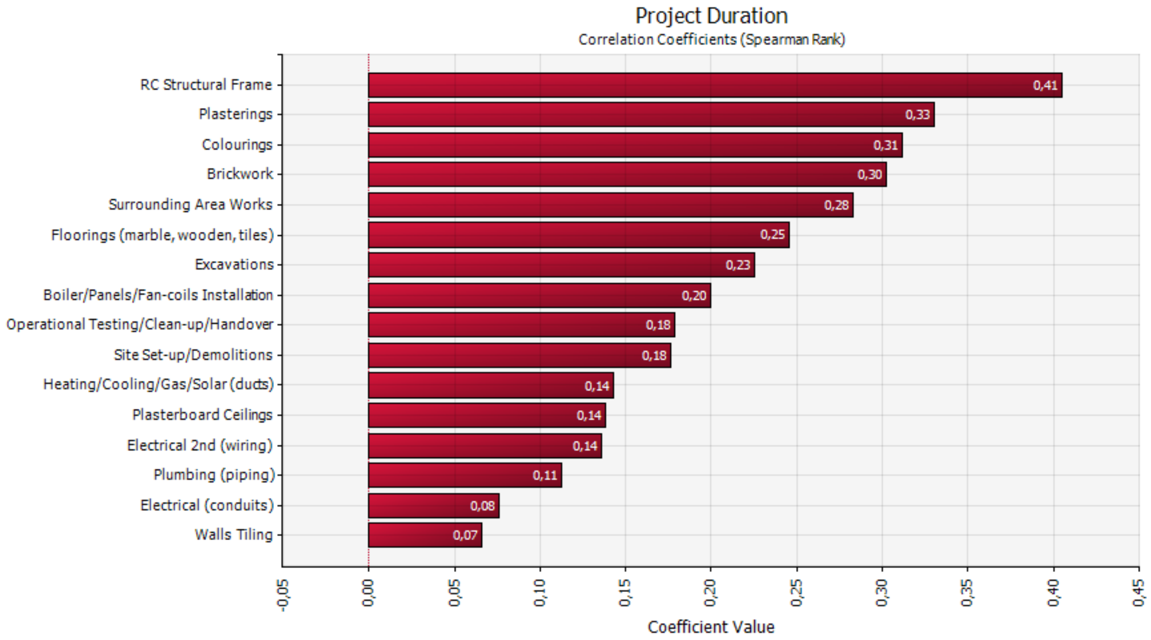


Fig. 4.21 Critical Work Packages for Project Duration – *Poisson* distribution

Most critical work package/element (coefficient value): RC Structural Frame (0,41)

Table 4.15 Summary of Results for Project Duration from MCS (10.000 iterations)

Probability Distribution	**Estimated Project Duration (in weeks)**					**Std Dev.**	**Most Critical Work Package/Element (Coefficient Value)**
	min	***5%***	***mean***	***95%***	***max***		
PERT	44,88	68,87	**75,57**	82,21	90,95	4,23	Colourings (0,26)
triangular	44,02	68,62	**75,65**	82,64	89,33	4,47	Colourings (0,28)
uniform	43,14	67,60	**76,00**	84,70	93,18	5,25	Surrounding Area Works (0,32)
Poisson	52,00	68,00	**82,15**	97,00	120,00	8,96	RC Structural Frame (0,41)

Table 4.15 indicates that the *PERT*, *triangular* and *uniform* distributions *underestimate* the average project completion – approx. 3 weeks earlier than the estimated project length of 79 weeks calculated by the standard CPM procedure. The *Poisson* distribution *overestimates* the average project completion time – approx. 3 weeks later than the CPM base case estimated duration and slightly higher than the contract deadline of 82 weeks. Furthermore, Figure 4.14 (page 268) shows that for a target value of 82 weeks, the calculated probability is 89,3%, higher than the 87,5% calculated by the traditional PERT analysis (Subsection 4.3.3.2, page 365). Nonetheless, it could be argued that the traditional PERT assumptions are justified.

4.3.3.3.2 Uncertain Project Direct Cost

In order to estimate project cost under uncertainty, the probability distribution functions are now assigned to work package or element direct cost. The three-point estimates (pessimistic, most likely and optimistic) for project direct cost that are used in the analysis are presented in Table 4.16 (page 273). The results in the form of histograms with cumulative distribution (*S*-curve) from each stochastic analysis for the estimated project cost (again 10.000 iterations), with the most significant (critical) work packages or elements (according to Spearman's rank correlation coefficients) are demonstrated in Figures 4.22-4.29 (pages 274-277) and are summarised in Table 4.17 (page 273).

Table 4.16 Three-Point Estimates for *Uncertain* Project Direct Cost (in €)

Work Package or Element (WP/E) **($i = 0, 1, \ldots, n, n+1$)**	**WP/E id no.**	**Optimistic (min) Direct Cost**	**Most Likely (normal) Direct Cost**	**Pessimistic (max) Direct Cost**
Project Start (Dummy)	0	0	0	0
Site Set-up/Demolitions	1	7600	8200	9000
Excavations	2	16600	18500	21100
RC Structural Frame	3	143300	145800	149100
Brickwork	4	14850	16100	17400
Metal Casing Pseudoframes	5	1900	2300	3000
Electrical 1st Fix (conduits)	6	28600	31900	35400
Plumbing (piping)	7	39100	42500	45800
Marble Sills	8	1800	2000	2400
Waterproofing/Roofs	9	12000	13700	15500
Plasterings	10	15200	16700	18600
Steelworks/Railings	11	11000	12000	13300
Electrical 2nd Fix (wiring)	12	17700	20100	22400
Walls Tiling	13	3800	4600	5000
Heating/Cooling/Gas/Solar (ducts)	14	16100	17200	19900
Floorings (marble, wooden, tiles)	15	11800	13400	15700
Doors/Windows	16	35600	39200	42000
Joinery	17	9000	10400	11900
Bathrooms/WC Fixtures	18	2900	3500	4700
Boiler/Panels/Fan-coils Installation	19	38500	43200	48000
Elevator	20	10200	12000	15300
Plasterboard Ceilings	21	6400	7700	9000
Colourings	22	17000	18900	22200
Lighting/Electrical Finishings/Minor Works	23	16500	17600	19800
Surrounding Area Works	24	22500	24700	27100
Operational Testing/Clean-up/Handover	25	2500	3300	4400
Project Finish (Dummy)	26	0	0	0

Table 4.17 Summary of Results for Project Direct Cost from MCS (10.000 iterations)

Probability Distribution	**Estimated Project Direct Cost (in €)**					**Std Dev.**	**Most Critical Work Package/Element (Coefficient Value)**
	min	***5%***	***mean***	***95%***	***max***		
PERT	532249	540400	**547075**	553840	561980	4089	Boiler/Panels/Fan-coils (0,43)
triangular	531883	541300	**548650**	556080	565481	4470	Boiler/Panels/Fan-coils (0,42)
uniform	529944	539660	**550225**	560710	572830	6346	Boiler/Panels/Fan-coils (0,42)
Poisson	542923	544300	**545500**	546730	548192	739	RC Structural Frame (0,49)

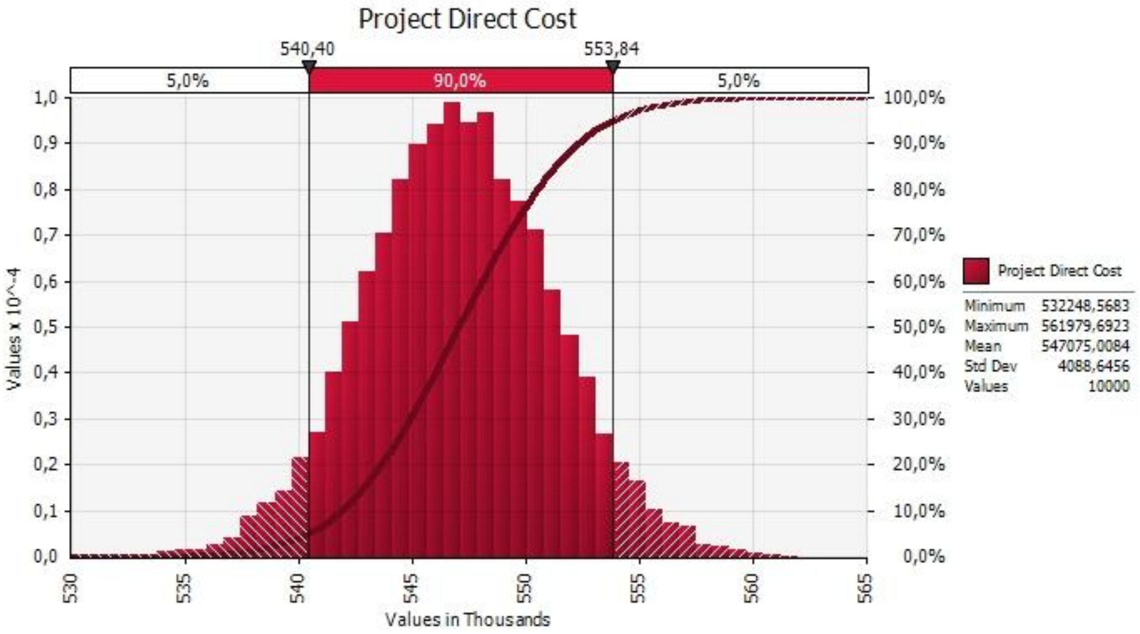


Fig. 4.22 Estimated Project Direct Cost – *PERT* distribution

Mean estimated project total direct cost: €547.075,00

Standard deviation: €4.088,65

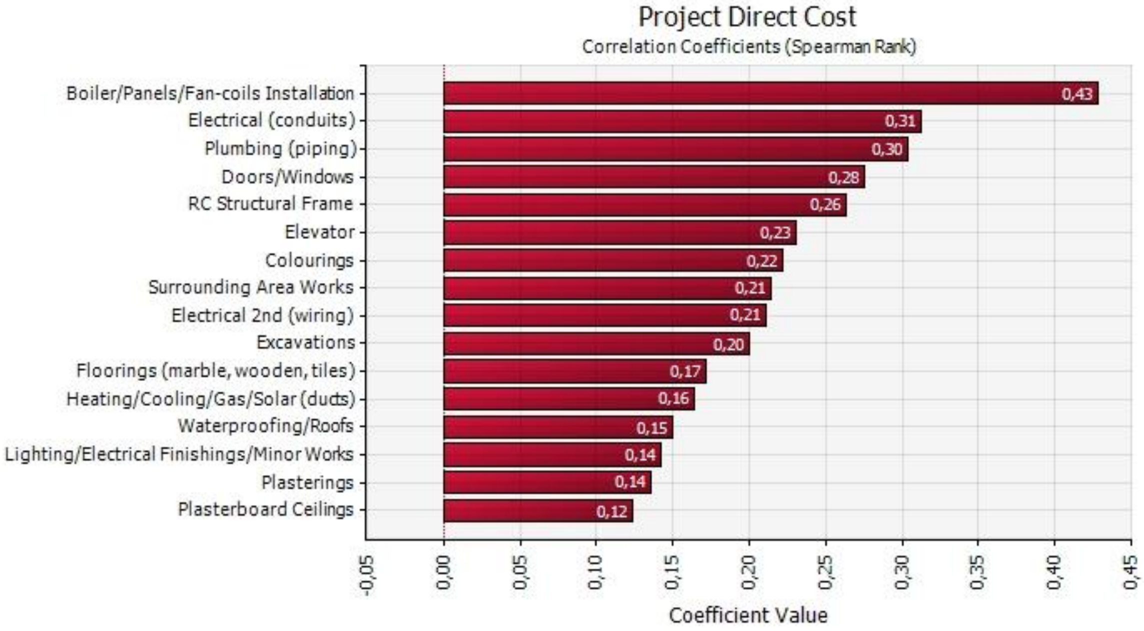


Fig. 4.23 Critical Work Packages for Project Direct Cost – *PERT* distribution

Most critical work package/element (coefficient value): Boiler/Panels/Fan-coils (0,43)

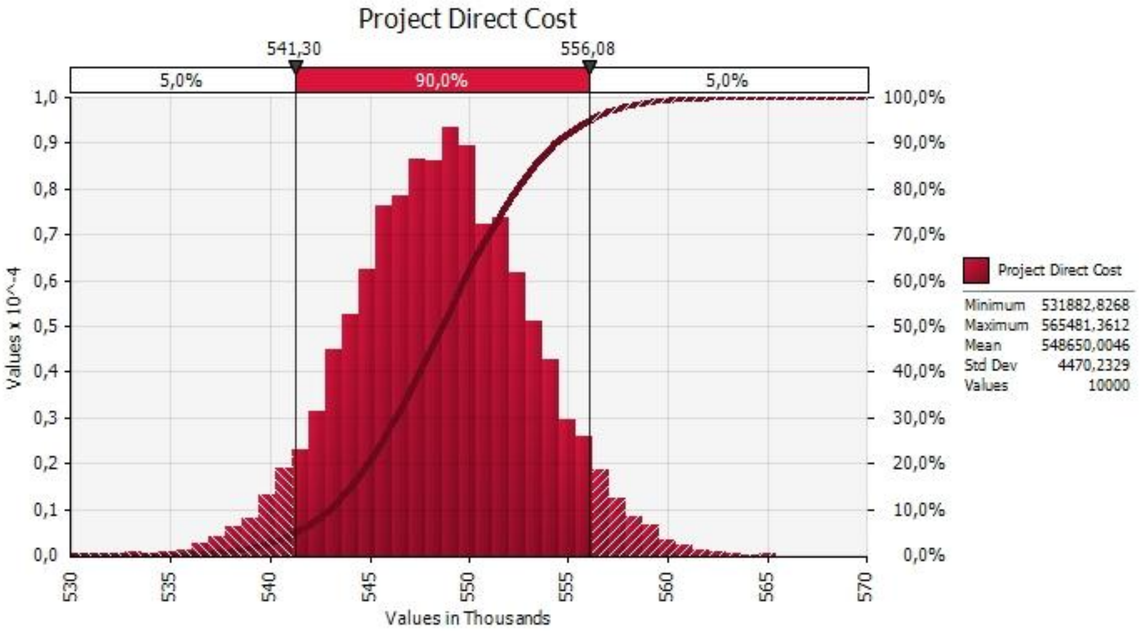


Fig. 4.24 Estimated Project Direct Cost – *triangular* distribution

Mean estimated project total direct cost: €548.650,00

Standard deviation: €4.470,23

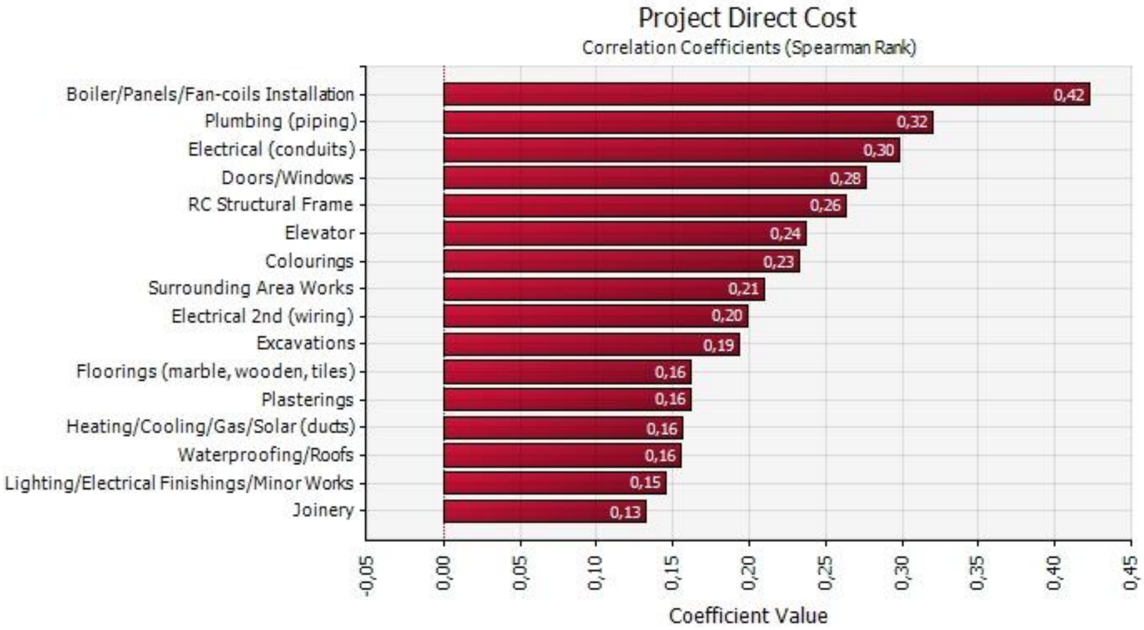


Fig. 4.25 Critical Work Packages for Project Direct Cost – *triangular* distribution

Most critical work package/element (coefficient value): Boiler/Panels/Fan-coils (0,42)

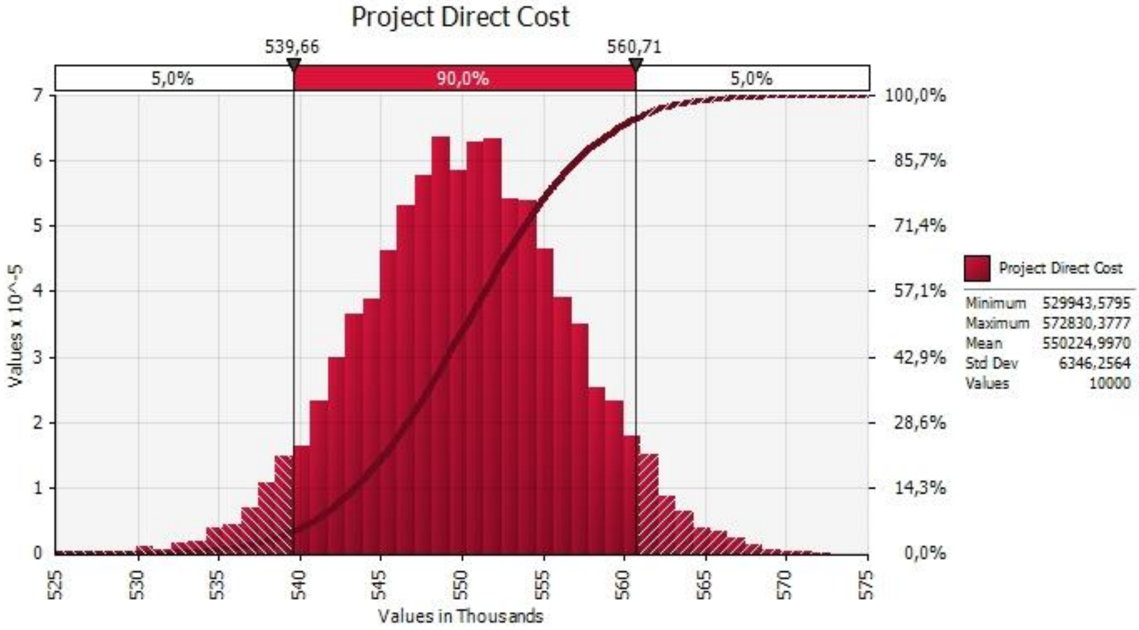


Fig. 4.26 Estimated Project Direct Cost – *uniform* distribution

Mean estimated project total direct cost: €550.225,00

Standard deviation: €6.346,26

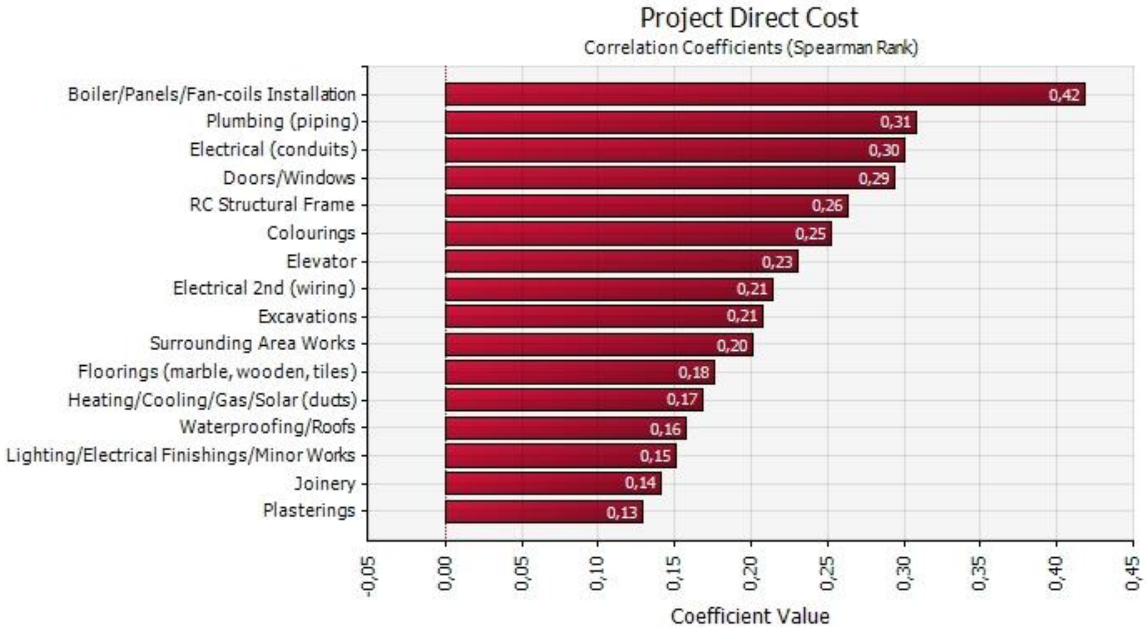


Fig. 4.27 Critical Work Packages for Project Direct Cost – *uniform* distribution

Most critical work package/element (coefficient value): Boiler/Panels/Fan-coils (0,42)

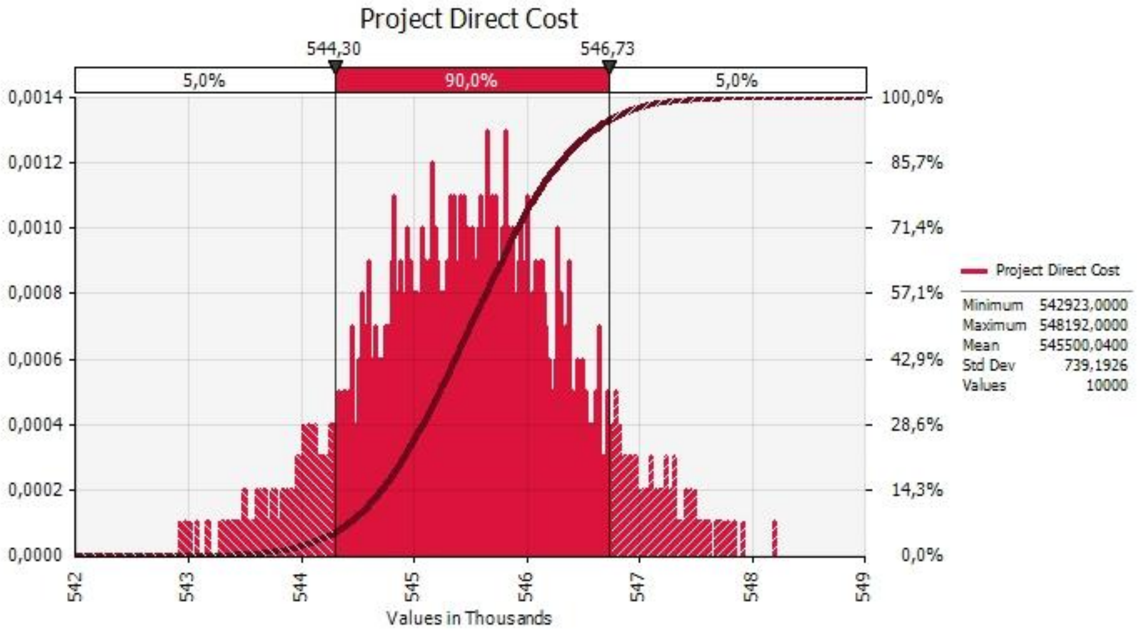


Fig. 4.28 Estimated Project Direct Cost – *Poisson* distribution

Mean estimated project total direct cost: €545.500,00

Standard deviation: €739,19

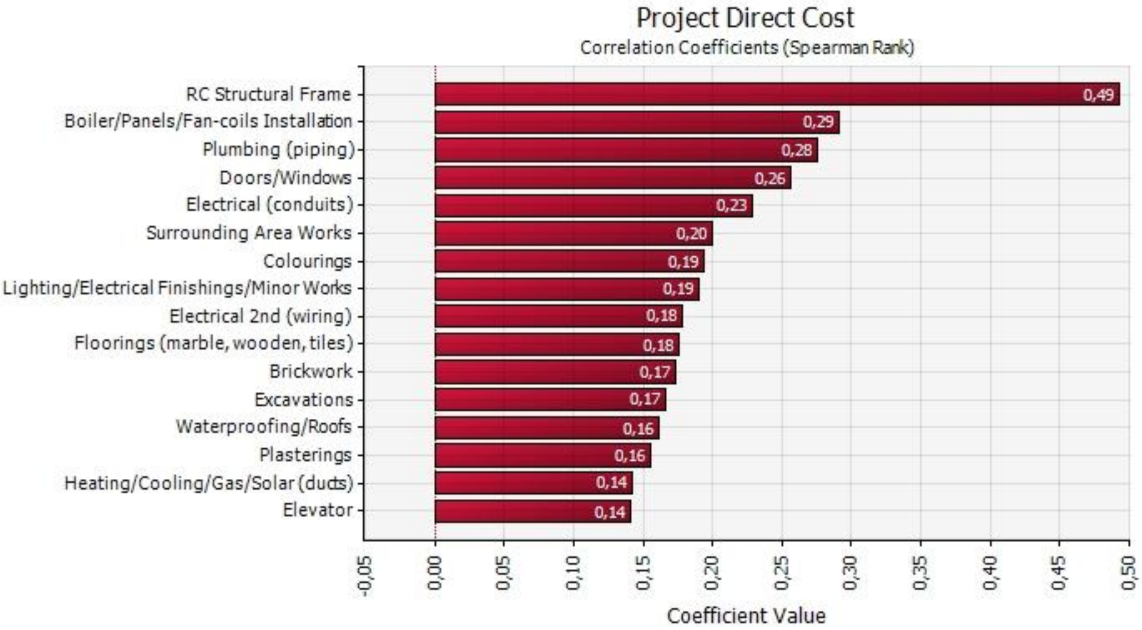


Fig. 4.29 Critical Work Packages for Project Direct Cost – *Poisson* distribution

Most critical work package/element (coefficient value): RC Structural Frame (0,49)

Table 4.17 (page 273) shows that the *PERT*, *triangular* and *uniform* distributions give almost equal estimates of project total direct cost, slightly *overestimating* the deterministic base-case and *Poisson* distribution estimates of €545.000,00 and €545.500,00 respectively. Furthermore, in all first three cases it appears that the installation of boiler, panels and fan-coils is the most significant work package or element whilst in the case of the *Poisson* distribution the most critical work is the reinforced concrete structural building frame.

Table 4.18 Time-Cost Trade-off (TCT) Analysis Required Data (in weeks and in €)

Work Package or Element (WP/E) **($i = 0, 1, \ldots, n, n+1$)**	**WP/E id no.**	**Normal Time (d_i)**	**Crash Time (c_i)**	**Normal Direct Cost (D_i^n)**	**Crash Direct Cost (D_i^c)**
Project Start (Dummy)	0	0	0	0	0
Site Setup/Demolitions	1	3	2	8200	13120
Excavations	2	4	3	18500	29600
RC Structural Frame	3	14	10	145800	233280
Brickwork	4	8	6	16100	25760
Metal Casing Pseudoframes	5	2	1	2300	3680
Electrical 1st Fix (conduits)	6	3	2	31900	51040
Plumbing (piping)	7	4	3	42500	68000
Marble Sills	8	2	1	2000	3200
Waterproofing/Roofs	9	4	3	13700	21920
Plasterings	10	9	6	16700	26720
Steelworks/Railings	11	2	1	12000	19200
Electrical 2nd Fix (wiring)	12	3	2	20100	32160
Walls Tiling	13	2	1	4600	7360
Heating/Cooling/Gas/Solar (ducts)	14	3	2	17200	27520
Floorings (marble, wooden, tiles)	15	6	4	13400	21440
Doors/Windows	16	5	3	39200	62720
Joinery	17	3	2	10400	16640
Bathrooms/WC Fixtures	18	2	1	3500	5600
Boiler/Panels/Fan-coils Installation	19	4	1	43200	69120
Elevator	20	2	1	12000	19200
Plasterboard Ceilings	21	2	1	7700	12320
Colourings	22	10	7	18900	30240
Lighting/Electrical Finishings/Minor Works	23	3	2	17600	28160
Surrounding Area Works	24	6	4	24700	39520
Operational Testing/Clean-up/Handover	25	3	2	3300	5280
Project Finish (Dummy)	26	0	0	0	0

Table 4.19 Time-Cost Trade-off (TCT) Analysis Basic Calculations (in weeks and in €)

Work Package or Element (WP/E) **($i = 0, 1, \ldots, n, n+1$)**	**WP/E id no.**	**max Time Reduction (r_i^{max})**	**Additional Cost for Crashing (A_i)**	**Additional Cost for Crashing per Time Unit Saved (A_i^t)**
Project Start (Dummy)	0	0	0	0
Site Setup/Demolitions	1	1	4920	4920
Excavations	2	1	11100	11100
RC Structural Frame	3	4	87480	21870
Brickwork	4	2	9660	4830
Metal Casing Pseudoframes	5	1	1380	1380
Electrical 1st Fix (conduits)	6	1	19140	19140
Plumbing (piping)	7	1	25500	25500
Marble Sills	8	1	1200	1200
Waterproofing/Roofs	9	1	8220	8220
Plasterings	10	3	10020	3340
Steelworks/Railings	11	1	7200	7200
Electrical 2nd Fix (wiring)	12	1	12060	12060
Walls Tiling	13	1	2760	2760
Heating/Cooling/Gas/Solar (ducts)	14	1	10320	10320
Floorings (marble, wooden, tiles)	15	2	8040	4020
Doors/Windows	16	2	23520	11760
Joinery	17	1	6240	6240
Bathrooms/WC Fixtures	18	1	2100	2100
Boiler/Panels/Fan-coils Installation	19	3	25920	8640
Elevator	20	1	7200	7200
Plasterboard Ceilings	21	1	4620	4620
Colourings	22	3	11340	3780
Lighting/Electrical Finishings/Minor Works	23	1	10560	10560
Surrounding Area Works	24	2	14820	7410
Operational Testing/Clean-up/Handover	25	1	1980	1980
Project Finish (Dummy)	26	0	0	0

4.3.3.4 Critical Path Method (CPM) and Time-Cost Trade-Off (TCT)

If the project duration is not compliant with the contract baseline, there is a need to impose other dependencies or added resources in order to reduce the project total duration (‘project crashing’). Scheduling is normally referred to as time allocation; however, since time is a function of resource usage and the inherent related cost, possible trade-offs exist between time and cost, and, generally, between time and resources. In such cases, the construction manager has the opportunity to select a work package or element time anywhere between *normal* (maximum) time and *crash* (minimum) time. This choice of operational timing, that clearly affects the project completion duration, implies an associated operational normal and crash cost (Tables 4.18-4.19, pages 278-279). The proposed mathematical model for project time/cost optimisation assumes the rough approximation that cost is a *linear* function of time as in the original CPM (Figure 2.22.a, page 136) (Lockyer, 1974).

Table 4.20 Numerical Results from TCT Linear Programming Analysis with Solver

	Project Duration	Direct Cost	Over-heads	Crash Cost	Total Cost	Bonus (B)	Penalty (P)	Contract ± (B/P)	Gross Profit
Crashed	**53**	**545500**	**265000**	**237780**	**1048280**			**1215000**	**166720**
	54	545500	270000	212280	1027780			1215000	187220
	55	545500	275000	190410	1010910			1215000	204090
	56	545500	280000	168540	994040			1215000	220960
	57	545500	285000	146670	977170			1215000	237830
	58	545500	290000	124800	960300			1215000	254700
	59	545500	295000	112740	953240			1215000	261760
	60	545500	300000	101640	947140			1215000	267860
	61	545500	305000	91320	941820			1215000	273180
	62	545500	310000	82680	938180			1215000	276820
	63	545500	315000	74040	934540			1215000	280460
	64	545500	320000	65400	930900			1215000	284100
	65	545500	325000	57990	928490			1215000	286510
Optimum*	**66**	**545500**	**330000**	**50580**	**926080**			**1215000**	**288920**
	67	545500	335000	45660	926160			1215000	288840
	68	545500	340000	40830	926330			1215000	288670
	69	545500	345000	36000	926500			1215000	288500
	70	545500	350000	31380	926880			1215000	288120
	71	545500	355000	27360	927860			1215000	287140
Bonus	**72**	**545500**	**360000**	**23340**	**928840**	**1500**		**1215000**	**286160**
Bonus	73	545500	365000	19560	930060	1500		1213500	283440
Bonus	74	545500	370000	15780	931280	1500		1212000	280720
Bonus	75	545500	375000	12000	932500	1500		1210500	278000
Bonus	76	545500	380000	8660	934160	1500		1209000	274840
Bonus	77	545500	385000	5320	935820	1500		1207500	271680
Bonus	78	545500	390000	1980	937480	1500		1206000	268520
Normal	**79**	**545500**	**395000**	**0**	**940500**	**1500**		**1204500**	**264000**
Bonus/Float	80	545500	400000	0	945500	1500		1203000	257500
Bonus/Float	81	545500	405000	0	950500	1500		1201500	251000
Deadline	**82**	**545500**	**410000**	**0**	**955500**	**0**	**0**	**1200000**	**244500**
Penalty	83	545500	415000	0	960500		-2500	1197500	237000
Penalty	84	545500	420000	0	965500		-2500	1195000	229500
Penalty	85	545500	425000	0	970500		-2500	1192500	222000
Penalty	86	545500	430000	0	975500		-2500	1190000	214500

Hajdu (2013b) argued that collecting reliable data on crash activity durations and costs is a demanding job, very often with highly uncertain results, and suggested that a ‘70-30’ principle can be applied to the construction TCT problem, i.e. to set crash durations to the 70% of the normal ones with an associated 30% rise in costs.

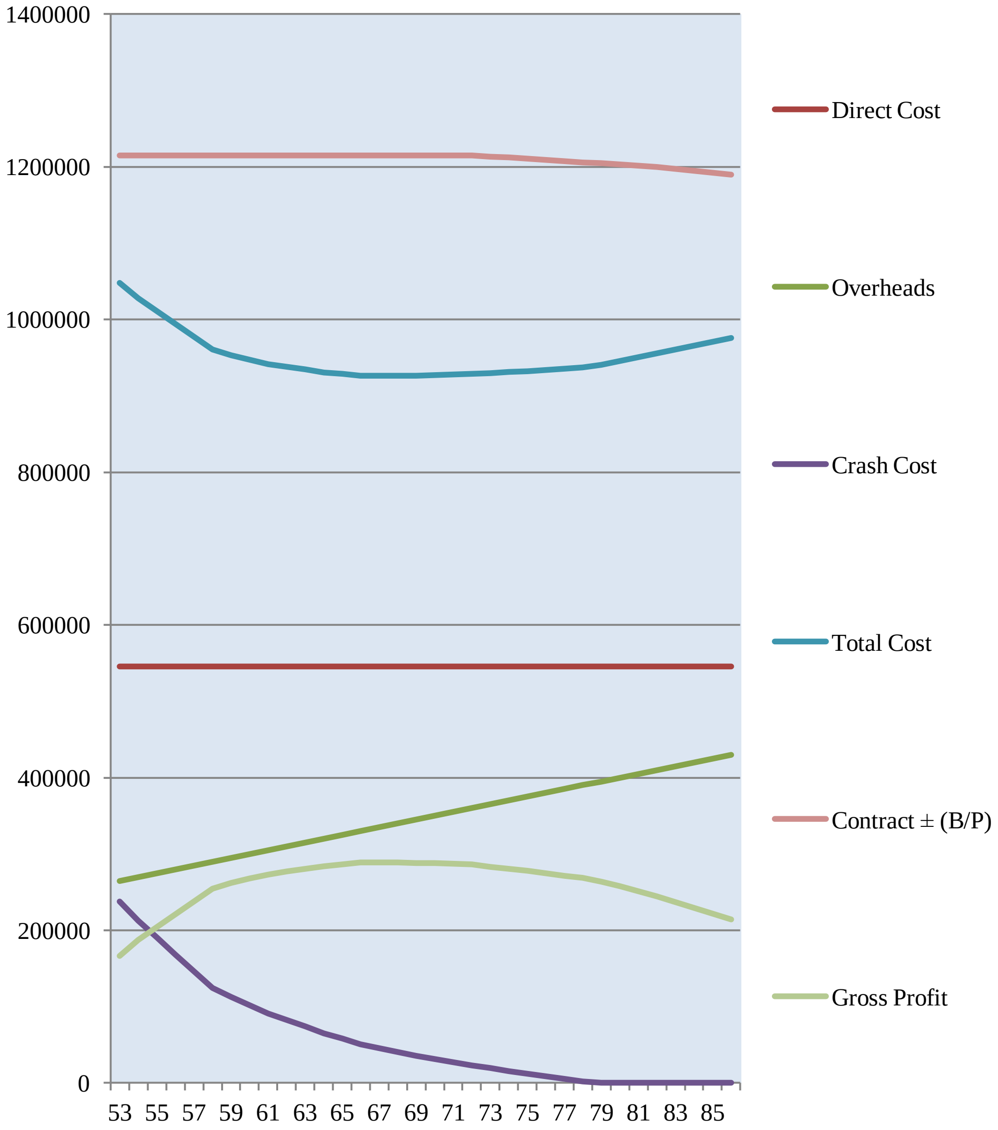


Fig. 4.30 Graphical Results from TCT Linear Programming Analysis with Solver

Therefore, the answer to the following critical TCT question is:

- *What is the least expensive (optimum) way of reducing the project duration below its normal value?*

The optimal project duration is 66 weeks at a total project cost of €926.080,00 with a gross profit of €288.920,00. Nonetheless, the results indicate that fully crashing the project may also be a viable management option, considering the (considerably less but) positive return (gross profit).

The schematic representation of the TCT numerical results of Table 4.20 (page 280) can be seen in Figure 4.30 (page 281). Furthermore, Figure 4.31 shows *'best fit'* cost and revenue curves per project completion time as derived from Excel.

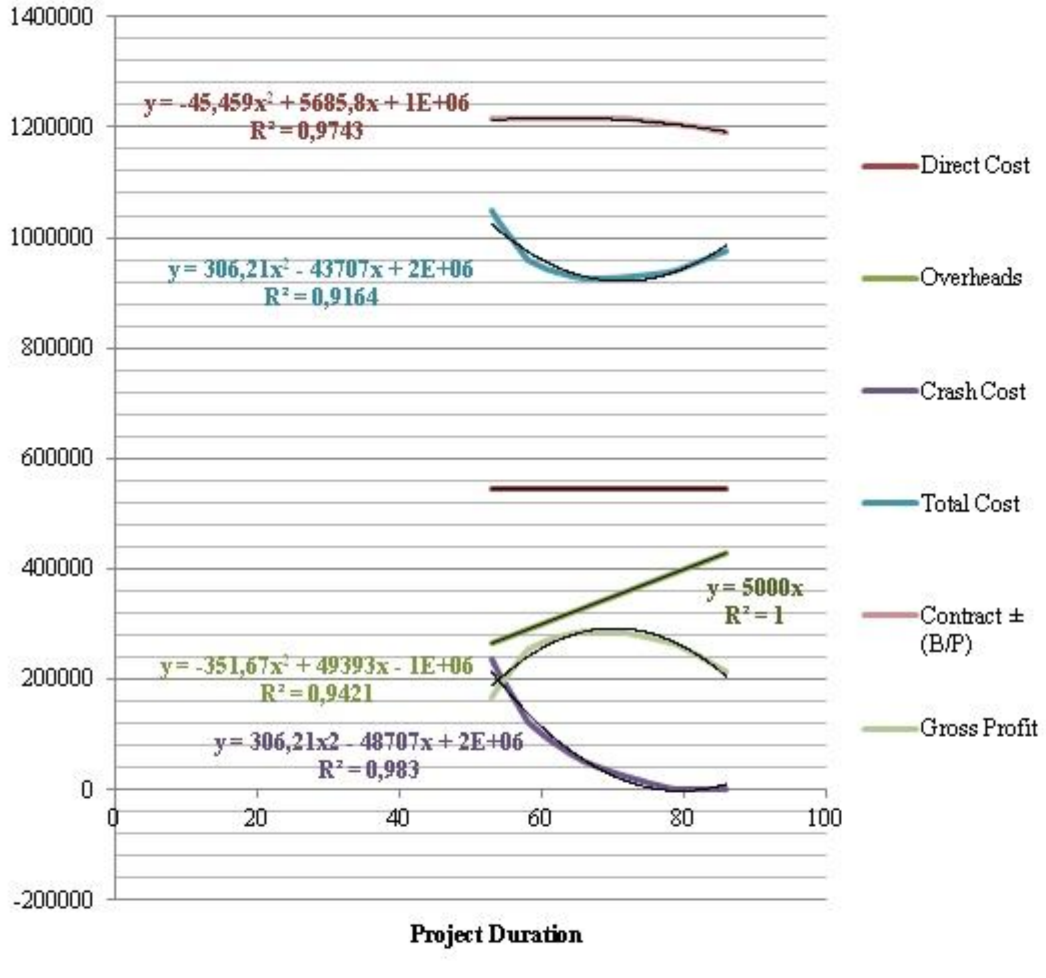


Fig. 4.31 Excel's *'Best Fit'* Cost and Revenue Curves per Project Duration

Figure 4.32 (page 283) illustrates the project AoN network for *optimum* scheduling based on the previously presented TCT analysis for the commercial building project.

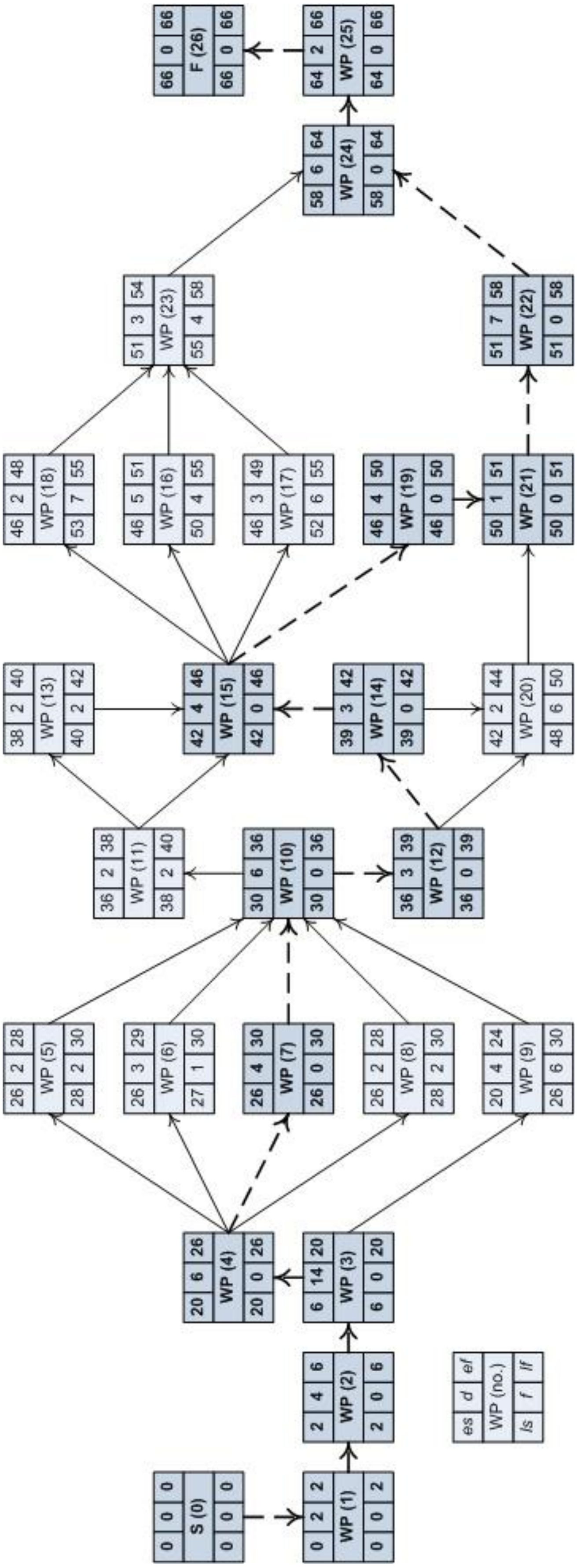


Fig. 4.32 AoN Network for *Optimum* Scheduling (**Critical Path** with **bold** and dashed lines)

4.3.3.5 Schedule/Cost Quantitative Risk Analysis (QRA)

A quantitative risk analysis (QRA) of the most significant schedule and cost risks (and opportunities) for the commercial building project and how these relate to each other is described as follows:

The excavations will take (*pessimistic*, *most likely*, *optimistic*) = (2, 4, 6) weeks at a total direct cost of €(16600, 18500, 21100). However, there is a 25% chance of finding significant artefacts that will require an archaeological survey (before any building work can start) which will take (5, 8, 11) weeks at a total cost of €(19700, 22000, 24500). In addition, from information gathered by nearby construction sites, there is a 30% chance of finding high water table that will delay the excavation work to a duration of (3, 5, 7) weeks at an associated total cost of €(18500, 20300, 22600). Accordingly, if the water table problem occurs, there is also a 30% chance of selecting the technique of *radier* foundation instead of the typical strip foundations; as a result, the total duration of the construction of the reinforced concrete structural frame will be reduced from (11, 14, 17) weeks to (10, 12, 15) at an increased total cost of €(157500, 165000, 168600). There is also a 50% chance of using thermal insulation special blocks instead of the typical bricks for constructing the external brickwork which will again reduce the duration of brickwork work package to (6, 7, 8) weeks at a higher total cost of €(18500, 19600, 20700). The selection of placing a ‘green roof’ on the building has a chance of 40% with a duration of (3, 5, 7) weeks and a cost of €(18800, 21500, 23400). There is a 50% chance that an external thermal insulation system will be preferred as external envelope instead of the traditional plasterings with a reduced duration of (4, 7, 10) weeks but an increased total cost of €(18400, 21500, 23800). The above selection of a thermal insulation system will have an effect on the colourings work package by reducing both total duration and cost to (5, 8, 11) weeks and €(9300, 11300, 13700) respectively. Moreover, there is a 35%

possibility that a ‘smart building’ installation is requested by the client at a total cost of €(23100, 25300, 27200) with a duration of (2, 4, 6) weeks. The surrounding area works are 25% likely to be affected by bad weather resulting in a delayed duration of (5, 8, 11) and an increased cost of €(24200, 26300, 29000). Finally, there is a 20% chance that the subcontractor for operational testing/clean-up/handover work package to will be called back for additional close-out work with a new duration of (4, 5, 6) weeks at a total new cost of €(3600, 4200, 5500).

Tables 4.21 and 4.24 (pages 286 and 292 respectively) present the uncertain durations and direct costs for the work packages or elements of the commercial building project under study, including the most significant *risks* and *opportunities*. Table 4.22 (page 287) shows the basic QRA/CPM calculations in order to find the project *critical path* based on the aforementioned project risks and opportunities. From the analysis, it is evident that the critical path is *not sensitive* to the type of probability distribution function used. Figures 4.33-4.36 (pages 288-291) illustrate QRA/MCS summary graphical results for the project duration for *PERT*, *triangular, uniform* and *Poisson* distribution functions. Selected results for specific work packages or elements are also presented (excavations, reinforced concrete structural frame, colourings and plasterings) in order to demonstrate the effect of using the *discrete* distribution for the modelling of the combined results from project risks and opportunities. Accordingly, Figures 4.37-4.40 (pages 293-296) give QRA/MCS summary results for the project total direct cost for *PERT*, *triangular*, *uniform* and *Poisson* distribution functions. Tables 4.23 (page 287) and 4.25 (page 297) present QRA/MCS numerical results for both project total duration and direct cost. It can be seen that the incorporation of the effect of potential risks and opportunities for the project can significantly change the analysis results. Therefore, it could be suggested that schedule and cost estimation of building projects should be performed with the use of QRA.

Table 4.21 QRA *Risks* and *Opportunities* for Project Duration (in weeks)

Work Package or Element (WP/E)	WP/E no.	*Uncertain Duration*	Minimum	Most Likely	Maximum	*Probability*
Project Start (Dummy)	**0**	0	0	0	0	
Site Set-up/Demolitions	**1**	3	2	3	4	
Excavations	**2**	4	2	4	6	0,45
Archaeological findings		8	5	8	11	0,25
Water table problem		5	3	5	7	0,30
Subtotal (2)		**5**				**1**
RC Structural Frame	**3**	14	11	14	17	0,70
Radier foundation (if water table problem)		12	10	12	14	0,30
Subtotal (3)		**14**				**1**
Brickwork	**4**	8	7	8	9	0,50
Use of thermal insulation blocks		7	6	7	8	0,50
Subtotal (4)		**7**				**1**
Metal Casing Pseudoframes	**5**	2	1	2	3	
Electrical (conduits)	**6**	3	1	3	5	
Plumbing (piping)	**7**	4	3	4	5	
Marble Sills	**8**	2	1	2	3	
Waterproofing/Roofs	**9**	4	2	4	6	0,60
Green roof		5	3	5	7	0,40
Subtotal (9)		**4**				**1**
Plasterings	**10**	9	6	9	12	0,50
External thermal insulation system		7	4	7	10	0,50
Subtotal (10)		**7**				**1**
Steelworks/Railings	**11**	2	1	2	3	
Electrical 2nd (wiring)	**12**	3	1	3	5	
Walls Tiling	**13**	2	1	2	3	
Heating/Cooling/Gas/Solar (ducts)	**14**	3	1	3	5	
Floorings (marble, wooden, tiles)	**15**	6	4	6	8	
Doors/Windows	**16**	5	2	5	8	
Joinery	**17**	3	2	3	4	
Bathrooms/WC Fixtures	**18**	2	1	2	3	
Boiler/Panels/Fan-coils Installation	**19**	4	2	4	6	
Elevator	**20**	2	1	2	3	
Plasterboard Ceilings	**21**	2	1	2	3	
Colourings	**22**	10	7	10	13	0,50
External thermal insulation system		8	5	8	11	0,50
Subtotal (22)		**8**				**1**
Lighting/Electrical Finishings/Minor Works	**23**	3	1	3	5	0,65
Smart Building installation		4	2	4	6	0,35
Subtotal (23)		**3**				**1**
Surrounding Area Works	**24**	6	3	6	9	0,75
Bad weather		8	5	8	11	0,25
Subtotal (24)		**6**				**1**
Operational Testing/Clean-up/Handover	**25**	3	2	3	4	0,80
Additional close-out work		5	4	5	6	0,20
Subtotal (25)		**3**				**1**
Project Finish (Dummy)	**26**	0	0	0	0	

Table 4.22 QRA/CPM Calculations (*PERT*, *triangular*, *uniform*, *Poisson* distributions)

Normal Time (d_i)	***Early Start Time (es_i)***	***Early Finish Time (ef_i)***	***Late Start Time (ls_i)***	***Late Finish Time (lf_i)***	***Total Float (tf_i)***	***Critical Path***
0	**0**	**0**	**0**	**0**	**0**	**1**
3	**0**	**3**	**0**	**3**	**0**	**1**
5	**3**	**8**	**3**	**8**	**0**	**1**
14	**8**	**22**	**8**	**22**	**0**	**1**
7	**22**	**29**	**22**	**29**	**0**	**1**
2	29	31	31	33	2	0
3	29	32	30	33	1	0
4	**29**	**33**	**29**	**33**	**0**	**1**
2	29	31	31	33	2	0
4	22	26	29	33	7	0
7	**33**	**40**	**33**	**40**	**0**	**1**
2	40	42	42	44	2	0
3	**40**	**43**	**40**	**43**	**0**	**1**
2	42	44	44	46	2	0
3	**43**	**46**	**43**	**46**	**0**	**1**
6	**46**	**52**	**46**	**52**	**0**	**1**
5	52	57	58	63	6	0
3	52	55	60	63	8	0
2	52	54	61	63	9	0
4	**52**	**56**	**52**	**56**	**0**	**1**
2	46	48	54	56	8	0
2	**56**	**58**	**56**	**58**	**0**	**1**
8	**58**	**66**	**58**	**66**	**0**	**1**
3	57	60	63	66	6	0
6	**66**	**72**	**66**	**72**	**0**	**1**
3	**72**	**75**	**72**	**75**	**0**	**1**
0	**75**	**75**	**75**	**75**	**0**	**1**

75	***Uncertain* Project Total Duration (*PERT, triangular, uniform* and *Poisson* distributions)**

Table 4.23 Summary of QRA/MCS Results for Project Duration (10.000 iterations)

Probability Distribution	**Estimated Project Duration (in weeks)**					**Std Dev.**	**Most Critical Work Package/Element (Coefficient Value)**
	min	***5%***	***mean***	***95%***	***max***		
PERT	45,38	66,39	**74,90**	83,05	92,51	5,13	Excavations (0,40)
triangular	44,92	66,37	**74,92**	83,25	94,27	5,19	Excavations (0,38)
uniform	38,08	64,80	**74,38**	84,10	96,40	5,98	Excavations (0,38)
Poisson	53,00	67,00	**81,52**	97,00	118,00	9,09	RC Structural Frame (0,39)

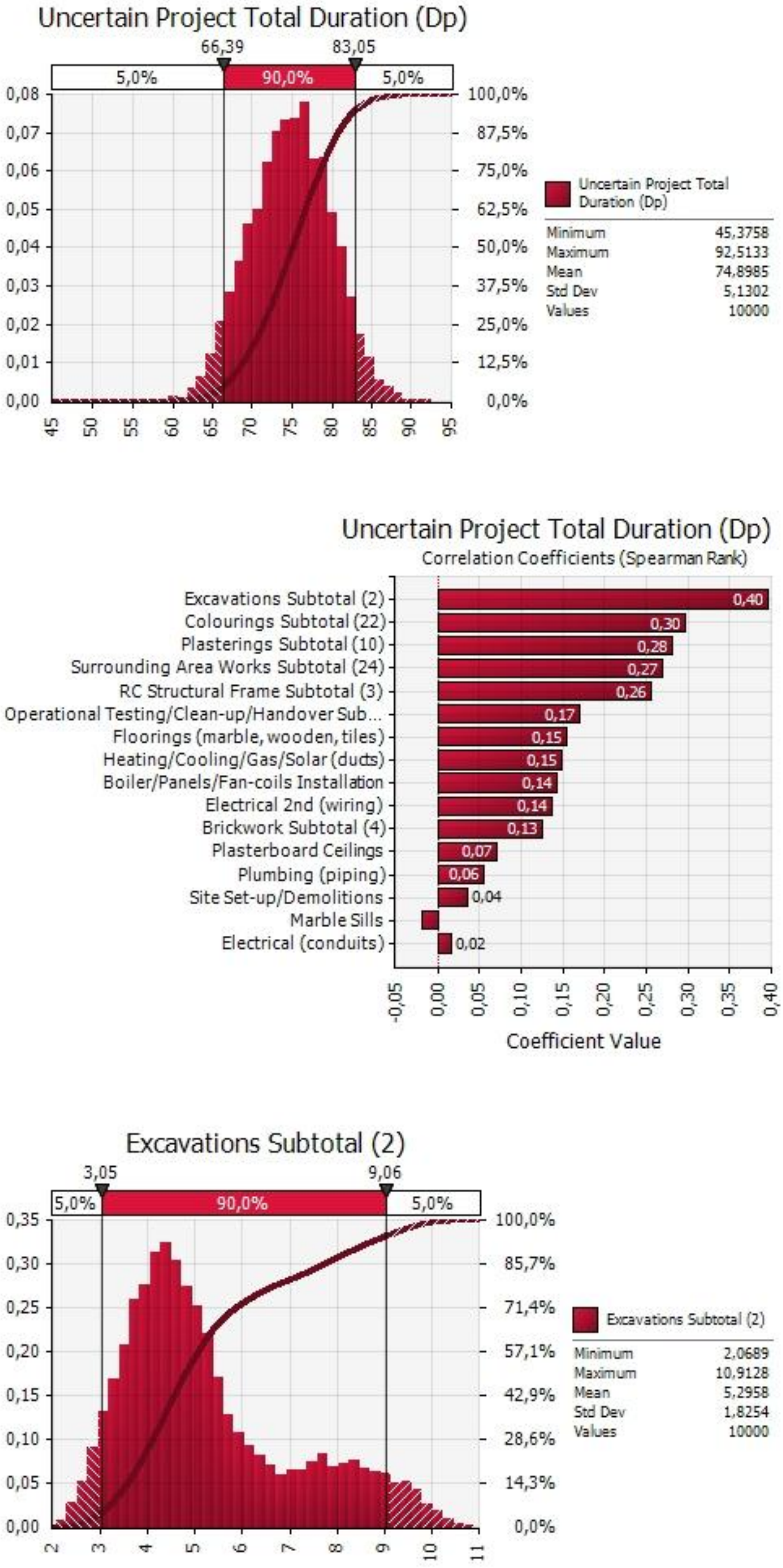


Fig. 4.33 QRA/MCS Summary Results for Project Duration – *PERT* distribution

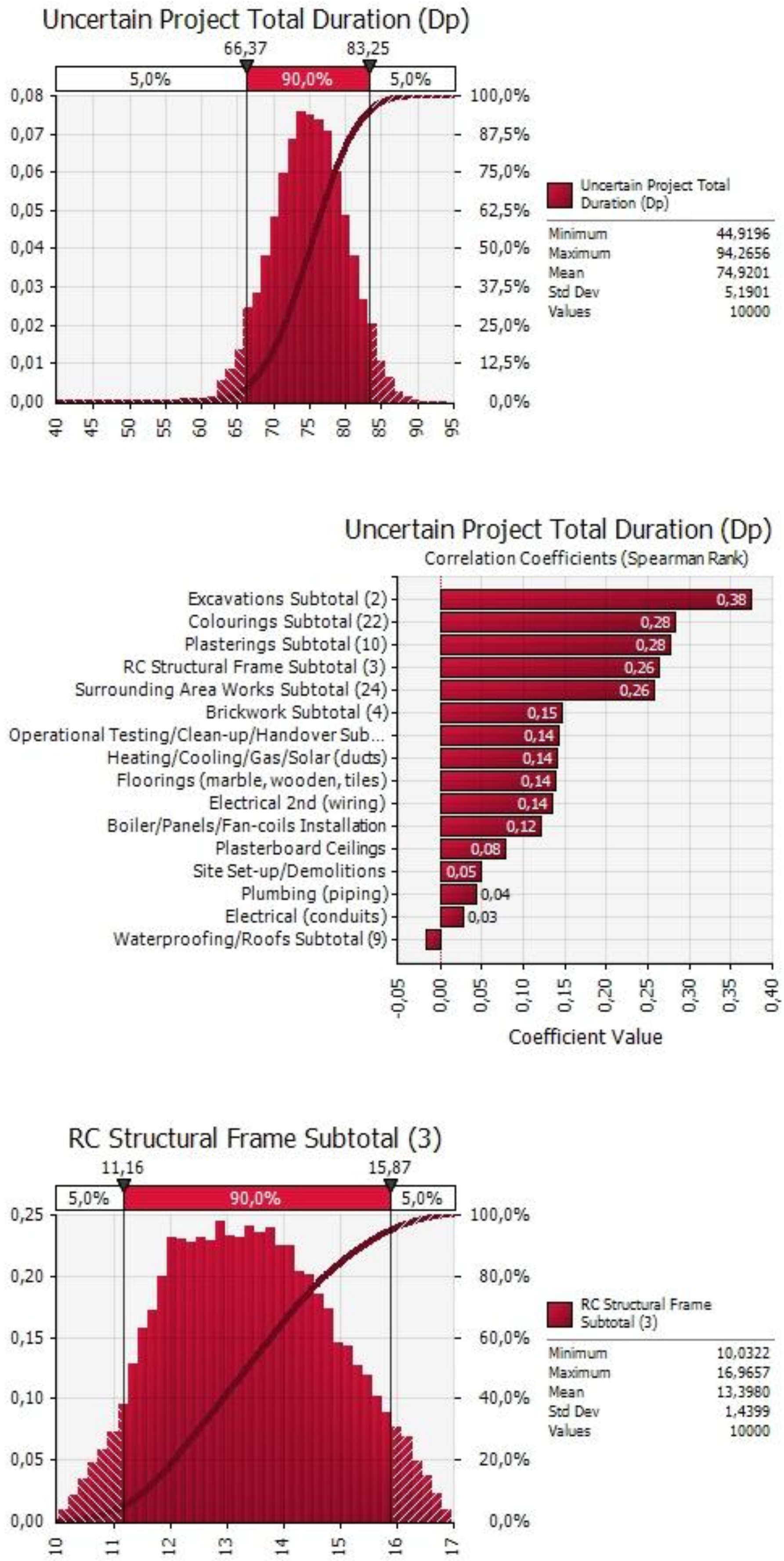
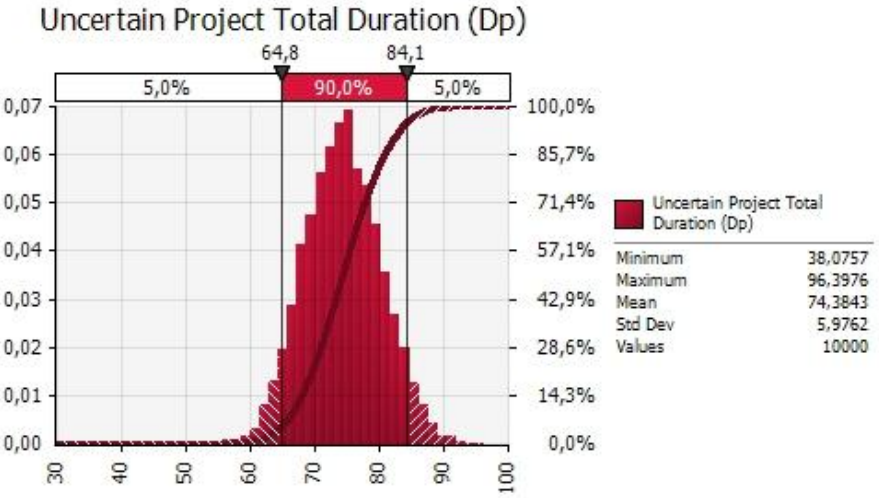
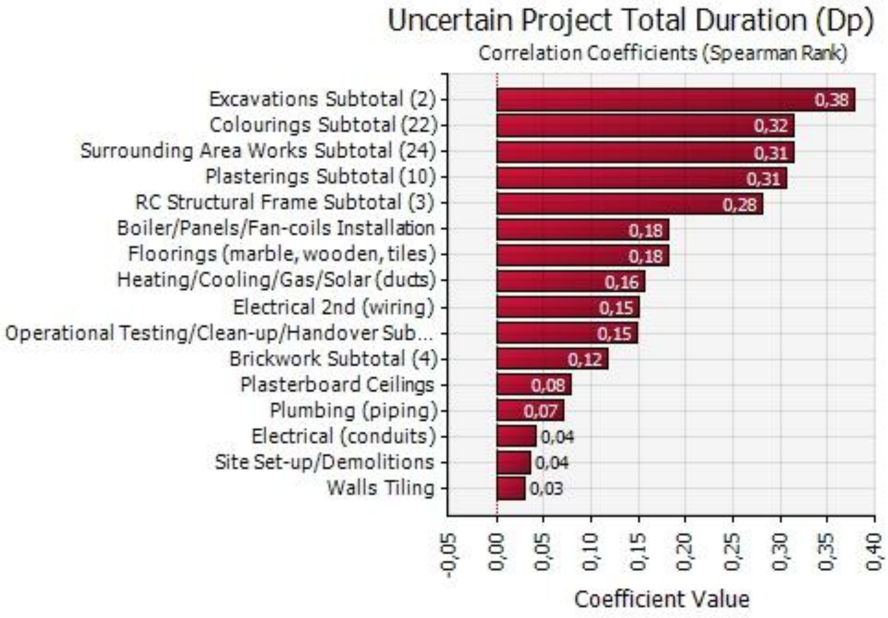


Fig. 4.34 QRA/MCS Summary Results for Project Duration – *triangular* distribution





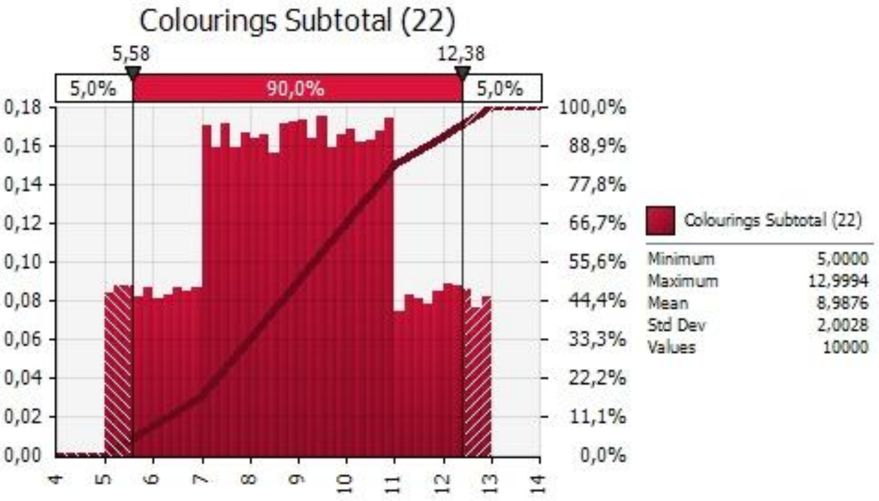


Fig. 4.35 QRA/MCS Summary Results for Project Duration – *uniform* distribution

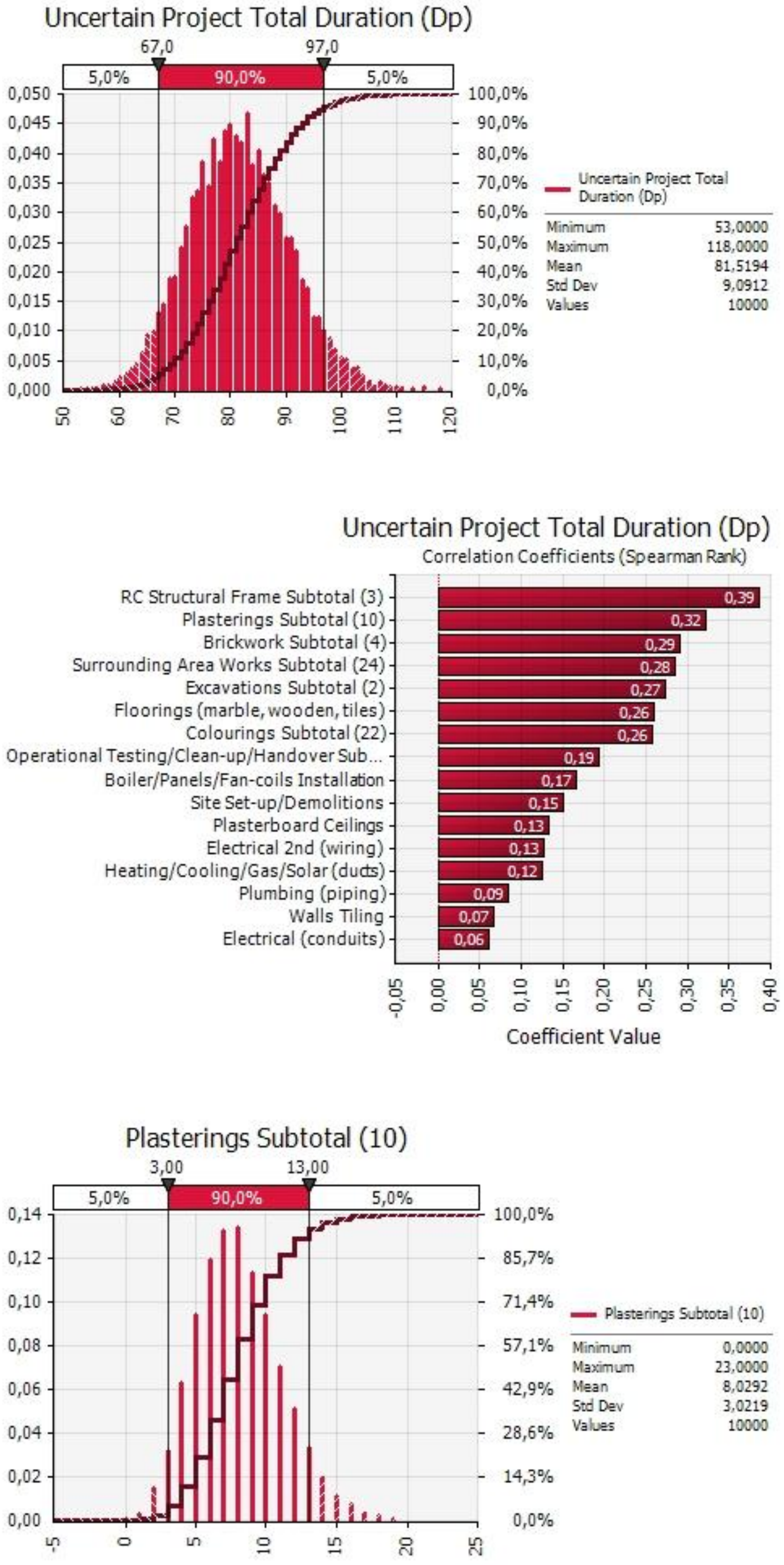


Fig. 4.36 QRA/MCS Summary Results for Project Duration – *Poisson* distribution

Table 4.24 QRA *Risks* and *Opportunities* for Project Direct Cost (in €)

Work Package or Element (WP/E)	**WP/E no.**	***Uncertain Cost***	**Minimum**	**Most Likely***	**Maximum**	***Probability***
Project Start (Dummy)	**0**	0	0	0	0	
Site Set-up/Demolitions	**1**	8233,33	7600	8200	9000	
Excavations	**2**	18616,67	16600	18500	21100	0,45
Archaeological findings		22033,33	19700	22000	24500	0,25
Water table problem		20383,33	18500	20300	22600	0,30
Subtotal (2)		**20383,33**				**1**
RC Structural Frame	**3**	145933,33	143300	145800	149100	0,70
Radier foundation (if water table problem)		164350,00	157500	165000	168600	0,30
Subtotal (3)		**145933,33**				**1**
Brickwork	**4**	16108,33	14850	16100	17400	0,50
Use of thermal insulation blocks		19600,00	18500	19600	20700	0,50
Subtotal (4)		**19600,00**				**1**
Metal Casing Pseudoframes	**5**	2350,00	1900	2300	3000	
Electrical (conduits)	**6**	31933,33	28600	31900	35400	
Plumbing (piping)	**7**	42483,33	39100	42500	45800	
Marble Sills	**8**	2033,33	1800	2000	2400	
Waterproofing/Roofs	**9**	13716,67	12000	13700	15500	0,60
Green roof		21366,67	18800	21500	23400	0,40
Subtotal (9)		**13716,67**				**1**
Plasterings	**10**	16766,67	15200	16700	18600	0,50
External thermal insulation system		21366,67	18400	21500	23800	0,50
Subtotal (10)		**16766,67**				**1**
Steelworks/Railings	**11**	12050,00	11000	12000	13300	
Electrical 2nd (wiring)	**12**	20083,33	17700	20100	22400	
Walls Tiling	**13**	4533,33	3800	4600	5000	
Heating/Cooling/Gas/Solar (ducts)	**14**	17466,67	16100	17200	19900	
Floorings (marble, wooden, tiles)	**15**	13516,67	11800	13400	15700	
Doors/Windows	**16**	39066,67	35600	39200	42000	
Joinery	**17**	10416,67	9000	10400	11900	
Bathrooms/WC Fixtures	**18**	3600,00	2900	3500	4700	
Boiler/Panels/Fan-coils Installation	**19**	43216,67	38500	43200	48000	
Elevator	**20**	12250,00	10200	12000	15300	
Plasterboard Ceilings	**21**	7700,00	6400	7700	9000	
Colourings	**22**	19133,33	17000	18900	22200	0,50
External thermal insulation system		11366,67	9300	11300	13700	0,50
Subtotal (22)		**19133,33**				**1**
Lighting/Electrical Finishings/Minor Works	**23**	17783,33	16500	17600	19800	0,65
Smart Building installation		25250,00	23100	25300	27200	0,35
Subtotal (23)		**17783,33**				**1**
Surrounding Area Works	**24**	24733,33	22500	24700	27100	0,75
Bad weather		26400,00	24200	26300	29000	0,25
Subtotal (24)		**24733,33**				**1**
Operational Testing/Clean-up/Handover	**25**	3350,00	2500	3300	4400	0,80
Additional close-out work		4316,67	3600	4200	5500	0,20
Subtotal (25)		**3350,00**				**1**
Project Finish (Dummy)	**26**	0	0	0	0	
Totals		**552333,33**				

*Normal Cost as estimated by using ABC methodology.

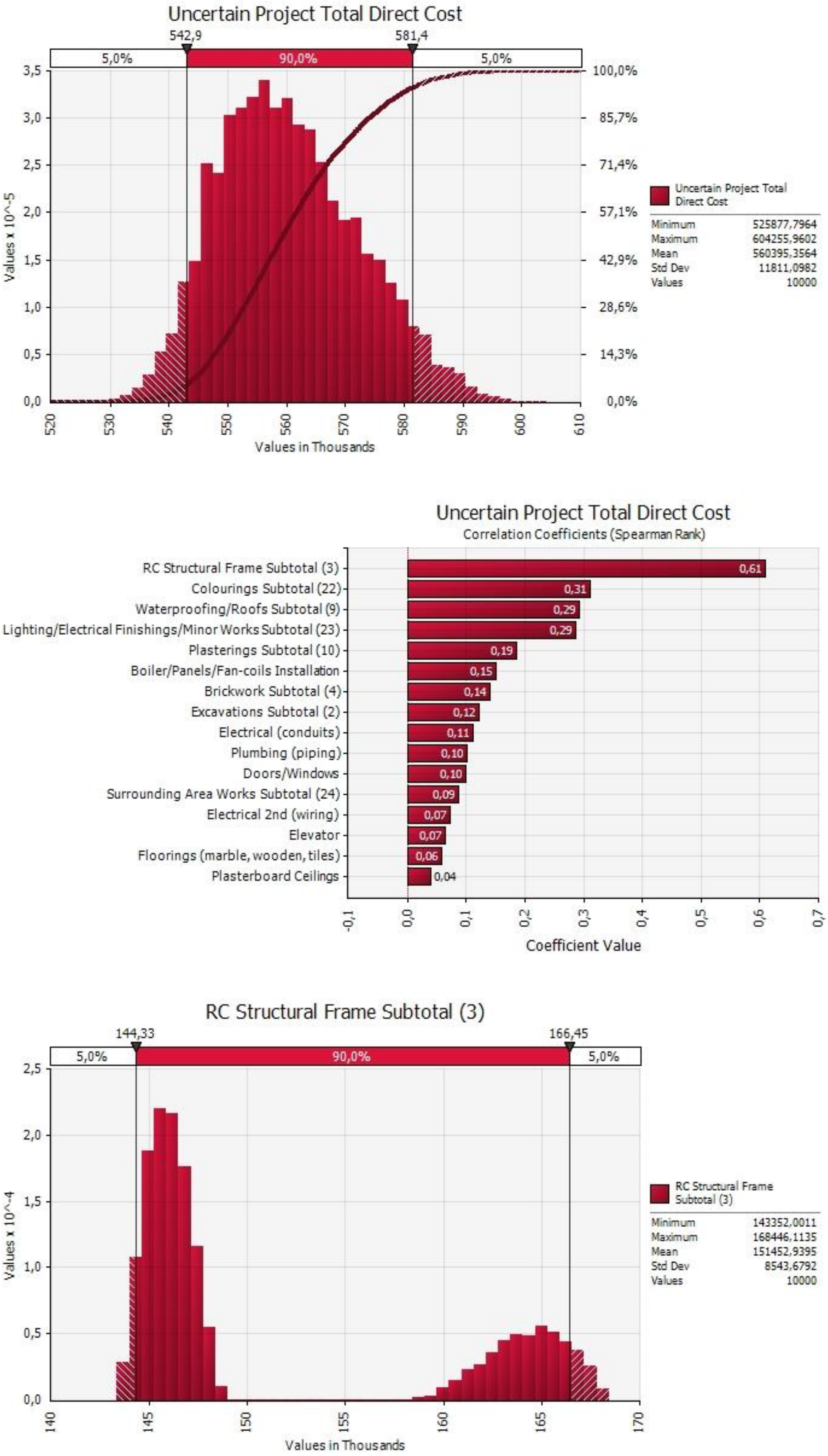


Fig. 4.37 QRA/MCS Summary Results for Project Direct Cost – *PERT* distribution

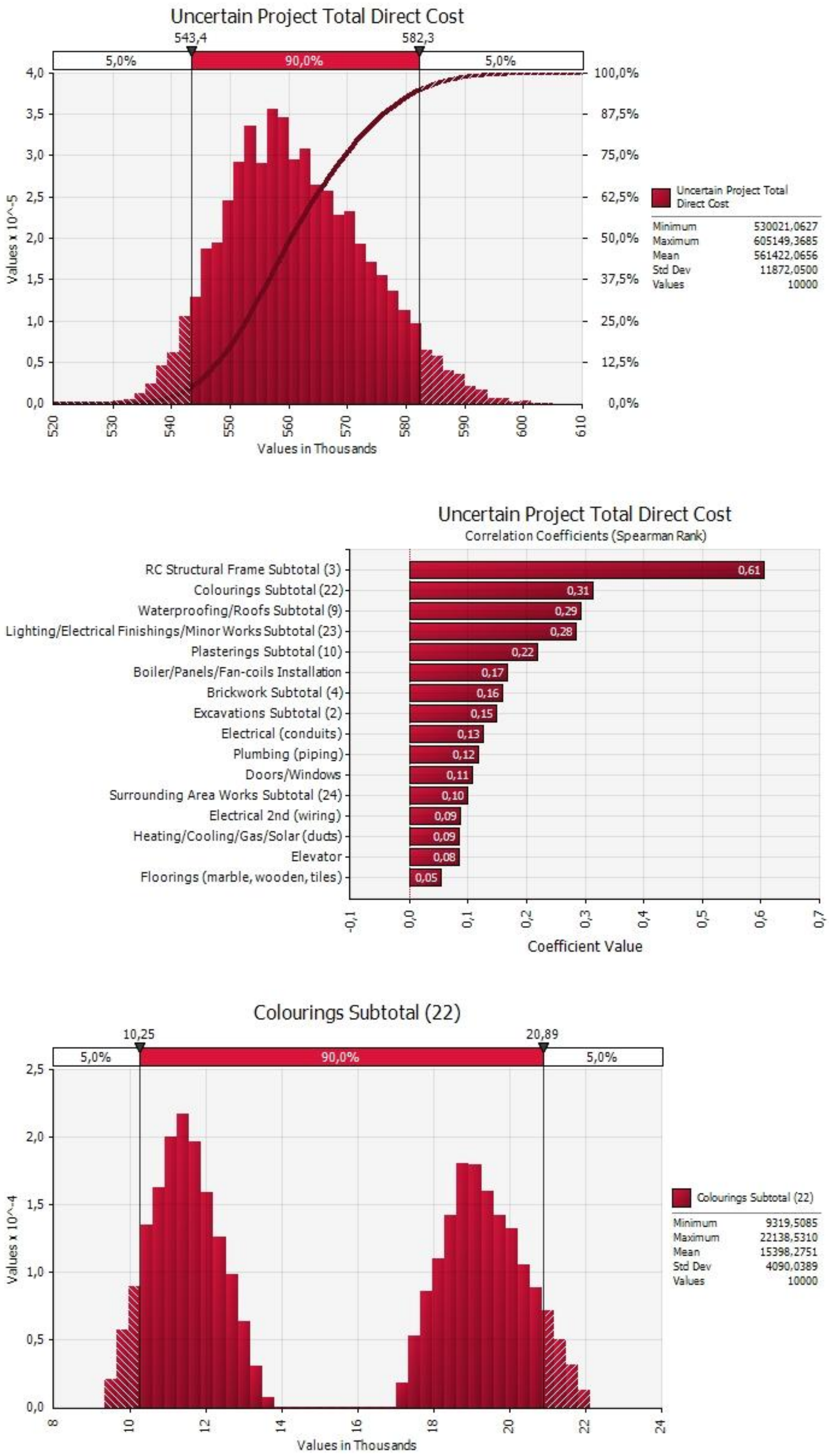


Fig. 4.38 QRA/MCS Summary Results for Project Direct Cost – *triangular* distribution

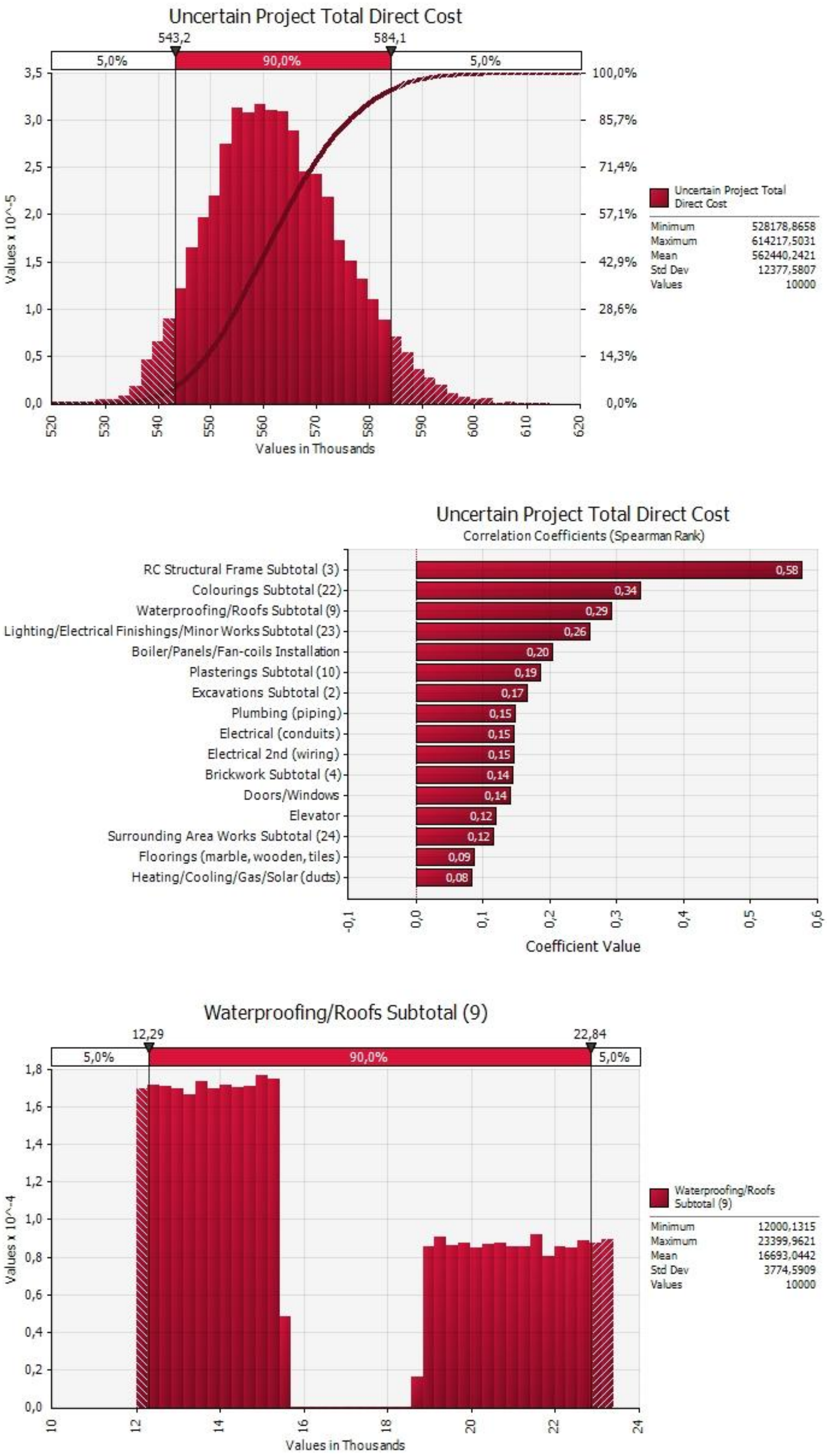
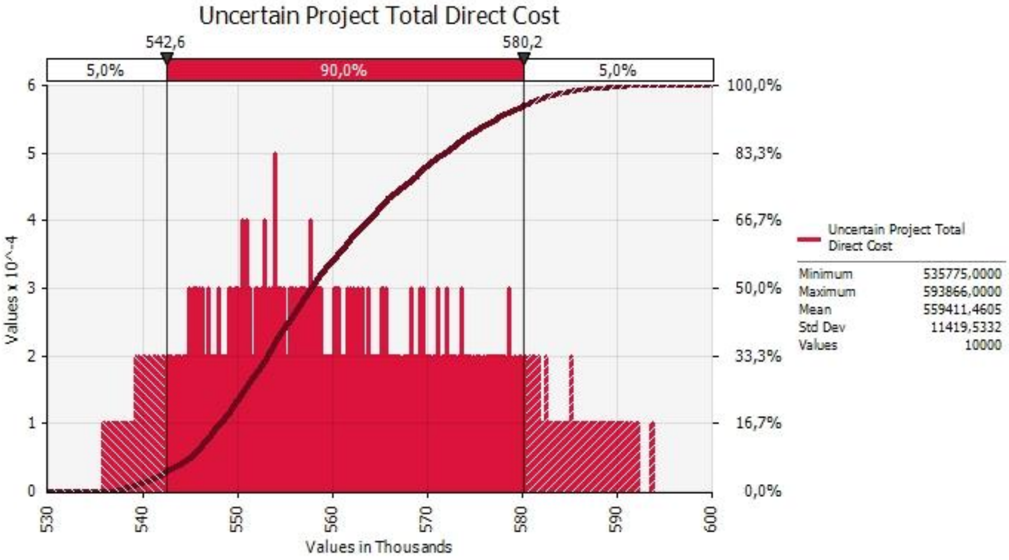
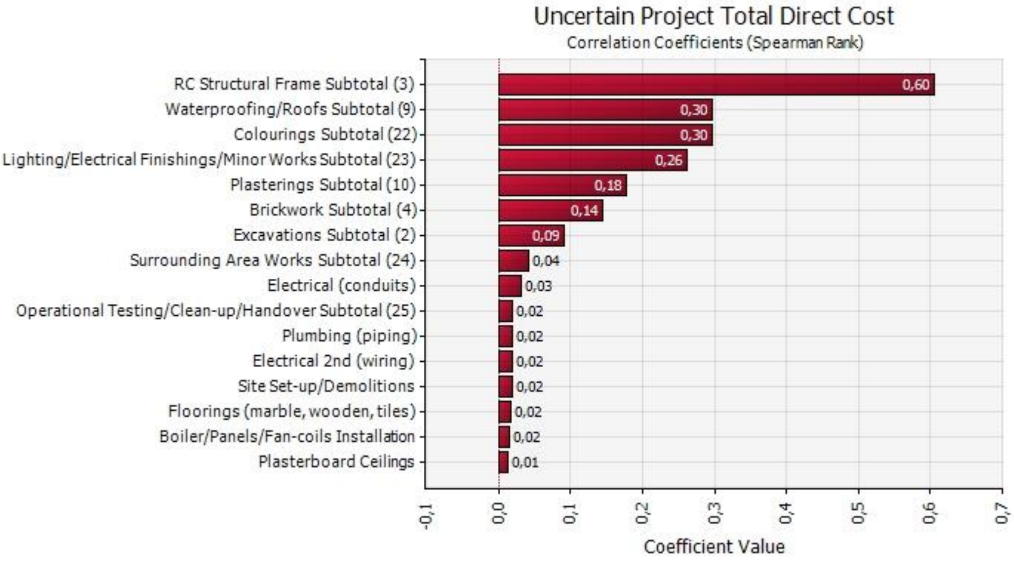


Fig. 4.39 QRA/MCS Summary Results for Project Direct Cost – *uniform* distribution





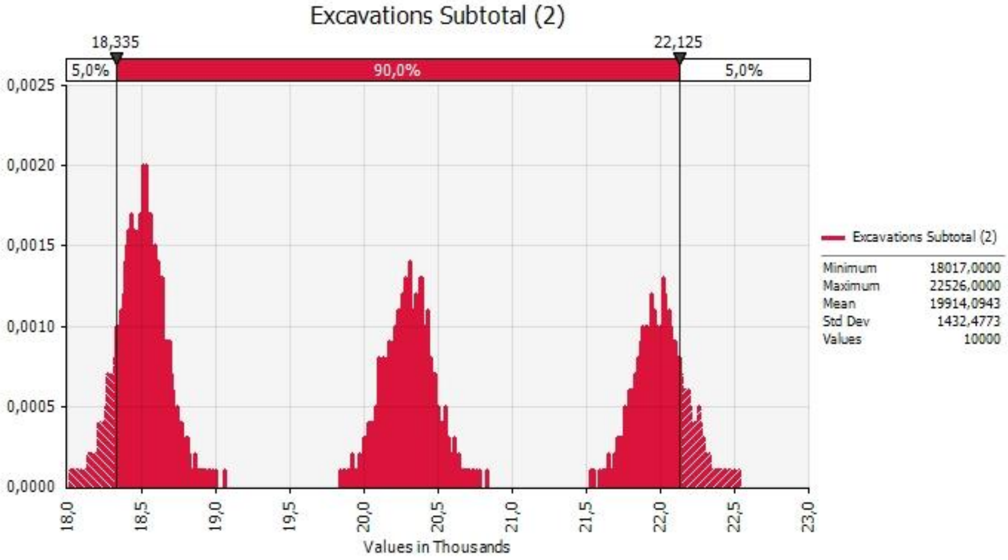


Fig. 4.40 QRA/MCS Summary Results for Project Direct Cost – *Poisson* distribution

Table 4.25 Summary of Results for Project Direct Cost from QRA/MCS (10.000 iterations)

Probability Distribution	**Estimated Project Direct Cost (in €)**					**Std Dev.**	**Most Critical Work Package/Element (Coefficient Value)**
	min	***5%***	***mean***	***95%***	***max***		
PERT	525878	542900	**560395**	581400	604256	11811	RC Structural Frame (0,61)
triangular	530021	543400	**561422**	582300	605149	11872	RC Structural Frame (0,61)
uniform	528179	543200	**562440**	584100	614217	12378	RC Structural Frame (0,58)
Poisson	535775	542600	**559411**	580200	593866	11420	RC Structural Frame (0,60)

This page intentionally left blank

CHAPTER 5

CONSTRUCTED PRODUCT USEFUL LIFE

5.1 Introduction

This chapter presents the modelling methodologies and processes, both *deterministic* and *stochastic*, for the *useful life* period of the constructed product. The procedure adopted entails: at first, the development of a unique *whole-life costing* (WLC) mathematical model as a practical and easy to implement decision-making tool to assist owners and construction professionals in the evaluation and financial control of building investment projects throughout the product *whole-life cycle*; and, secondly, the use of the above *holistic* management technique in *fair value accounting* and *depreciated cost accounting* for capital building projects.

The uniqueness of the herein proposed WLC methodology is founded on the *integration* of *life-cycle costing* (LCC) fundamental concepts with the widely used *investment appraisal* techniques for built facilities and the critical variables imposed by the *economic* and *taxation* environments. Through the analysis of capital requirements, owners and/or building developers can assess the net contribution of the investment project to their *equity* and the effects of potential changes in the cost and value of main decision parameters and financing schemes.

5.2 Whole-Life Costing (WLC) Mathematical Model Development

Prior to discussing and calculating the time value of money, the following definitions must be introduced first (Mislick and Nussbaum, 2015):

- *Cash flow*: A representation of the time-phased costs or benefits associated with the project, usually provided in a cash flow diagram in tabular or graphic form.
- *Interest rate*: The cost of money. It is usually expressed as a percent of the amount borrowed for a given amount of time. An example might be '5% per year.'
- *Compound interest*: When interest accrued from a bank account is added to your account balance and the next calculation of interest includes the prior interest earned, then this process of calculating interest is called compounding, and the interest earned often goes by the name 'compound interest.' A bank may have its interest compounded at the end of each year or several times during the year.
- *Discount rate*: The percentage rate used to calculate the *present value* (PV) of future cash flows.
- *Future value*: The value of a sum or investment after investing it over one or more time periods. This is also known as compounding.
- *Present value*: The value of future cash flows reduced at the appropriate discount rate to a value today. This is also known as discounting, and it is the opposite, in the sense of time, of compounding.
- *Net present value* (NPV) *or discounted cash flow* (DCF): A cash flow summary adjusted to reflect the time value of money.

5.2.1 Time Value of Money/Net Present Value (NPV)

The following basic equation of NPV is found in Kishk *et al.* (2003):

$$\mathrm{NPV} = \mathrm{C_o} + \sum_{t=1}^{t=T} \mathrm{O_t} + \sum_{t=1}^{t=T} \mathrm{M_t} - \mathrm{SAV} \qquad (5.1)$$

$\mathrm{C_o}$ the initial construction costs (at time zero)

$\sum_{t=1}^{t=T} O_t$ the sum of discounted operation costs at time t

$\sum_{t=1}^{t=T} M_t$ the sum of discounted maintenance costs at time t

SAV the discounted salvage value, with:

$$SAV = RV_T - DC_T \tag{5.2}$$

RV_T the discounted resale value (at the end of the analysis period)

DC_T the discounted disposal costs (at the end of the analysis period)

T the analysis period in years (product life-cycle)

The (undiscounted) *net value* (NV) of a built asset can be expressed mathematically as:

$$NV = R - WLC \tag{5.3}$$

Where:

NV *net value*

R *revenue* (i.e. income from sales/rents, tax allowances)

WLC *whole-life cost*

Based on the BS ISO 15686-5:2008 (see again Figure 2.26 in Chapter 2), the *whole-life cost breakdown structure* (WLCBS) of a constructed asset can be analysed as follows:

$$WLC = LCC + NCC + EXT \tag{5.4}$$

$$LCC = C + O + M + OC - SAV \tag{5.5}$$

$$SAV = RV - DC \tag{5.6}$$

Where:

LCC *life-cycle cost*

NCC *non-construction cost* (initial capital costs, i.e. land acquisition, pre-construction design, engineering and consulting costs, costs of town planning permits, finance for land purchase and/or construction)

EXT	*externalities* (positive like public health and safety improvement and/or other social benefits and negative like environmental pollution, traffic congestion and/or social costs) – *the analysis and evaluation of these external costs and benefits is beyond the scope of this research project and will be addressed by the writer in future work*
C	*construction cost* (i.e. preliminaries, site set-up, earthworks, substructures, super-structures, installations, finishing works, etc. including quality assurance costs)
O	*operation cost* (cleaning, utilities and administrative costs)
M	*maintenance cost* (for major replacements, minor scheduled and unscheduled works, adaptations, redecorations, grounds maintenance and gardening)
OC	*occupancy cost* (security, help-desks, telephones, IT services, car parks, etc.)
SAV	*salvage value*
RV	*resale value*
DC	*disposal cost* (materials disposal and/or recycling, demolitions and site clearance, reconstruction/restoration/refurbishment)

Therefore:

$$\mathrm{NV} = (\mathrm{R} + \mathrm{RV}) - (\mathrm{C} + \mathrm{O} + \mathrm{M} + \mathrm{OC} + \mathrm{DC} + \mathrm{NCC} + \mathrm{EXT}) \tag{5.7}$$

According to the theory of finance, the NPV of an investment project can be calculated as follows:

$$\mathrm{NPV} = \sum_{t=1}^{t=T} \frac{\mathrm{NCF}_t}{(1+\mathrm{WACC})^t} \tag{5.8}$$

Where:

NCF_t	*net cash-flow* of the project at year t
t	1, …, T and T = total years of property life-cycle (the analysis period)
WACC	the discount rate or the *weighted average cost of capital*.

5.2.2 Operating Cash-Flow (OCF) and Net Cash-Flow (NCF)

The cash-flow of an investment project in construction, whereas returns measures (NPV; IRR) are frequently applied, is the operating cash-flow (OCF). The OCF is calculated if, from the revenues of the investment project, the fixed and variable costs are subtracted. Thus:

$$\mathrm{OCF_t = R_t - TC_{ot}} \tag{5.9}$$

Where:

$\mathrm{OCF_t}$ operating cash-flow at year t

$\mathrm{R_t}$ revenue (income) at year t:

$$\mathrm{R_t = (R_{ot} + RV_T)} \tag{5.10}$$

ot operating period

T end year of product life-cycle

$\mathrm{R_{ot}}$ revenue (income) at operating year t

$\mathrm{RV_T}$ resale value at the end year of product life-cycle

$\mathrm{TC_{ot}}$ fixed and variable (total) costs at operating year t:

$$\mathrm{TC_{ot} = (O_{ot} + M_{ot} + OC_{ot})} \tag{5.11}$$

$\mathrm{O_{ot}}$ operating costs at operating year t

$\mathrm{M_{ot}}$ maintenance costs at operating year t

$\mathrm{OC_{ot}}$ occupancy costs at operating year t

Thus:

$$\mathrm{OCF_t = (R_{ot} + RV_T) - (O_{ot} + M_{ot} + OC_{ot})} \tag{5.12}$$

In order to calculate the net cash-flow (NCF) of the investment project, the initial costs of the investment (construction, non-construction and disposal costs) and the taxes that correspond to the revenues minus the tax deductive amounts (i.e. the depreciation of the fixed asset) are subtracted from the OCF:

$$\mathrm{NCF_t} = \mathrm{OCF_t} - \varphi_t^y * (\mathrm{OCF_t} - \mathrm{D_t}) - \mathrm{P_{ct,T}} = \mathrm{OCF_t} * \left(1 - \varphi_t^y\right) + \varphi_t^y . \mathrm{D_t} - \mathrm{P_{ct,T}} \qquad (5.13)$$

Where:

t	1, …, T and T = total years of product life-cycle (the analysis period)
φ_t^y	corporate tax rate (tax on income)
$\mathrm{D_t}$	annual depreciation
$\mathrm{P_{ct,T}}$	initial construction and non-construction costs plus disposal cost at the end year of product life-cycle:

$$\mathrm{P_{ct,T}} = \left(\mathrm{C_{ct}} + \mathrm{NCC_{pct}} + \mathrm{DC_T}\right) \qquad (5.14)$$

ct	construction period
pct	pre-construction period
$\mathrm{C_{ct}}$	construction cost at construction period
$\mathrm{NCC_{pct}}$	non-construction cost at pre-construction period
$\mathrm{DC_T}$	disposal cost at the end year of product life-cycle

Thus:

$$\mathrm{NCF_t} = [(\mathrm{R_{ot}} + \mathrm{RV_T}) - (\mathrm{O_{ot}} + \mathrm{M_{ot}} + \mathrm{OC_{ot}})] * (1 - \varphi_t^y) + \varphi_t^y * \mathrm{D_t} - \left(\mathrm{C_{ct}} + \mathrm{NCC_{pct}} + \mathrm{DC_T}\right) \qquad (5.15)$$

Assuming that the constant depreciation method per year is followed and that there is a *salvage value* (SAV) of the investment at the end of construction period:

$$\mathrm{D_t} = a * \left(\mathrm{C_{ct}} + \mathrm{NCC_{pct}} - \mathrm{SAV_{T,ct}}\right) = a * \left(\mathrm{C_{ct}} + \mathrm{NCC_{pct}} - (\mathrm{RV_{T,ct}} - \mathrm{DC_{T,ct}})\right) \qquad (5.16)$$

Where:

a	rate of constant depreciation of fixed asset (1/useful life)
$\mathrm{SAV_{T,ct}}$	salvage value of fixed asset at the end of construction period:

$$\mathrm{SAV_{T,ct}} = (\mathrm{RV_{T,ct}} - \mathrm{DC_{T,ct}}) \qquad (5.17)$$

Thus:

$$D_t = a * \left(C_{ct} + NCC_{pct} + DC_{T,ct} - RV_{T,ct}\right) \quad (5.18)$$

Therefore:

$$NCF_t = [(R_{ot} + RV_T) - (O_{ot} + M_{ot} + OC_{ot})] * (1 - \varphi_t^y) + \varphi_t^y * a * \left(C_{ct} + NCC_{pct} + DC_{T,ct} - RV_{T,ct}\right) - \left(C_{ct} + NCC_{pct} + DC_T\right) \quad (5.19)$$

In addition, *property tax* rate is:

φ_t^p property tax rate

Usually, property tax is not a tax deductible amount, thus increasing the product whole-life cost:

$$NCF_t = [(R_{ot} + RV_T) - (O_{ot} + M_{ot} + OC_{ot})] * (1 - \varphi_t^y) + \varphi_t^y * a * \left(C_{ct} + NCC_{pct} + DC_{T,ct} - RV_{T,ct}\right) - \varphi_t^p * \left(C_{ct} + NCC_{pct}\right) - \left(C_{ct} + NCC_{pct} + DC_T\right) \quad (5.20)$$

But, Value Added Tax (VAT) and other indirect taxes also exist in construction and operational periods, thus:

$$NCF_t = [(R_{ot} + RV_T) - (O_{ot} + M_{ot} + OC_{ot}) * (1 + \varphi_t^{ind})] * (1 - \varphi_t^y) + \varphi_t^y * a * \left(C_{ct} + NCC_{pct} + DC_{T,ct} - RV_{T,ct}\right) - \varphi_t^p * \left(C_{ct} + NCC_{pct}\right) - \left(C_{ct} + NCC_{pct} + DC_T\right) * (1 + \varphi_t^{ind}) \quad (5.21)$$

If indirect taxes like VAT also exist on revenues and resale value, then:

$$NCF_t = [(R_{ot} + RV_T) * \left(1 + \varphi_t^{ind}\right) - (O_{ot} + M_{ot} + OC_{ot}) * \left(1 + \varphi_t^{ind}\right)] * \left(1 - \varphi_t^y\right) + \varphi_t^y * a * \left(C_{ct} + NCC_{pct} + DC_{T,ct} - RV_{T,ct}\right) - \varphi_t^p * \left(C_{ct} + NCC_{pct}\right) - \left(C_{ct} + NCC_{pct} + DC_T\right) * (1 + \varphi_t^{ind}) \quad (5.22)$$

Hence:

$$NCF_t = [(R_{ot} + RV_T) - (O_{ot} + M_{ot} + OC_{ot})] * \left(1 + \varphi_t^{ind}\right) * (1 - \varphi_t^y) + \varphi_t^y * a * \left(C_{ct} + NCC_{pct} + DC_{T,ct} - RV_{T,ct}\right) - \varphi_t^p * \left(C_{ct} + NCC_{pct}\right) - \left(C_{ct} + NCC_{pct} + DC_T\right) * (1 + \varphi_t^{ind}) \quad (5.23)$$

Where:

φ_t^{ind}	indirect tax rate.

5.2.3 The Relationship between Price and Revenue

According to the theory of finance and existing literature (Liapis *et al.*, 2011), the relationship between price and revenue (income) is described by the following formula:

$$R_t = P_t * \left[\left(i_{FR} - \varphi_t^p\right) * \left(1 - \varphi_t^y\right) + \delta_t + \Lambda_t - EG_{t+1}\right] \quad (5.24)$$

If depreciation on the price of the built asset is tax deductible, then:

$$R_t = P_t * \left[\left(i_{FR} - \varphi_t^p\right) * \left(1 - \varphi_t^y + a * \varphi_t^y\right) + \delta_t + \Lambda_t - EG_{t+1}\right] \quad (5.25)$$

Where:

i_{FR}	risk-free rate of interest
φ_t^p	property tax
φ_t^y	income tax (corporate tax) on built asset yield (annual rent)
a	depreciation rate on tax deductible amount of price of property
δ_t	rate of operating, maintenance and occupancy cost
Λ_t	risk premium, for commercial investment projects
EG_{t+1}	expected capital gain (profit) at year t+1 (in terms of WLC is close to zero)

But:

$$R_t = (R_{ot} + RV_T) \quad (5.26)$$

$$P_t = \left(C_{ct} + NCC_{pct} + DC_T - RV_T\right) * (1 + \varphi_t^{ind}) \quad (5.27)$$

Thus:

$$R_{ot} + RV_T = \left(C_{ct} + NCC_{pct} + DC_T - RV_T\right) * \left(1 + \varphi_t^{ind}\right) * \left[\left(i_{FR} - \varphi_t^p\right) * \left(1 - \varphi_t^y + a * \varphi_t^y\right) + \delta_t + \Lambda_t - EG_{t+1}\right] \quad (5.28)$$

According to the above equation, a Price per Revenue (P/R) formula for built assets can be derived, similar to the Price per Earnings (P/E) formula used in capital markets:

$$\frac{P_t}{R_t} = \frac{\left(C_{ct} + NCC_{pct} + DC_T - RV_T\right) * \left(1 + \varphi_t^{ind}\right)}{R_{ot} + RV_T}$$

$$= \frac{1}{\left[\left(i_{FR} - \varphi_t^p\right) * \left(1 - \varphi_t^y + a * \varphi_t^y\right) + \delta_t + \Lambda_t - EG_{t+1}\right]} \tag{5.29}$$

If indirect taxes (like VAT) exist also on revenues and resale value, then:

$$(P_t/R_t) = \frac{\left(C_{ct} + NCC_{pct} + DC_T - RV_T\right) * (1 + \varphi_t^{ind})}{(R_{ot} + RV_T) * (1 + \varphi_t^{ind})} = \frac{1}{\left[\left(i_{FR} - \varphi_t^p\right) * \left(1 - \varphi_t^y + a * \varphi_t^y\right) + \delta_t + \Lambda_t - EG_{t+1}\right]} \tag{5.30}$$

and

$$(P_t/R_t) = \frac{\left(C_{ct} + NCC_{pct} + DC_T - RV_T\right)}{R_{ot} + RV_T} = \frac{1}{\left[\left(i_{FR} - \varphi_t^p\right) * \left(1 - \varphi_t^y + a * \varphi_t^y\right) + \delta_t + \Lambda_t - EG_{t+1}\right]} \tag{5.31}$$

If AC denotes the acquisition cost of the built asset which is equal to cost ratio exempt risk premium (Λ_t) and expected capital gains (EG_{t+1}), then:

$$AC_t = \left[\left(i_{FR} - \varphi_t^p\right)\left(1 - \varphi_t^y + a * \varphi_t^y\right) + \delta_t\right] \tag{5.32}$$

Where:

$$\delta_t = \frac{(O_{ot} + M_{ot} + OC_{ot})}{\left(C_{ct} + NCC_{pct}\right)} \tag{5.33}$$

Also, according to finance theory:

$$i_{FR} = i_* + i_{inf} \tag{5.34}$$

Where:

i_* risk-free rate of interest in an economy without inflation

i_{inf} inflation rate.

5.2.4 Discount Factor/Weighted Average Cost of Capital (WACC)

As discount factor in evaluation measures, a rate from funding cost of investment is commonly used. ‘The appropriate discount rate will vary significantly from organisation to organisation and will need to be determined by the skill of the industrial accountant rather than by mere arbitrary selection (Woodward, 1997)’.

An investor could be using his own capital or debt financing or a mix of them. The investor's total cost of capital is an important benchmark in many popular forms of performance analysis in building projects. The total cost of capital or the *weighted average cost of capital* (WACC) is:

$$\mathrm{WACC} = \mathrm{i_D} * \left(1 - \varphi_t^y\right) * \left(\frac{\mathrm{D}}{\mathrm{D+S}}\right) + \mathrm{i_S} * \left(\frac{\mathrm{S}}{\mathrm{D+S}}\right) \tag{5.35}$$

Where:

$\mathrm{i_D}$	average interest rate of debt

$$\mathrm{i_D} = \mathrm{i_{FR}} + \mathrm{CS} \tag{5.36}$$

CS	credit spread – risk premium for the banking sector for long-term investments (like commercial investment projects)
$\mathrm{i_S}$	average interest rate of investor's capital
D	debt
S	investor's equity capital
φ_t^y	income tax rate

The average interest rate of investor's capital, according to the work of Liapis *et al.* (2011), is calculated by the following equation:

$$\mathrm{i_S} = \exp\left(\frac{\ln 2 * \ln(1+\mathrm{g})}{\ln\left(1 + \frac{\mathrm{g}}{\mathrm{AC_t} + \Lambda_t - \mathrm{g}}\right)}\right) - 1 \tag{5.37}$$

Where:

g	growth rate = $\mathrm{EG_{t+1}}$ (expected capital gains)

Thus, investor's equity return depends on acquisition cost, risk premium and growth rate.

5.2.5 Constructed Product Whole-Life Appraisal

Summarising the above mentioned analysis for constructed assets, one arrives at the following mathematical expressions of the proposed WLC model:

$$\mathrm{NCF_t} = [(\mathrm{R_{ot}} + \mathrm{RV_T}) - (\mathrm{O_{ot}} + \mathrm{M_{ot}} + \mathrm{OC_{ot}})] * \left(1 + \varphi_t^{ind}\right) * (1 - \varphi_t^{y}) + \varphi_t^{y} * a * \left(\mathrm{C_{ct}} + \mathrm{NCC_{pct}} + \mathrm{DC_{T,ct}} - \mathrm{RV_{T,ct}}\right) - \varphi_t^{p} * \left(\mathrm{C_{ct}} + \mathrm{NCC_{pct}}\right) - \left(\mathrm{C_{ct}} + \mathrm{NCC_{pct}} + \mathrm{DC_T}\right) * (1 + \varphi_t^{ind}) \tag{5.38}$$

$$\mathrm{AC_t} = \left[\left(\mathrm{i_{FR}} - \varphi_t^{p}\right) * \left(1 - \varphi_t^{y} + a * \varphi_t^{y}\right) + \delta_t\right] \tag{5.39}$$

$$\mathrm{i_S} = \exp\left(\frac{\ln 2 * \ln(1+g)}{\ln\left(1 + \frac{g}{\mathrm{AC_t} + \Lambda_t - g}\right)}\right) - 1 \tag{5.40}$$

$$\mathrm{WACC} = \mathrm{i_D} * \left(1 - \varphi_t^{y}\right) * \left(\frac{D}{D+S}\right) + \mathrm{i_S} * \left(\frac{S}{D+S}\right) \tag{5.41}$$

Furthermore, for any year t of property life-cycle, the project *cost* in *present values* is:

$$\mathrm{Cost_t} = \mathrm{NCF_{t-1}}(1 + \mathrm{WACC})^1 + \mathrm{NCF_{t-2}}(1 + \mathrm{WACC})^2 + \cdots + \mathrm{NCF_0}(1 + \mathrm{WACC})^t \tag{5.42}$$

$$\mathbf{Cost_t} = \sum_{\mathbf{t=1}}^{\mathbf{T}} \mathbf{NCF_{T-t}}\,(\mathbf{1} + \mathbf{WACC})^{\mathbf{t}} \tag{5.43}$$

In addition, for any year t of property life-cycle, the *remaining value* of the project is:

$$\mathbf{Value_t} = \sum_{\mathbf{t=1}}^{\mathbf{T}} \mathbf{NCF_{t+1}}/(\mathbf{1} + \mathbf{WACC})^{\mathbf{t+1}} \tag{5.44}$$

Finally, the project's *profit* at any year t, in *present values*, can be calculated as follows:

$$\mathbf{Profit_t} = \mathbf{Value_t} - \mathbf{Cost_t} \tag{5.45}$$

5.3 Case Study (II): *Whole-Life Appraisal of a Commercial Built Asset*

The developed WLC mathematical model is applied to a typical commercial building project (an office building) of a 1.000,00 m^2 of total gross floor area (TGFA), with a 2-year pre-construction period (for architectural/engineering design and issuing of building permit, archaeological and other town planning approvals) and a 3-year construction period starting from the second year of the pre-construction period. The project, after its completion, will be operated, maintained and repaired by the developer for rental purposes for a time horizon of 45 years. Finally, the disposal (end of life) period is 1 year and, hence, the total analysis period (whole-life cycle) is 50 years. The construction plot area (PA) is 1.250,00 m^2. Since the construction plot is already owned by the building developer as part of their real property portfolio, expenses during the non-construction period do not include any land acquisition cost and are specifically treated as a percentage (normally 15-20%) of project construction cost (mainly for design/engineering fees).

5.3.1 Deterministic Fair Value Accounting

Depending on the additional assumptions made concerning the required input rates and values, the model calculates the output rates and values as described in Table 5.1 (page 312). From the WLC model's calculations, the *net present value* (NPV) of the investment project at any time of product life-cycle is presented in Figure 5.1 (page 311). In addition, in Figures 5.2-5.5 (pages 311 and 316), the results for the rest of the output variables (in present values) are demonstrated.

Any change in anyone of the selected model inputs, impacts the investment appraisal of the constructed asset. For example, an increase in property tax ratio from 1% to 2% or more; or today's limited leverage of funds as a result of the liquidity problem of the Greek economic debt crisis. Thus, if one assumes:

- a rise in property tax rate from 1% to 2% ($\varphi^p = 2\%$);
- that the whole project is funded entirely by the developer's equity capital ($D = 0\%$ and $S = 100\%$); and
- the adoption of fiscal policies by the Greek Government which decrease inflation rate to, say, $i_{inf} = 0,5\%$, thus, influencing future revenues and the cost of capital;

the NPV graph of Figure 5.1 (page 311) is altered to the one presented in Figure 5.6 (page

321). It can be seen that, the *payback period* of the investment project increases from 25 to 48 years, indicating that the current Greek economic environment restrains investments in construction. Accordingly, the NPV figure decreases from €725.134,00 under *normal* circumstances to €9.841,00 under *debt crisis* economic conditions.

Table 5.2 (pages 313-315) illustrates the complete set of the model's calculations for a *normal* economic situation, while in Table 5.3 (page 317) the calculations for a *debt crisis* situation can be found. Figures 5.7-5.10 (pages 321-322) present the results under *debt crisis* for Value, Cost and Profit of the investment project.

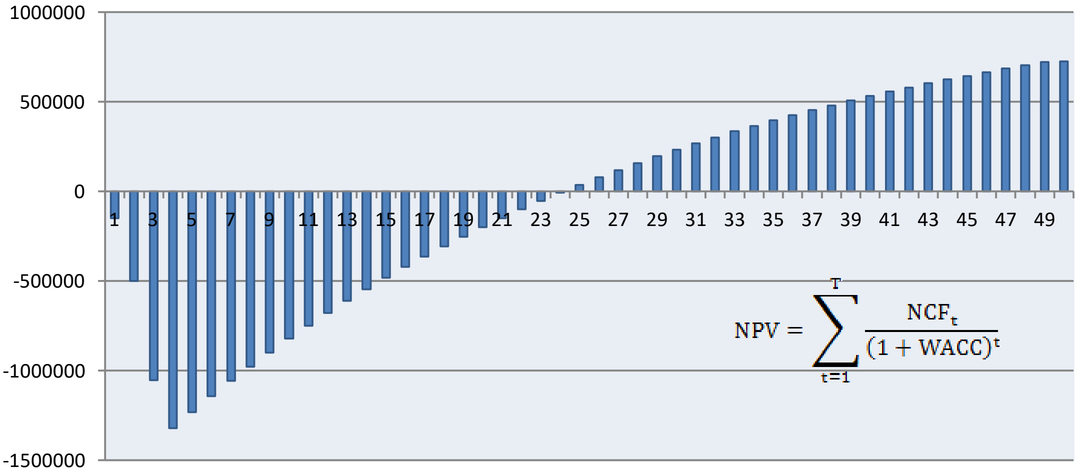


Fig. 5.1 NPV per Year of Product Life-Cycle under *Normal* Economy

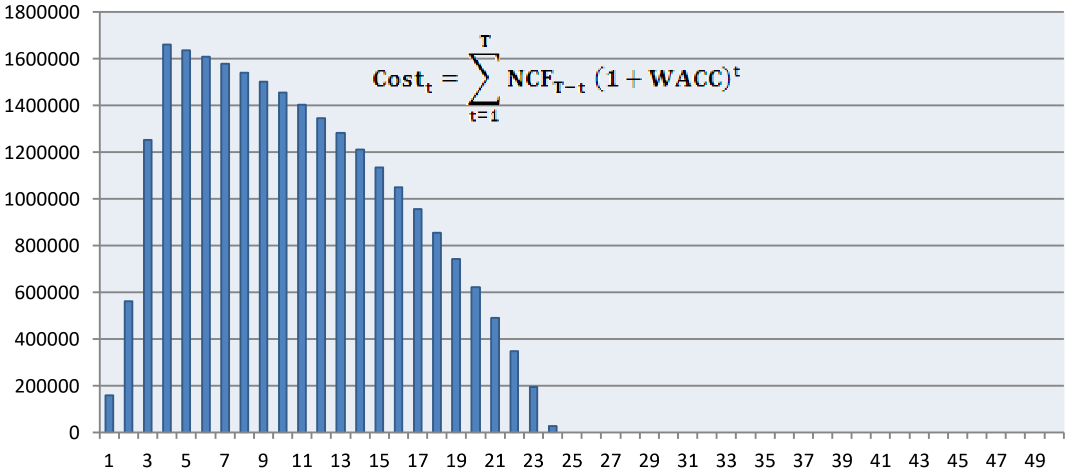


Fig. 5.2 Cost in Present Values under *Normal* Economy

Table 5.1 WLC Model's Inputs/Outputs under *Normal* Economy

INPUT VARIABLES:				
TGFA	m2	1.000		
PA	m2	1.250		
LV	€/m2 **PA**	0	0 €	
NCC	% **C**	18%	180.000 €	
C	€/m2 **TGFA**	1.000	1.000.000 €	
R	€/m2 **TGFA**	180	180.000 €	15,25%
O	€/m2 **TGFA**	10	10.000 €	0,85%
M	€/m2 **TGFA**	15	15.000 €	1,27%
OC	€/m2 **TGFA**	18	18.000 €	1,53%
RV	% **C**	10%	100.000 €	
DC	€/m2 **TGFA**	50	50.000 €	
$\mathbf{i_{inf}}$	%	2%		
$\mathbf{i_{*}}$	%	2%		
$\boldsymbol{\varphi^{p}}$	%	1%		
$\boldsymbol{\varphi^{y}}$	%	33%		
a	%	2%		
g	%	0,1%		
Λ	%	5%		
D	%	60%		
S	%	40%		
CS	%	3%		
$\boldsymbol{\varphi^{ind}}$	%	24%		

T	years	50

	COST DISTRIBUTION:			
LV				
NCC	70%	30%		
C		25%	50%	25%
	Year 1	Year 2	Year 3	Year 4

CALCULATED INPUTS:		
δ	%	3,65%
SAV	€	50.000
$\mathbf{i_{FR}}$	%	4%
AC	%	5,67%
$\mathbf{i_{S}}$	%	7,64%
WACC	%	**5,87%**
$\mathbf{i_{D}}$	%	7,00%

OUTPUT VARIABLES:		
NPV	€	**725.134**
IRR	%	**7,89%**

🟩	**Input Value**
🟧	**Value calculated by Model**

OTHER CALCULATIONS:	
ln(2) =	0,6931
ln(1+g) =	0,0010
(g/AC+Λ-g) =	0,0095
1+(g/AC+Λ-g) =	1,0095
ln[1+(g/AC+Λ-g)] =	0,0094
{ln(2)*ln(1+g)/ln[1+(g/AC+Λ-g)]} =	0,0736
exp{ln(2)*ln(1+g)/ln[1+(g/AC+Λ-g)]}-1 =	0,0764
$(1-\varphi^{y})$ =	67%
D/(D+S) =	0,60
S/(D+S) =	0,40
$i_D*(1-\varphi^{y})*[D/(D+S)]+i_S*[S/(D+S)]$ =	0,0587
A1 = $(R_{ot} + RV_{T})$	Table 5.2
A2 = $(O_{ot} + M_{ot} + OC_{ot})$	Table 5.2
A3 = $(RV_{T} - DC_{T})$	Table 5.2
A4 = $(C_{ct} + NCC_{pct})$	Table 5.2
A5 = $(C_{ct} + NCC_{pct} + DC_{T})$	Table 5.2
A6 = $(1 + \varphi^{ind})*(1 - \varphi^{y})$	Table 5.2
A7 = (A1 - A2)*A6	Table 5.2
A8 = (sumA4 - A3)*φ^{y}*a	Table 5.2
A9 = sumA4*φ^{p}	Table 5.2
A10 = A5*$(1 + \varphi^{ind})$	Table 5.2
NCF_t = A7 + A8 - A9 - A10	Table 5.2
$DCF_t = NCF_t / (1 + WACC)^t$	Table 5.2

$$i_S = \exp\left(\frac{\ln 2 * \ln(1+g)}{\ln\left(1+\frac{g}{AC_t+\Lambda_t-g}\right)}\right) - 1$$

$$WACC = i_D.\left(1-\varphi_t^y\right).\left(\frac{D}{D+S}\right) + i_S.\left(\frac{S}{D+S}\right)$$

$$AC_t = \left[\left(i_{FR}-\varphi_t^p\right)\left(1-\varphi_t^y + a.\varphi_t^y\right) + \delta_t\right]$$

$$NPV = \sum_{t=1}^{T} \frac{NCF_t}{(1+WACC)^t}$$

$$\mathbf{Value_t} = \sum_{t=1}^{T} \mathbf{NCF_{t+1}/(1+WACC)^{t+1}}$$

$$\mathbf{Cost_t} = \sum_{t=1}^{T} \mathbf{NCF_{T-t}\,(1+WACC)^{t}}$$

$$\mathbf{Profit_t = Value_t - Cost_t}$$

Table 5.2 WLC Model's Calculations under *Normal* Economy

t	pct	ct	ot	T	NCC_{pct}	C_{ct}	R_{ot}	RV_T	O_{ot}	M_{ot}	OC_{ot}	DC_T
1	1	0	0	0	128520							
2	2	1	0	0	56182	260100						
3	0	2	0	0		530604						
4	0	3	0	0		270608						
5	0	0	1	0			198735		11041	16561	19873	
6	0	0	2	0			202709		11262	16892	20271	
7	0	0	3	0			206763		11487	17230	20676	
8	0	0	4	0			210899		11717	17575	21090	
9	0	0	5	0			215117		11951	17926	21512	
10	0	0	6	0			219419		12190	18285	21942	
11	0	0	7	0			223807		12434	18651	22381	
12	0	0	8	0			228284		12682	19024	22828	
13	0	0	9	0			232849		12936	19404	23285	
14	0	0	10	0			237506		13195	19792	23751	
15	0	0	11	0			242256		13459	20188	24226	
16	0	0	12	0			247101		13728	20592	24710	
17	0	0	13	0			252043		14002	21004	25204	
18	0	0	14	0			257084		14282	21424	25708	
19	0	0	15	0			262226		14568	21852	26223	
20	0	0	16	0			267471		14859	22289	26747	
21	0	0	17	0			272820		15157	22735	27282	
22	0	0	18	0			278276		15460	23190	27828	
23	0	0	19	0			283842		15769	23653	28384	
24	0	0	20	0			289519		16084	24127	28952	
25	0	0	21	0			295309		16406	24609	29531	
26	0	0	22	0			301215		16734	25101	30122	
27	0	0	23	0			307240		17069	25603	30724	
28	0	0	24	0			313384		17410	26115	31338	
29	0	0	25	0			319652		17758	26638	31965	
30	0	0	26	0			326045		18114	27170	32605	
31	0	0	27	0			332566		18476	27714	33257	
32	0	0	28	0			339217		18845	28268	33922	
33	0	0	29	0			346002		19222	28833	34600	
34	0	0	30	0			352922		19607	29410	35292	
35	0	0	31	0			359980		19999	29998	35998	
36	0	0	32	0			367180		20399	30598	36718	
37	0	0	33	0			374523		20807	31210	37452	
38	0	0	34	0			382014		21223	31834	38201	
39	0	0	35	0			389654		21647	32471	38965	
40	0	0	36	0			397447		22080	33121	39745	
41	0	0	37	0			405396		22522	33783	40540	
42	0	0	38	0			413504		22972	34459	41350	
43	0	0	39	0			421774		23432	35148	42177	
44	0	0	40	0			430210		23901	35851	43021	
45	0	0	41	0			438814		24379	36568	43881	
46	0	0	42	0			447590		24866	37299	44759	
47	0	0	43	0			456542		25363	38045	45654	
48	0	0	44	0			465673		25871	38806	46567	
49	0	0	45	0			474986		26388	39582	47499	
50	0	0	0	50				269159				134579
					184702	1061312	14287565		793754	1190630	1428757	

Table 5.2 WLC Model's Calculations under *Normal* Economy – *cont'd.*

A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
0	0	0	128520	128520	0,8308	0	0	0	159365
0	0	0	316282	316282	0,8308	0	0	0	392189
0	0	0	530604	530604	0,8308	0	0	0	657949
0	0	0	270608	270608	0,8308	0	0	0	335554
198735	47475	0	0	0	0,8308	125666	7894	12460	0
202709	48425	0	0	0	0,8308	128179	7894	12460	0
206763	49393	0	0	0	0,8308	130743	7894	12460	0
210899	50381	0	0	0	0,8308	133358	7894	12460	0
215117	51389	0	0	0	0,8308	136025	7894	12460	0
219419	52417	0	0	0	0,8308	138745	7894	12460	0
223807	53465	0	0	0	0,8308	141520	7894	12460	0
228284	54534	0	0	0	0,8308	144351	7894	12460	0
232849	55625	0	0	0	0,8308	147238	7894	12460	0
237506	56738	0	0	0	0,8308	150183	7894	12460	0
242256	57872	0	0	0	0,8308	153186	7894	12460	0
247101	59030	0	0	0	0,8308	156250	7894	12460	0
252043	60210	0	0	0	0,8308	159375	7894	12460	0
257084	61415	0	0	0	0,8308	162562	7894	12460	0
262226	62643	0	0	0	0,8308	165814	7894	12460	0
267471	63896	0	0	0	0,8308	169130	7894	12460	0
272820	65174	0	0	0	0,8308	172513	7894	12460	0
278276	66477	0	0	0	0,8308	175963	7894	12460	0
283842	67807	0	0	0	0,8308	179482	7894	12460	0
289519	69163	0	0	0	0,8308	183072	7894	12460	0
295309	70546	0	0	0	0,8308	186733	7894	12460	0
301215	71957	0	0	0	0,8308	190468	7894	12460	0
307240	73396	0	0	0	0,8308	194277	7894	12460	0
313384	74864	0	0	0	0,8308	198163	7894	12460	0
319652	76361	0	0	0	0,8308	202126	7894	12460	0
326045	77889	0	0	0	0,8308	206168	7894	12460	0
332566	79446	0	0	0	0,8308	210292	7894	12460	0
339217	81035	0	0	0	0,8308	214498	7894	12460	0
346002	82656	0	0	0	0,8308	218788	7894	12460	0
352922	84309	0	0	0	0,8308	223163	7894	12460	0
359980	85995	0	0	0	0,8308	227627	7894	12460	0
367180	87715	0	0	0	0,8308	232179	7894	12460	0
374523	89469	0	0	0	0,8308	236823	7894	12460	0
382014	91259	0	0	0	0,8308	241559	7894	12460	0
389654	93084	0	0	0	0,8308	246390	7894	12460	0
397447	94946	0	0	0	0,8308	251318	7894	12460	0
405396	96845	0	0	0	0,8308	256345	7894	12460	0
413504	98782	0	0	0	0,8308	261471	7894	12460	0
421774	100757	0	0	0	0,8308	266701	7894	12460	0
430210	102772	0	0	0	0,8308	272035	7894	12460	0
438814	104828	0	0	0	0,8308	277476	7894	12460	0
447590	106924	0	0	0	0,8308	283025	7894	12460	0
456542	109063	0	0	0	0,8308	288686	7894	12460	0
465673	111244	0	0	0	0,8308	294459	7894	12460	0
474986	113469	0	0	0	0,8308	300349	7894	12460	0
269159	0	134579	0	134579	0,8308	223617	7894	12460	166878
			1246014	1380593					

Table 5.2 WLC Model's Calculations under *Normal* Economy – *cont'd.*

NCF	cumNCF	DCF	NPV	Cost	Value	Profit
-159365	-159365	-150530	-150530	159365	927058	767693
-392189	-551554	-349911	-500441	560907	1373657	812750
-657949	-1209503	-554478	-1054919	1251777	2112228	860451
-335554	-1545057	-267107	-1322025	1660799	2571751	910952
121100	-1423957	91053	-1230972	1637174	2601591	964417
123613	-1300344	87791	-1143181	1609648	2630668	1021020
126176	-1174168	84643	-1058538	1577944	2658889	1080945
128791	-1045377	81608	-976930	1541764	2686151	1144387
131459	-913918	78680	-898250	1500794	2712346	1211552
134179	-779739	75856	-822394	1454698	2737358	1282660
136954	-642785	73133	-749261	1403122	2761062	1357941
139784	-503001	70506	-678755	1345688	2783328	1437640
142671	-360329	67973	-610782	1281997	2804014	1522017
145616	-214713	65530	-545252	1211623	2822969	1611346
148620	-66094	63174	-482078	1134115	2840032	1705917
151683	85590	60902	-421177	1048994	2855034	1806040
154808	240398	58711	-362466	955752	2867791	1912038
157996	398394	56598	-305868	853851	2878109	2024258
161247	559642	54560	-251308	742717	2885781	2143064
164563	724205	52595	-198713	621744	2890588	2268843
167946	892151	50701	-148012	490289	2892294	2402004
171396	1063547	48874	-99138	347668	2890649	2542981
174916	1238463	47112	-52026	193158	2885389	2692231
178505	1416968	45414	-6612	25989	2876231	2850242
182167	1599135	43776	37164	0	2862874	2862874
185901	1785036	42197	79361	0	2844998	2844998
189711	1974747	40674	120035	0	2822264	2822264
193596	2168343	39206	159242	0	2794310	2794310
197559	2365903	37791	197033	0	2760751	2760751
201602	2567505	36426	233459	0	2721181	2721181
205725	2773230	35111	268570	0	2675165	2675165
209931	2983161	33842	302412	0	2622243	2622243
214221	3197382	32619	335031	0	2561924	2561924
218597	3415979	31440	366472	0	2493690	2493690
223060	3639040	30304	396775	0	2416987	2416987
227613	3866652	29208	425983	0	2331230	2331230
232256	4098909	28152	454135	0	2235797	2235797
236993	4335901	27133	481268	0	2130026	2130026
241824	4577725	26151	507420	0	2013215	2013215
246752	4824477	25205	532625	0	1884622	1884622
251778	5076255	24293	556918	0	1743454	1743454
256905	5333160	23413	580331	0	1588875	1588875
262134	5595295	22565	602896	0	1419993	1419993
267468	5862763	21748	624644	0	1235866	1235866
272909	6135672	20960	645605	0	1035491	1035491
278459	6414131	20201	665806	0	817807	817807
284119	6698250	19469	685275	0	581686	581686
289893	6988143	18763	704038	0	325933	325933
295782	7283925	18083	722121	0	49280	49280
52172	7336097	3013	**725134**	0	0	0
		725134				

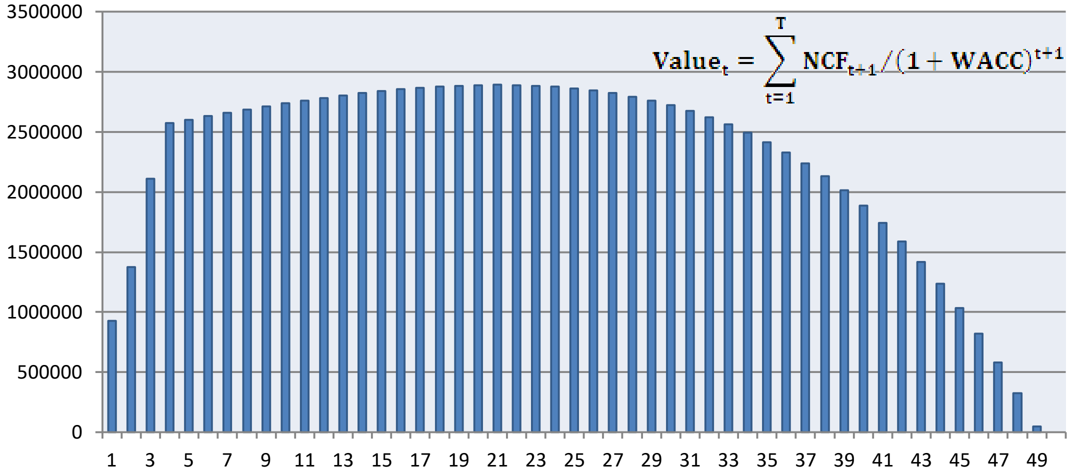


Fig. 5.3 Value in Present Values under *Normal* Economy

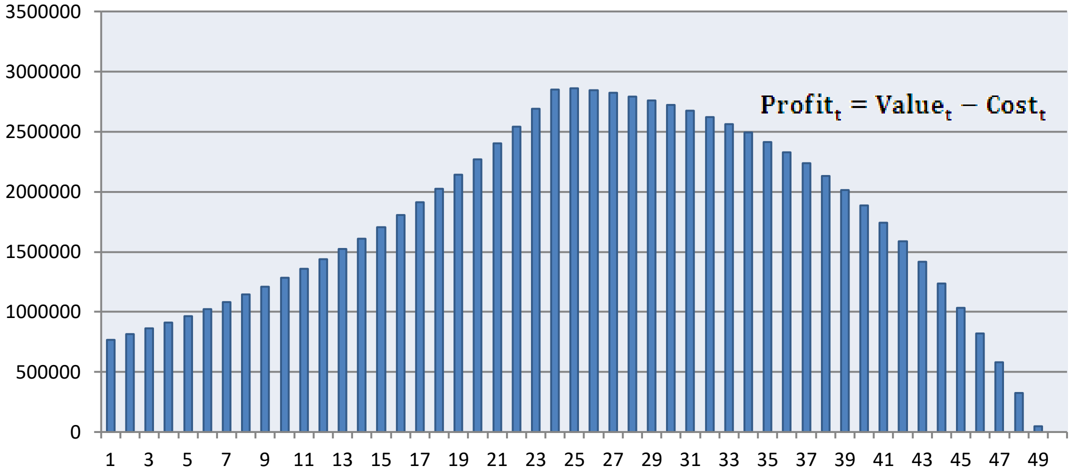


Fig. 5.4 Profit in Present Values under *Normal* Economy

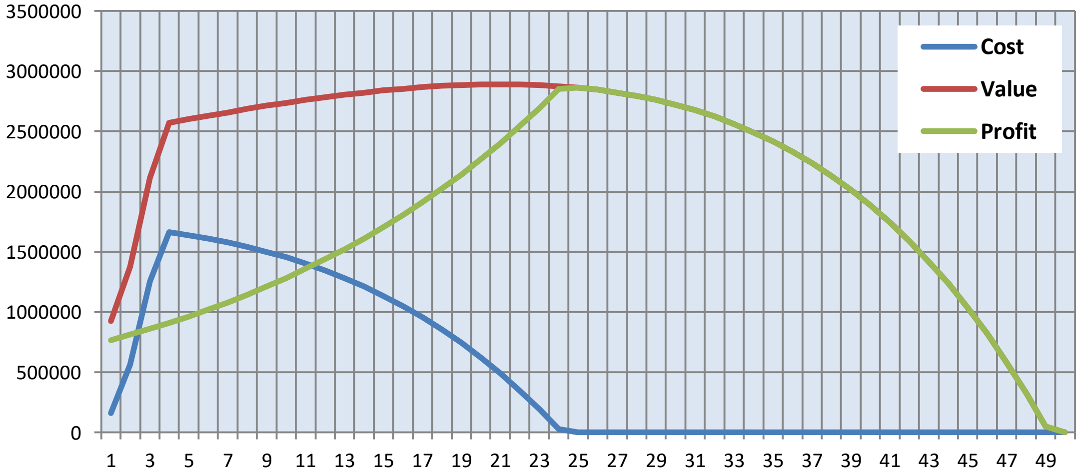


Fig. 5.5 Cost-Value-Profit Curves in Present Values under *Normal* Economy

Table 5.3 WLC Model's Inputs/Outputs under *Debt Crisis* Economy

INPUT VARIABLES:				
TGFA	m2	1.000		
PA	m2	1.250		
LV	€/m2 **PA**	0	0 €	
NCC	% **C**	18%	180.000 €	
C	€/m2 **TGFA**	1.000	1.000.000 €	
R	€/m2 **TGFA**	180	180.000 €	15,25%
O	€/m2 **TGFA**	10	10.000 €	0,85%
M	€/m2 **TGFA**	15	15.000 €	1,27%
OC	€/m2 **TGFA**	18	18.000 €	1,53%
RV	% **C**	10%	100.000 €	
DC	€/m2 **TGFA**	50	50.000 €	
$\mathbf{i_{inf}}$	%	0,5%		
$\mathbf{i_*}$	%	2%		
$\boldsymbol{\varphi^p}$	%	2%		
$\boldsymbol{\varphi^y}$	%	33%		
a	%	2%		
g	%	0,1%		
Λ	%	5%		
D	%	0%		
S	%	100%		
CS	%	3%		
$\boldsymbol{\varphi^{ind}}$	%	24%		

T	years	50

	COST DISTRIBUTION:			
LV				
NCC	70%	30%		
C		25%	50%	25%
	Year 1	Year 2	Year 3	Year 4

CALCULATED INPUTS:		
δ	%	3,65%
SAV	€	50.000
$\mathbf{i_{FR}}$	%	3%
AC	%	4,32%
$\mathbf{i_S}$	%	6,63%
WACC	%	**6,63%**
$\mathbf{i_D}$	%	5,50%

OUTPUT VARIABLES:		
NPV	€	**9.841**
IRR	%	**5,47%**

🟩	**Input Value**
🟧	**Value calculated by Model**

OTHER CALCULATIONS:	
ln(2) =	0,6931
ln(1+g) =	0,0010
(g/AC+Λ-g) =	0,0108
1+(g/AC+Λ-g) =	1,0108
ln[1+(g/AC+Λ-g)] =	0,0108
{ln(2)*ln(1+g)/ln[1+(g/AC+Λ-g)]} =	0,0642
exp{ln(2)*ln(1+g)/ln[1+(g/AC+Λ-g)]}-1 =	0,0663
$(1-\varphi^y)$ =	67%
D/(D+S) =	0,00
S/(D+S) =	1,00
$i_D*(1-\varphi^y)*[D/(D+S)]+i_S*[S/(D+S)]$ =	0,0663
$A1 = (R_{ot} + RV_T)$	Table 5.4
$A2 = (O_{ot} + M_{ot} + OC_{ot})$	Table 5.4
$A3 = (RV_T - DC_T)$	Table 5.4
$A4 = (C_{ct} + NCC_{pct})$	Table 5.4
$A5 = (C_{ct} + NCC_{pct} + DC_T)$	Table 5.4
$A6 = (1 + \varphi^{ind})*(1 - \varphi^y)$	Table 5.4
$A7 = (A1 - A2)*A6$	Table 5.4
$A8 = (sumA4 - A3)*\varphi^y*a$	Table 5.4
$A9 = sumA4*\varphi^p$	Table 5.4
$A10 = A5*(1 + \varphi^{ind})$	Table 5.4
$NCF_t = A7 + A8 - A9 - A10$	Table 5.4
$DCF_t = NCF_t / (1 + WACC)^t$	Table 5.4

$$i_S = \exp\left(\frac{\ln 2 * \ln(1+g)}{\ln\left(1 + \frac{g}{AC_t + \Lambda_t - g}\right)}\right) - 1$$

$$WACC = i_D.\left(1 - \varphi_t^y\right).\left(\frac{D}{D+S}\right) + i_S.\left(\frac{S}{D+S}\right)$$

$$AC_t = \left[\left(i_{FR} - \varphi_t^p\right)\left(1 - \varphi_t^y + a.\varphi_t^y\right) + \delta_t\right]$$

$$NPV = \sum_{t=1}^{T} \frac{NCF_t}{(1+WACC)^t}$$

$$\mathbf{Value_t} = \sum_{t=1}^{T} \mathbf{NCF_{t+1}/(1+WACC)^{t+1}}$$

$$\mathbf{Cost_t} = \sum_{t=1}^{T} \mathbf{NCF_{T-t}\,(1+WACC)^t}$$

$$\mathbf{Profit_t = Value_t - Cost_t}$$

Table 5.4 WLC Model's Calculations under *Debt Crisis* Economy

t	pct	ct	ot	T	NCC_{pct}	C_{ct}	R_{ot}	RV_T	O_{ot}	M_{ot}	OC_{ot}	DC_T
1	1	0	0	0	126630							
2	2	1	0	0	54541	252506						
3	0	2	0	0		507538						
4	0	3	0	0		255038						
5	0	0	1	0			184545		10253	15379	18455	
6	0	0	2	0			185468		10304	15456	18547	
7	0	0	3	0			186395		10355	15533	18640	
8	0	0	4	0			187327		10407	15611	18733	
9	0	0	5	0			188264		10459	15689	18826	
10	0	0	6	0			189205		10511	15767	18921	
11	0	0	7	0			190151		10564	15846	19015	
12	0	0	8	0			191102		10617	15925	19110	
13	0	0	9	0			192058		10670	16005	19206	
14	0	0	10	0			193018		10723	16085	19302	
15	0	0	11	0			193983		10777	16165	19398	
16	0	0	12	0			194953		10831	16246	19495	
17	0	0	13	0			195928		10885	16327	19593	
18	0	0	14	0			196907		10939	16409	19691	
19	0	0	15	0			197892		10994	16491	19789	
20	0	0	16	0			198881		11049	16573	19888	
21	0	0	17	0			199876		11104	16656	19988	
22	0	0	18	0			200875		11160	16740	20087	
23	0	0	19	0			201879		11216	16823	20188	
24	0	0	20	0			202889		11272	16907	20289	
25	0	0	21	0			203903		11328	16992	20390	
26	0	0	22	0			204923		11385	17077	20492	
27	0	0	23	0			205947		11442	17162	20595	
28	0	0	24	0			206977		11499	17248	20698	
29	0	0	25	0			208012		11556	17334	20801	
30	0	0	26	0			209052		11614	17421	20905	
31	0	0	27	0			210097		11672	17508	21010	
32	0	0	28	0			211148		11730	17596	21115	
33	0	0	29	0			212204		11789	17684	21220	
34	0	0	30	0			213265		11848	17772	21326	
35	0	0	31	0			214331		11907	17861	21433	
36	0	0	32	0			215402		11967	17950	21540	
37	0	0	33	0			216480		12027	18040	21648	
38	0	0	34	0			217562		12087	18130	21756	
39	0	0	35	0			218650		12147	18221	21865	
40	0	0	36	0			219743		12208	18312	21974	
41	0	0	37	0			220842		12269	18403	22084	
42	0	0	38	0			221946		12330	18495	22195	
43	0	0	39	0			223056		12392	18588	22306	
44	0	0	40	0			224171		12454	18681	22417	
45	0	0	41	0			225292		12516	18774	22529	
46	0	0	42	0			226418		12579	18868	22642	
47	0	0	43	0			227550		12642	18963	22755	
48	0	0	44	0			228688		12705	19057	22869	
49	0	0	45	0			229831		12768	19153	22983	
50	0	0	0	50				128323				64161
					181171	1015081	9287084		515949	773924	928708	

Table 5.4 WLC Model's Calculations under *Debt Crisis* Economy – *cont'd.*

A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
0	0	0	126630	126630	0,8308	0	0	0	157021
0	0	0	307048	307048	0,8308	0	0	0	380739
0	0	0	507538	507538	0,8308	0	0	0	629347
0	0	0	255038	255038	0,8308	0	0	0	316247
184545	44086	0	0	0	0,8308	116694	7565	17944	0
185468	44306	0	0	0	0,8308	117277	7565	17944	0
186395	44528	0	0	0	0,8308	117864	7565	17944	0
187327	44750	0	0	0	0,8308	118453	7565	17944	0
188264	44974	0	0	0	0,8308	119045	7565	17944	0
189205	45199	0	0	0	0,8308	119640	7565	17944	0
190151	45425	0	0	0	0,8308	120239	7565	17944	0
191102	45652	0	0	0	0,8308	120840	7565	17944	0
192058	45880	0	0	0	0,8308	121444	7565	17944	0
193018	46110	0	0	0	0,8308	122051	7565	17944	0
193983	46340	0	0	0	0,8308	122661	7565	17944	0
194953	46572	0	0	0	0,8308	123275	7565	17944	0
195928	46805	0	0	0	0,8308	123891	7565	17944	0
196907	47039	0	0	0	0,8308	124511	7565	17944	0
197892	47274	0	0	0	0,8308	125133	7565	17944	0
198881	47511	0	0	0	0,8308	125759	7565	17944	0
199876	47748	0	0	0	0,8308	126388	7565	17944	0
200875	47987	0	0	0	0,8308	127020	7565	17944	0
201879	48227	0	0	0	0,8308	127655	7565	17944	0
202889	48468	0	0	0	0,8308	128293	7565	17944	0
203903	48710	0	0	0	0,8308	128934	7565	17944	0
204923	48954	0	0	0	0,8308	129579	7565	17944	0
205947	49199	0	0	0	0,8308	130227	7565	17944	0
206977	49445	0	0	0	0,8308	130878	7565	17944	0
208012	49692	0	0	0	0,8308	131532	7565	17944	0
209052	49940	0	0	0	0,8308	132190	7565	17944	0
210097	50190	0	0	0	0,8308	132851	7565	17944	0
211148	50441	0	0	0	0,8308	133515	7565	17944	0
212204	50693	0	0	0	0,8308	134183	7565	17944	0
213265	50947	0	0	0	0,8308	134854	7565	17944	0
214331	51201	0	0	0	0,8308	135528	7565	17944	0
215402	51457	0	0	0	0,8308	136206	7565	17944	0
216480	51715	0	0	0	0,8308	136887	7565	17944	0
217562	51973	0	0	0	0,8308	137571	7565	17944	0
218650	52233	0	0	0	0,8308	138259	7565	17944	0
219743	52494	0	0	0	0,8308	138950	7565	17944	0
220842	52757	0	0	0	0,8308	139645	7565	17944	0
221946	53020	0	0	0	0,8308	140343	7565	17944	0
223056	53286	0	0	0	0,8308	141045	7565	17944	0
224171	53552	0	0	0	0,8308	141750	7565	17944	0
225292	53820	0	0	0	0,8308	142459	7565	17944	0
226418	54089	0	0	0	0,8308	143171	7565	17944	0
227550	54359	0	0	0	0,8308	143887	7565	17944	0
228688	54631	0	0	0	0,8308	144607	7565	17944	0
229831	54904	0	0	0	0,8308	145330	7565	17944	0
128323	0	64161	0	64161	0,8308	106610	7565	17944	79560
			1196253	1260414					

Table 5.4 WLC Model's Calculations under *Debt Crisis* Economy – *cont'd.*

NCF	cumNCF	DCF	NPV	Cost	Value	Profit
-157021	-157021	-147253	-147253	157021	167515	10494
-380739	-537760	-334843	-482096	548176	559366	11190
-629347	-1167107	-519051	-1001147	1213885	1225818	11932
-316247	-1483353	-244598	-1245745	1610654	1623378	12724
106315	-1377038	77113	-1168632	1611180	1624748	13568
106899	-1270140	72713	-1095919	1611157	1625625	14468
107485	-1162655	68564	-1027355	1610547	1625974	15427
108074	-1054580	64651	-962704	1609307	1625757	16451
108667	-945914	60962	-901742	1607392	1624934	17542
109262	-836652	57483	-844260	1604755	1623461	18706
109860	-726792	54202	-790058	1601345	1621291	19946
110461	-616331	51108	-738950	1597107	1618377	21269
111065	-505265	48191	-690759	1591985	1614665	22680
111673	-393593	45440	-645318	1585915	1610100	24185
112283	-281310	42846	-602472	1578832	1604621	25789
112896	-168413	40401	-562071	1570666	1598166	27500
113513	-54901	38094	-523977	1561342	1590666	29324
114132	59231	35919	-488058	1550780	1582049	31269
114755	173986	33869	-454189	1538895	1572239	33343
115380	289366	31935	-422254	1525596	1561151	35555
116009	405375	30112	-392143	1510786	1548700	37914
116641	522016	28392	-363751	1494362	1534790	40429
117276	639292	26771	-336980	1476212	1519323	43110
117914	757206	25242	-311737	1456221	1502191	45970
118556	875762	23801	-287937	1434263	1483282	49020
119200	994963	22442	-265495	1410202	1462474	52271
119848	1114811	21160	-244335	1383899	1439637	55739
120500	1235311	19951	-224384	1355199	1414635	59436
121154	1356465	18812	-205572	1323941	1387319	63379
121812	1478276	17737	-187834	1289951	1357534	67583
122473	1600749	16724	-171110	1253046	1325112	72066
123137	1723885	15769	-155341	1213029	1289875	76846
123804	1847690	14868	-140473	1169690	1251634	81944
124475	1972165	14019	-126454	1122805	1210184	87379
125150	2097315	13218	-113236	1072136	1165311	93176
125827	2223142	12463	-100773	1017428	1116784	99356
126508	2349650	11751	-89023	958410	1064357	105947
127193	2476843	11079	-77943	894792	1007767	112975
127880	2604723	10446	-67497	826267	946736	120469
128572	2733295	9850	-57647	752505	880965	128460
129267	2862561	9287	-48360	673155	810136	136981
129965	2992526	8756	-39604	587843	733911	146068
130666	3123193	8256	-31349	496171	651928	155757
131372	3254564	7784	-23565	397712	563801	166089
132080	3386645	7339	-16226	292013	469120	177107
132793	3519438	6920	-9306	178591	367446	188855
133509	3652946	6524	-2782	56929	258311	201382
134228	3787174	6151	3369	0	141218	141218
134951	3922125	5800	9169	0	15635	15635
16672	3938797	672	**9841**	0	0	0
		9841				

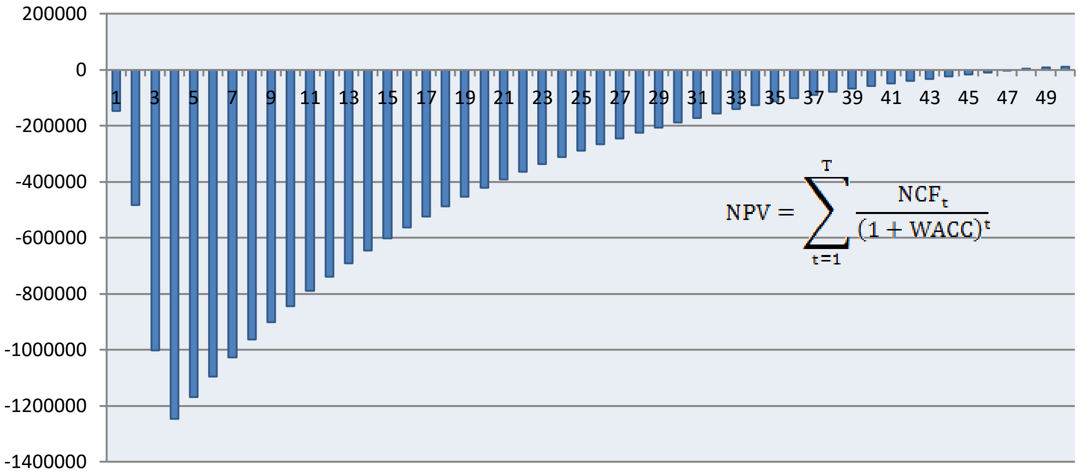


Fig. 5.6 NPV per Year of Product Life-Cycle under *Debt Crisis* Economy

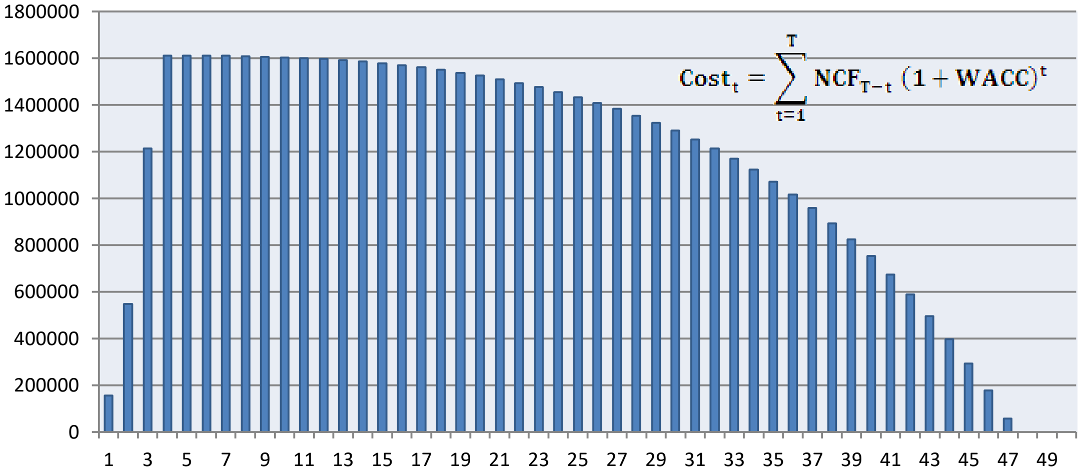


Fig. 5.7 Cost in Present Values under *Debt Crisis* Economy

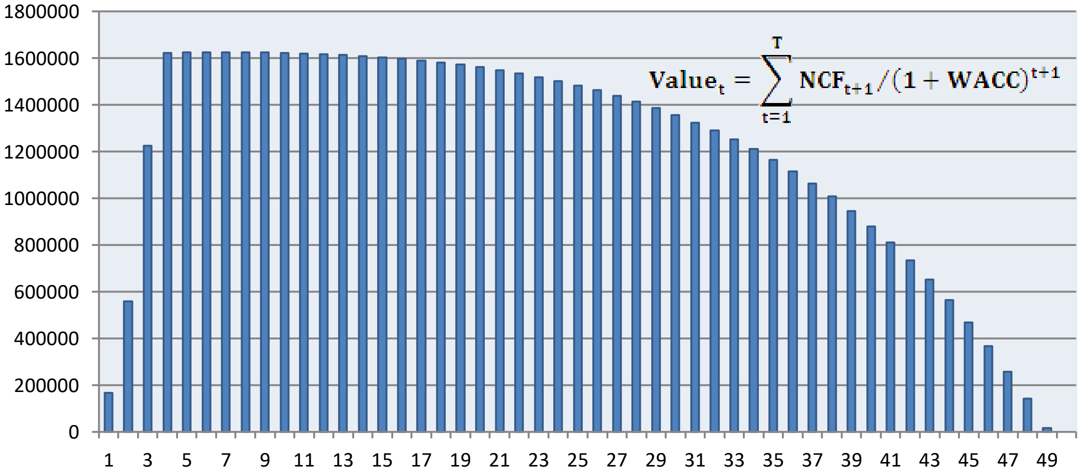


Fig. 5.8 Value in Present Values under *Debt Crisis* Economy

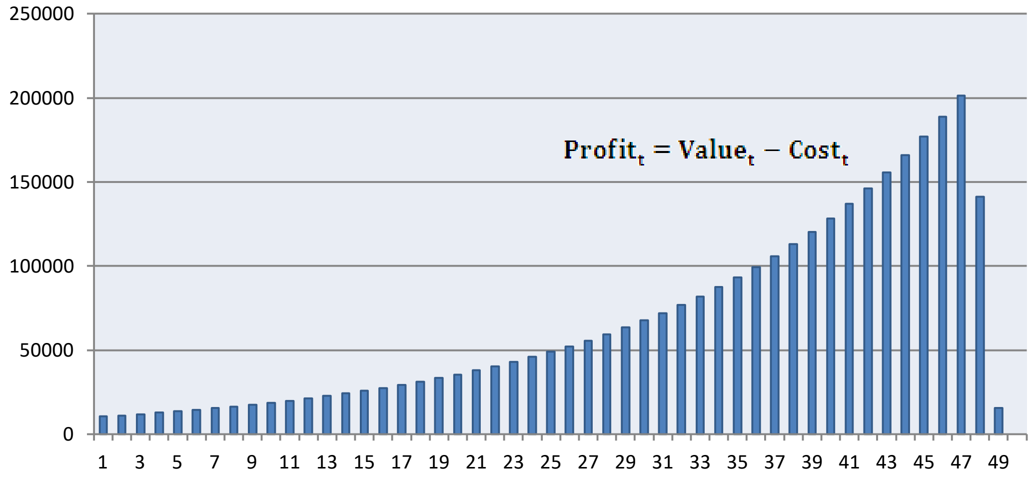


Fig. 5.9 Profit in Present Values under *Debt Crisis* Economy

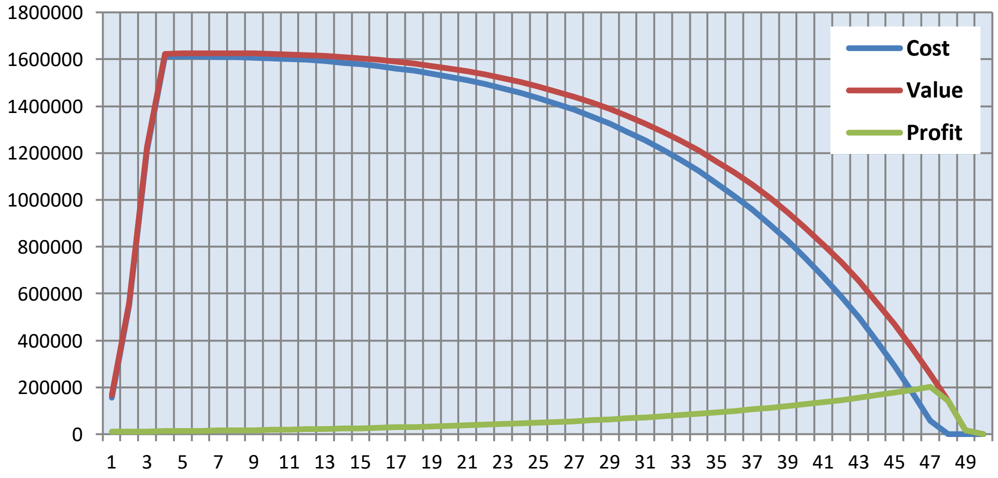


Fig. 5.10 Cost-Value-Profit Curves under *Debt Crisis* Economy

5.3.2 Fair Value Accounting under Uncertainty

Suppose that all input/independent variables of the WLC model are following the *PERT* probability distribution function in order to recalculate the output/dependent variables of NPV (for investment project appraisal) and Value (for product valuation per year of life-cycle) under *uncertainty* by assigning to each input/independent variable *minimum, most likely* and *maximum* values. These values differ among countries and depend on the current economic situation of each country. In addition, these figures obviously may change during the built asset's life-cycle. The above three-point estimates for each input/independent variable are given in **bold** figures in Table 5.5; it can be seen that, the *most likely* values are the single 'best-guess' values of the *deterministic* WLC model. Furthermore, project cost follows the same distribution pattern (see Subsection 5.3.1).

Table 5.5 WLC Model's Input Variables under *Uncertainty*

INPUT VARIABLES:					*minimum*	*most likely*	*maximum*
TGFA	m2	1.000					
PA	m2	1.250					
LV	€/m2 **PA**	85,83	107.292 €		**75**	**85**	**100**
NCC	% **C**	17,83%	182.792 €		**15%**	**18%**	**20%**
C	€/m2 **TGFA**	1.025	1.025.000 €		**850**	**1.000**	**1.300**
R	€/m2 **TGFA**	173,33	173.333 €	13,18%	**120**	**180**	**200**
O	€/m2 **TGFA**	10,167	10.167 €	0,77%	**8**	**10**	**13**
M	€/m2 **TGFA**	15,167	15.167 €	1,15%	**13**	**15**	**18**
OC	€/m2 **TGFA**	18,167	18.167 €	1,38%	**16**	**18**	**21**
RV	% **C**	10%	100.792 €		**8%**	**10%**	**11%**
DC	€/m2 **TGFA**	50,83	50.833 €		**40**	**50**	**65**
i_{inf}	%	1,83%			**0,5%**	**2%**	**2,5%**
i_*	%	2%			**1%**	**2%**	**3%**
φ^p	%	1,08%			**0,5%**	**1%**	**2%**
φ^y	%	29,33%			**27%**	**29%**	**33%**
a	%	2%			**1%**	**2%**	**3%**
g	%	0,11%			**0,05%**	**0,1%**	**0,2%**
Λ	%	5,00%			**4%**	**5%**	**6%**
D	%	60%			**45%**	**60%**	**75%**
S	%	40%			**25%**	**40%**	**55%**
CS	%	3,17%			**2%**	**3%**	**5%**
φ^{ind}	%	24%			**22%**	**24%**	**26%**

Table 5.5 also includes both fixed and probabilistic rates for land acquisition assuming that now the building site has to be purchased by the land developer prior to construction. Figure 5.11 (page 324) provides an example of the assignment of the *PERT* distribution to the input variables of the model with the histogram for Revenue (Rent – R) per m^2 per year of UL, R = *PERT* (120,180,200). Table 5.6 (page 324) shows descriptive statistics for all input variables. In order to recalculate the NPV and Value curves, MCS is used (10.000 iterations) with the Latin Hypercube sampling method (see Iman *et al.*, 1980).

Table 5.6 Descriptive Statistics for Input Variables – *PERT* distribution

Input	Minimum	Maximum	Mean	Std. Dev.	Variance	Skewness	Kurtosis
LV	75,08402	99,10535	**85,8333**	4,682555	21,92632	0,1778715	2,375574
NCC	0,1508626	0,1995098	**0,1783333**	9,365333E-03	8,770947E-05	-0,1780642	2,376108
C	850,2705	1285,388	**1025**	82,92232	6876,11	0,3017179	2,45561
R	124,0141	199,8533	**173,3334**	14,25456	203,1925	-0,467761	2,625362
O	8,044878	12,86766	**10,16667**	0,936519	0,8770679	0,1779625	2,375793
M	13,04577	17,9011	**15,16667**	0,9365376	0,8771027	0,1781331	2,37628
OC	16,04262	20,86359	**18,16667**	0,9365188	0,8770675	0,1780162	2,37589
RV	8,136834E-02	0,1098262	**9,833335E-02**	5,527933E-03	3,055804E-05	-0,3014908	2,454568
DC	40,24885	64,31445	**50,83332**	4,682571	21,92647	0,1779959	2,375745
$\mathbf{i_{inf}}$	5,958492E-03	0,0249673	**1,833331E-02**	3,56371E-03	1,270003E-05	-0,4678843	2,625833
$\mathbf{i_*}$	1,043297E-02	2,983129E-02	**2,000004E-02**	3,77984E-03	1,428719E-05	1,464401E-04	2,333622
$\boldsymbol{\varphi^p}$	5,095068E-03	1,935528E-02	**1,083333E-02**	2,763958E-03	7,639463E-06	0,3015073	2,454612
$\boldsymbol{\varphi^y}$	0,2704117	0,3271144	**0,2933333**	1,105582E-02	1,222311E-04	0,3014711	2,454524
a	1,036339E-02	2,981511E-02	**2,000001E-02**	3,779884E-03	1,428752E-05	7,831045E-05	2,333785
g	5,058074E-04	1,958424E-03	**1,083335E-03**	2,764068E-04	7,64007E-08	0,3017114	2,455492
$\boldsymbol{\Lambda}$	4,024276E-02	5,986803E-02	**0,05**	3,779957E-03	1,428807E-05	-1,483874E-05	2,334083
D	0,454296	0,7454917	**0,5999998**	0,0566978	3,214641E-03	-3,053756E-05	2,333703
S	0,2560619	0,5439697	**0,3999998**	5,669698E-02	3,214548E-03	-4,298337E-05	2,333454
CS	2,010547E-02	4,858443E-02	**3,166664E-02**	5,527896E-03	3,055763E-05	0,3014393	2,454396
$\boldsymbol{\varphi^{ind}}$	0,2207415	0,2594097	**0,24**	7,559643E-03	5,714821E-05	3,545345E-05	2,333539

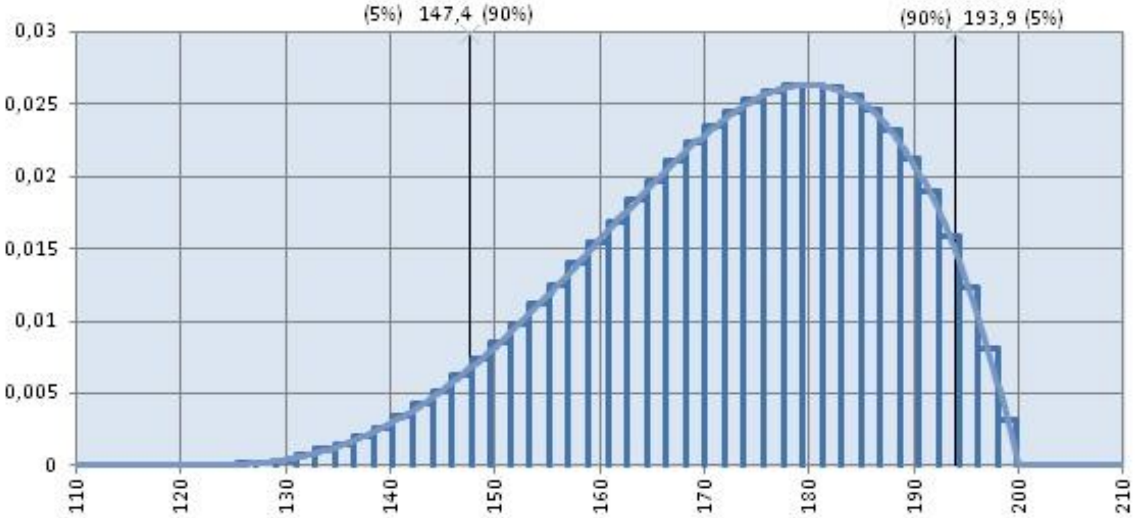


Fig. 5.11 *PERT* Distribution for Revenue Input Variable (Rent)

Figure 5.12 illustrates the resulted NPV histogram with cumulative probability (*S*-curve); the mean NPV figure is approx. €466.392,00. In addition, Figure 5.13 indicates the degree of significance of the input variables to the NPV output; it can be seen that the most critical positive and negative input variables are Revenue (R) and Construction Cost (C) with correlation coefficients of 0,78 and -0,30 respectively.

Table 5.7 NPV Results with Descriptive Statistics – *PERT* distribution

NPV	**Minimum**	**Maximum**	**Mean**	**Std. Dev.**	**Variance**	**Skewness**	**Kurtosis**
Y-1	-344437	-230783	**-278213**	16.607,56	275811049	-0,212283	2,824011
Y-5	-1760909	-1116567	**-1383629**	114.646,97	13143927730	-0,2991599	2,510901
Y-10	-1439348	-653469	**-989755**	127.954,42	16372333597	-0,2611635	2,677504
Y-15	-1210887	-257791	**-664148**	149.858,48	22457564028	-0,2607381	2,831588
Y-20	-1043745	91657	**-394992**	173.660,41	30157938001	-0,2634853	2,881686
Y-25	-909215	391802	**-172506**	196.808,67	38733652587	-0,2531016	2,886431
Y-30	-800977	642643	**11404**	218.428,86	47711166881	-0,2313375	2,878958
Y-35	-713922	852277	**163435**	238.257,00	56766398049	-0,2027937	2,871263
Y-40	-643928	1052712	**289122**	256.256,88	65667588547	-0,1711399	2,866928
Y-45	-587670	1246243	**393039**	272.482,76	74246854497	-0,1387872	2,866536
Y-50	-546621	1386654	**466302**	284.238,13	80791314546	-0,1122177	2,86898

For investment appraisal (project evaluation) purposes, a *sensitivity analysis* on NPV output (dependent variable) is performed per year of built asset's life-cycle in order to find the uncertain *minimum*, *maximum* and *mean* estimates and to produce a confidence interval for project's NPV. The corresponding results per 5-year periods are summarised in Table 5.7 whilst Figures 5.12-5.33 (pages 326-336) present the histograms with cumulative probability *S*-curves together with associated correlation coefficients. The estimated *confidence interval* for NPV can be found in Figure 5.34 (page 337).

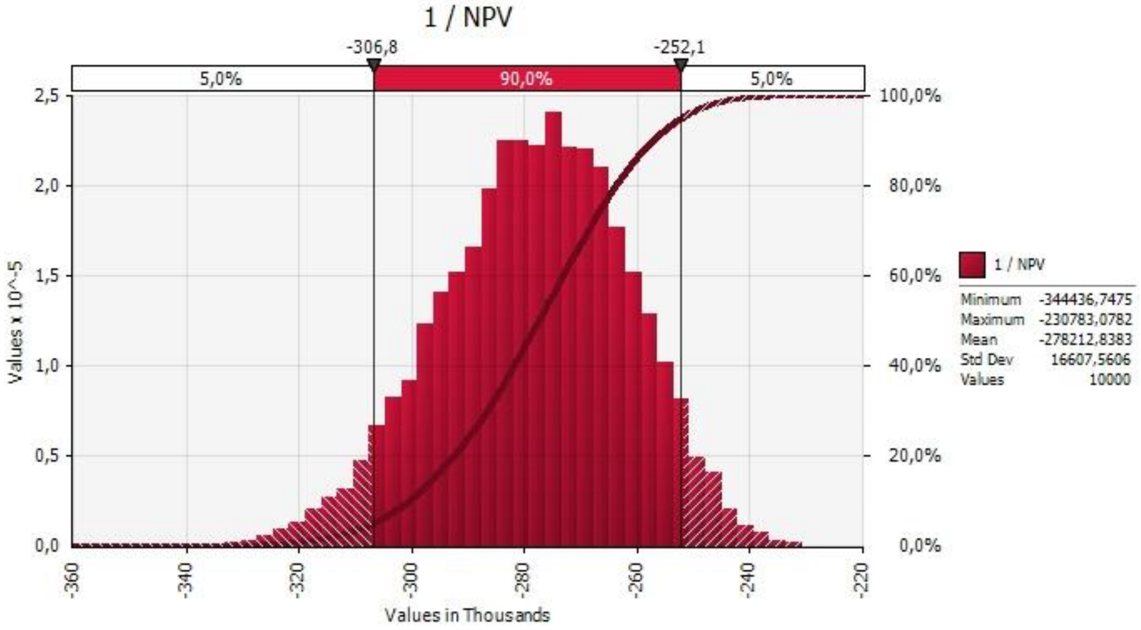


Fig. 5.12 NPV Histogram with Cumulative *S*-Curve – *PERT* distribution/Year-1

Mean estimated NPV: € -278.212,84

Standard deviation: € 16.607,56

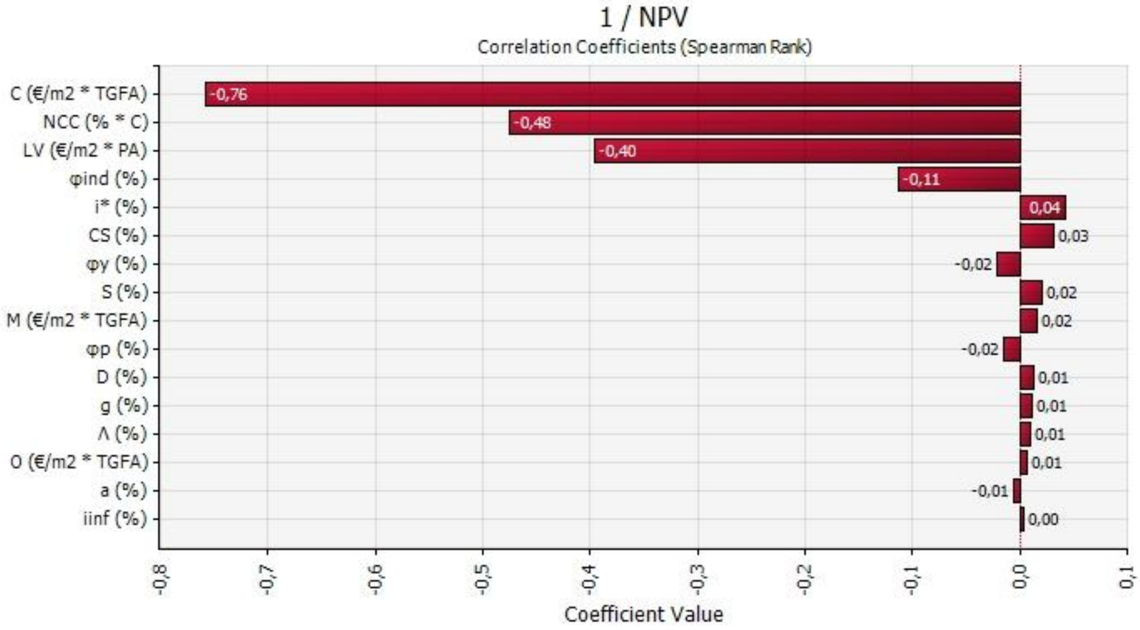


Fig. 5.13 NPV Correlation Coefficients – *PERT* distribution/Year-1

Most critical WLC negative input variable (coefficient value): Construction Cost (C) (-0,76)

Most critical WLC positive input variable (coefficient value): Risk-Free Rate (i^*) (0,04)

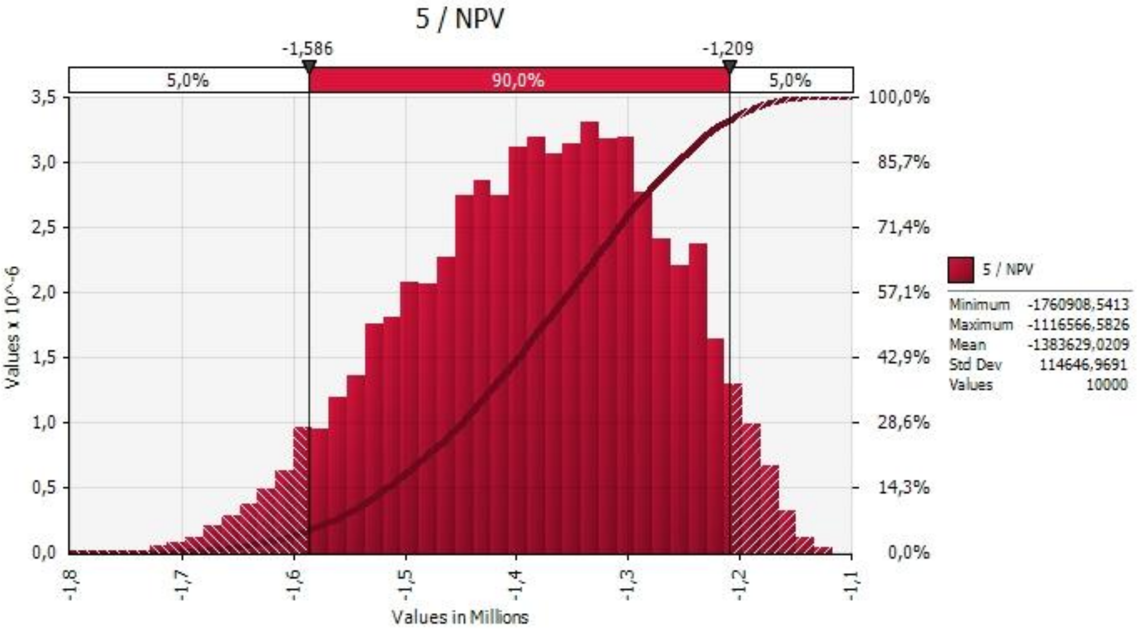


Fig. 5.14 NPV Histogram with Cumulative *S*-Curve – *PERT* distribution/Year-5

Mean estimated NPV: € -1.383.629,02

Standard deviation: € 114.646,97

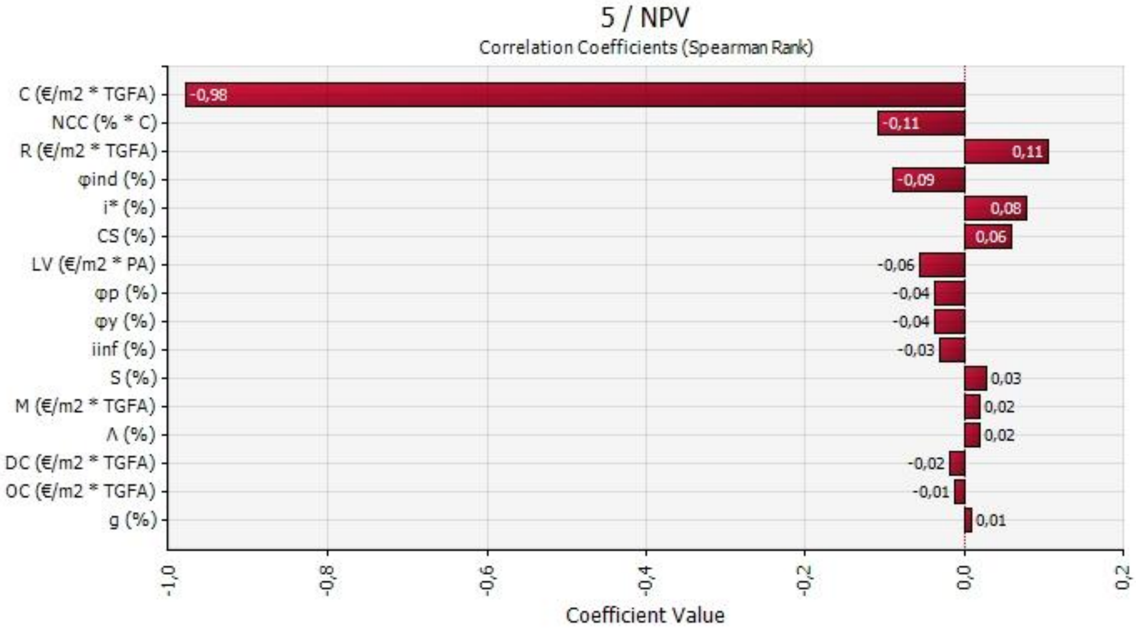


Fig. 5.15 NPV Correlation Coefficients – *PERT* distribution/Year-5

Most critical WLC negative input variable (coefficient value): Construction Cost (C) (-0,98)

Most critical WLC positive input variable (coefficient value): Rent (R) (0,11)

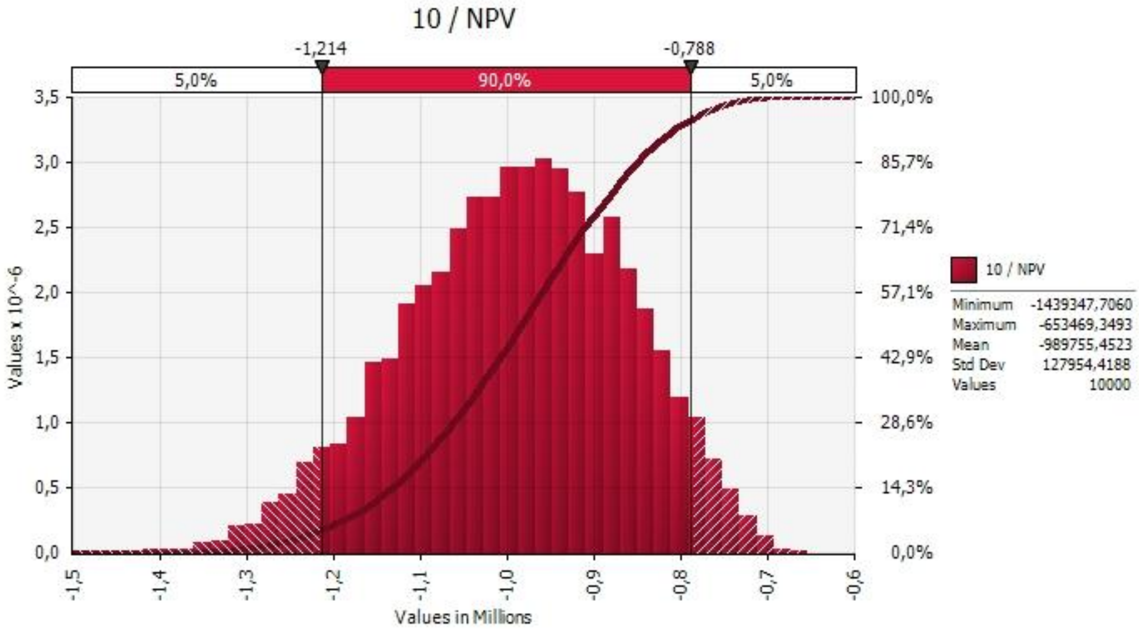


Fig. 5.16 NPV Histogram with Cumulative *S*-Curve – *PERT* distribution/Year-10

Mean estimated NPV: € -989.755,45

Standard deviation: € 127.954,42

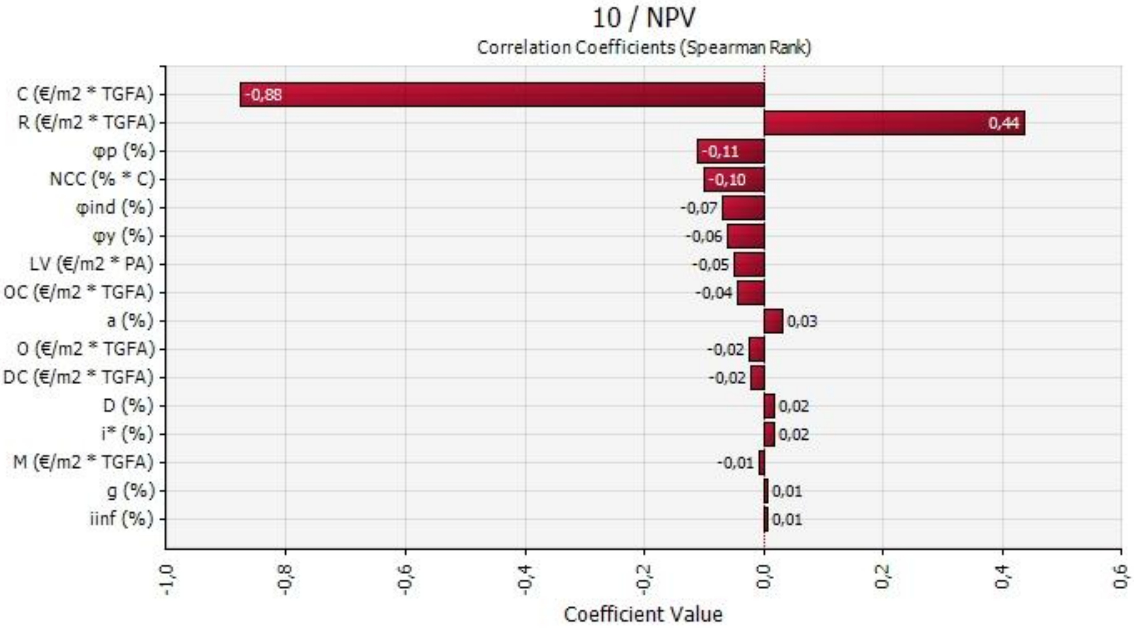


Fig. 5.17 NPV Correlation Coefficients – *PERT* distribution/Year-10

Most critical WLC negative input variable (coefficient value): Construction Cost (C) (-0,88)

Most critical WLC positive input variable (coefficient value): Rent (R) (0,44)

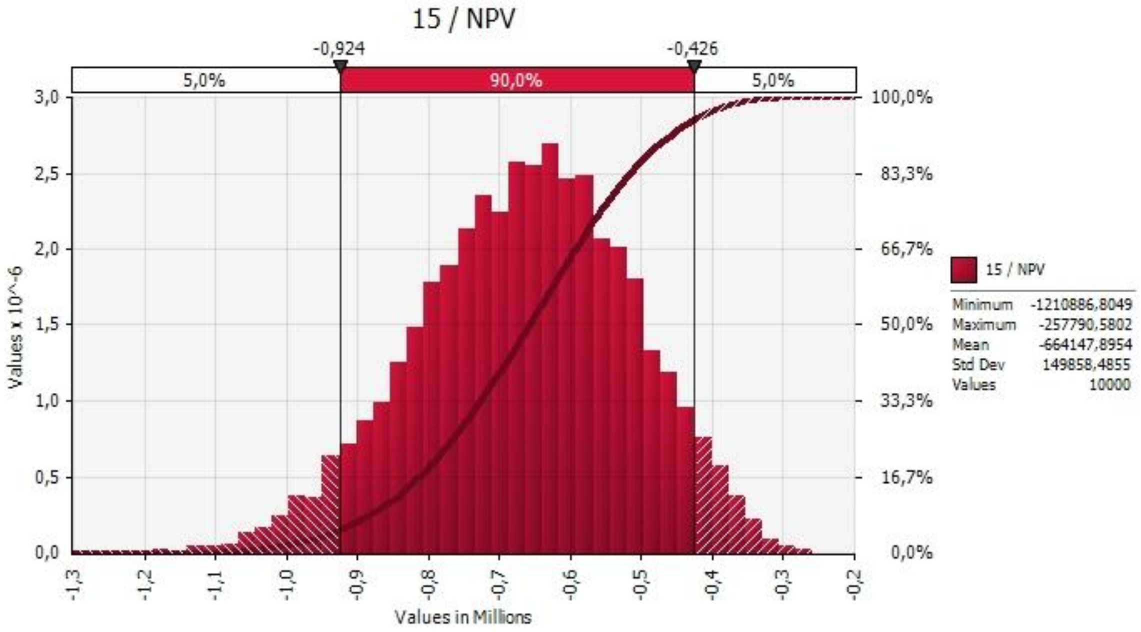


Fig. 5.18 NPV Histogram with Cumulative *S*-Curve – *PERT* distribution/Year-15

Mean estimated NPV: € -664.147,89

Standard deviation: € 149.858,48

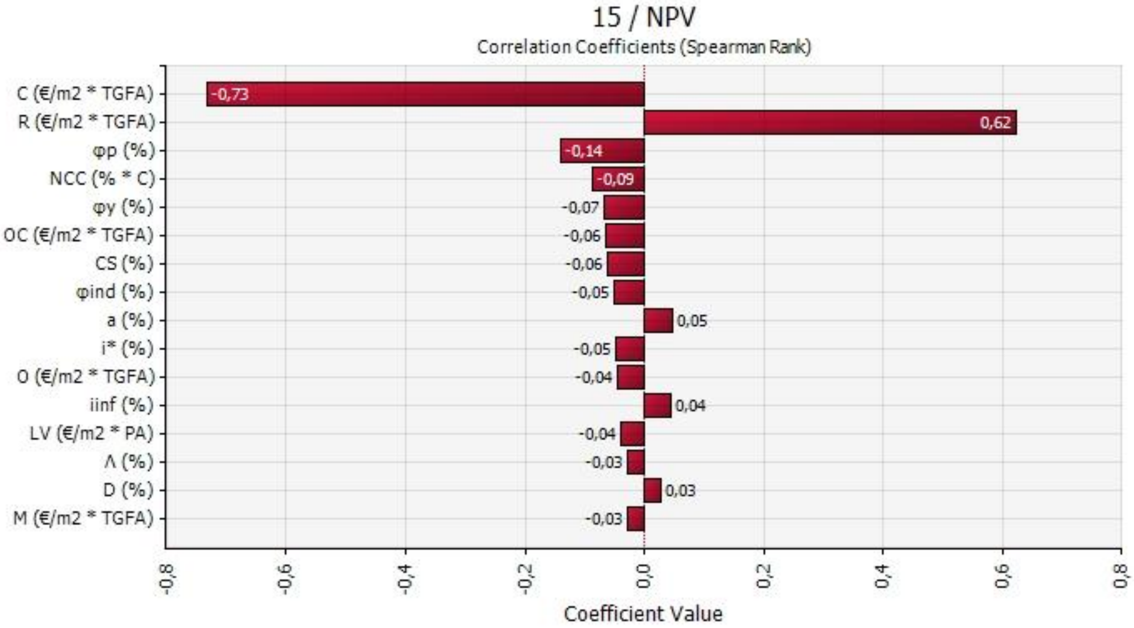


Fig. 5.19 NPV Correlation Coefficients – *PERT* distribution/Year-15

Most critical WLC negative input variable (coefficient value): Construction Cost (C) (-0,73)

Most critical WLC positive input variable (coefficient value): Rent (R) (0,62)

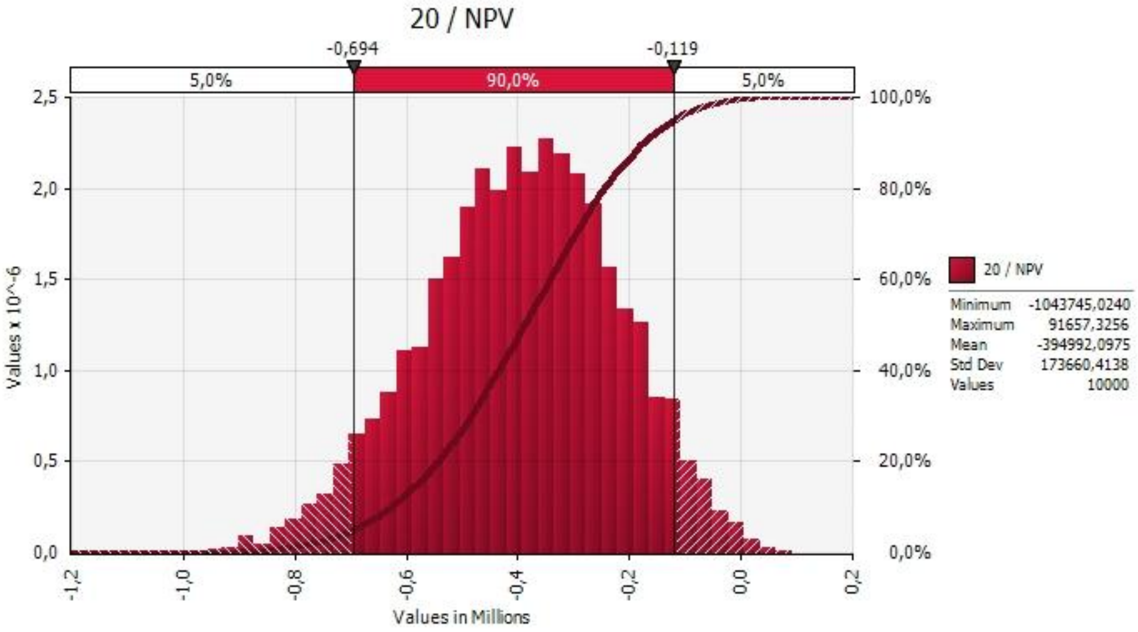


Fig. 5.20 NPV Histogram with Cumulative *S*-Curve – *PERT* distribution/Year-20

Mean estimated NPV: € -394.992,10

Standard deviation: € 173.660,41

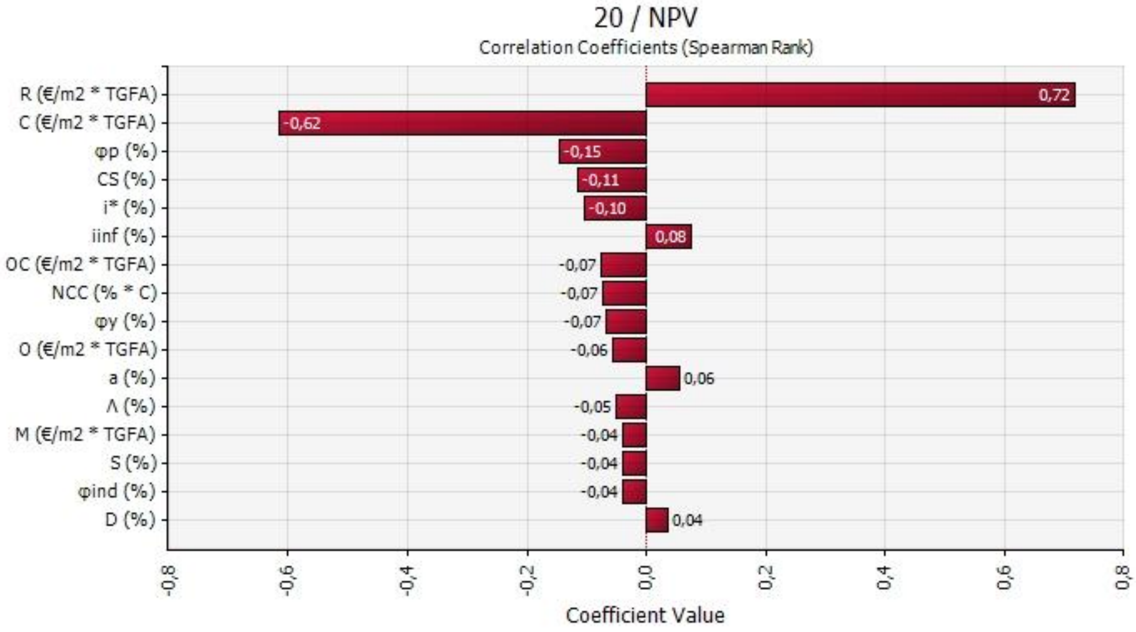


Fig. 5.21 NPV Correlation Coefficients – *PERT* distribution/Year-20

Most critical WLC negative input variable (coefficient value): Construction Cost (C) (-0,62)

Most critical WLC positive input variable (coefficient value): Rent (R) (0,72)

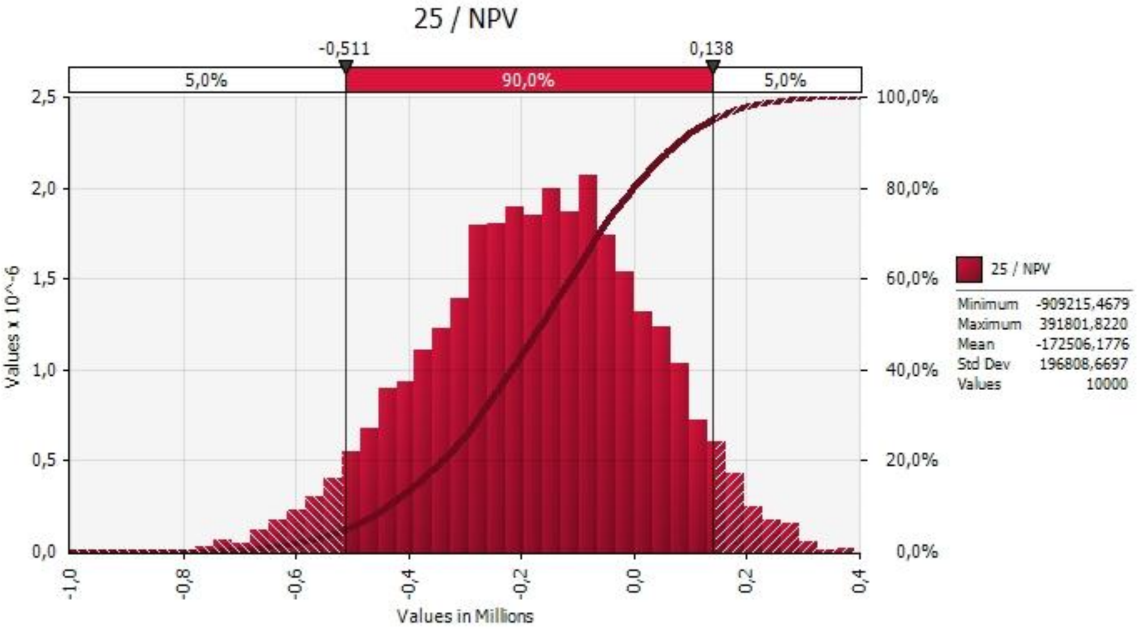


Fig. 5.22 NPV Histogram with Cumulative *S*-Curve – *PERT* distribution/Year-25

Mean estimated NPV: € -172.506,18

Standard deviation: € 196.808,67

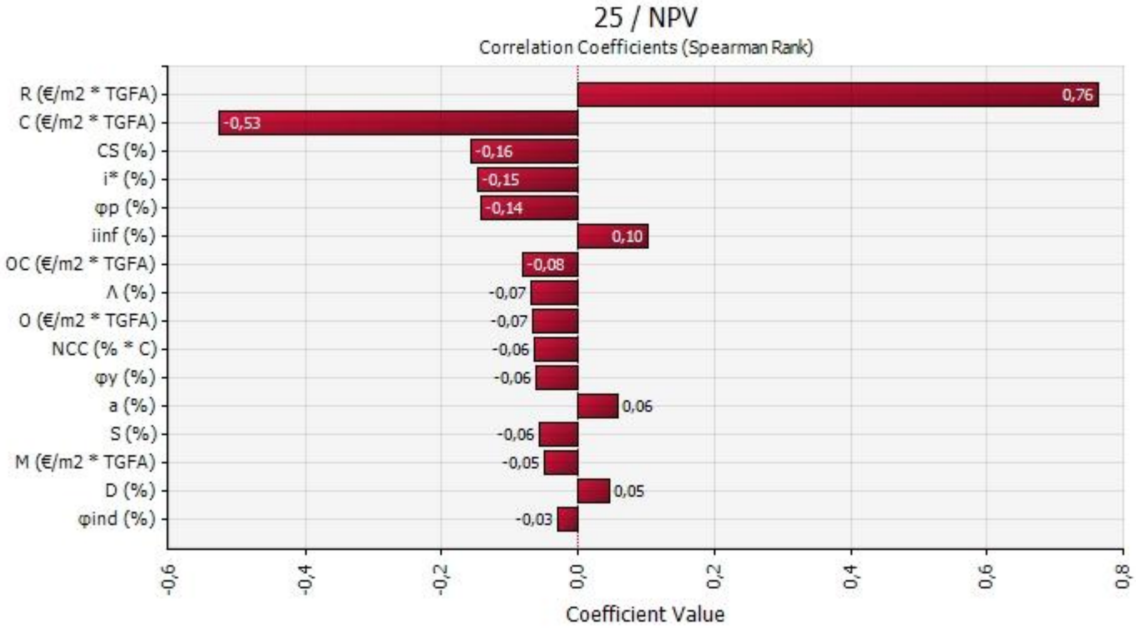


Fig. 5.23 NPV Correlation Coefficients – *PERT* distribution/Year-25

Most critical WLC negative input variable (coefficient value): Construction Cost (C) (-0,53)

Most critical WLC positive input variable (coefficient value): Rent (R) (0,76)

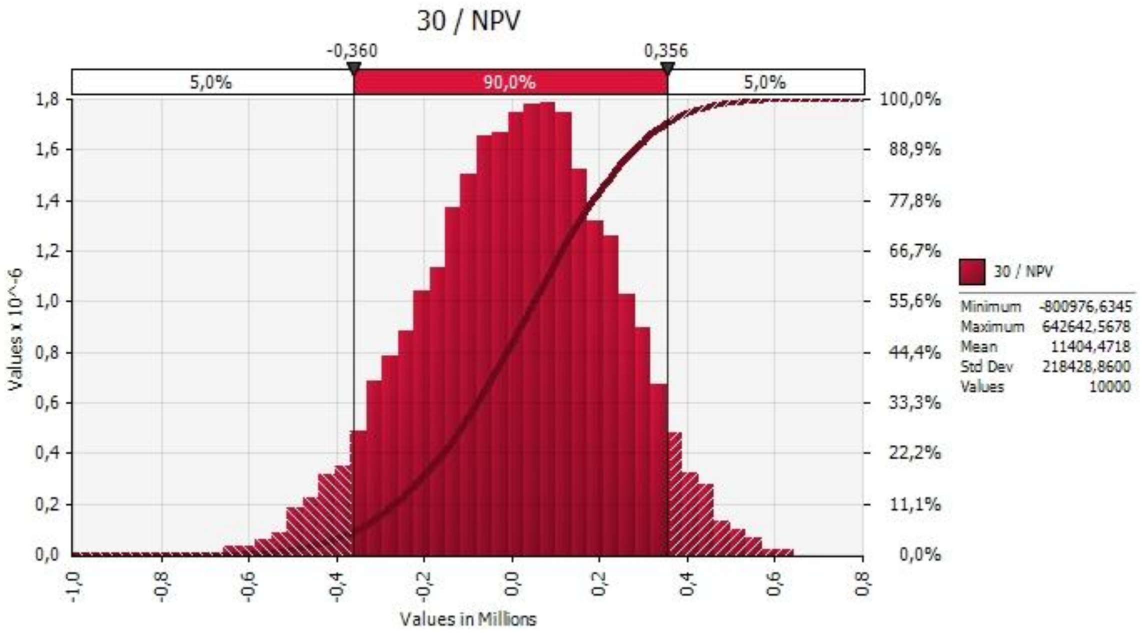


Fig. 5.24 NPV Histogram with Cumulative *S*-Curve – *PERT* distribution/Year-30

Mean estimated NPV: € 11.404,47

Standard deviation: € 218.428,86

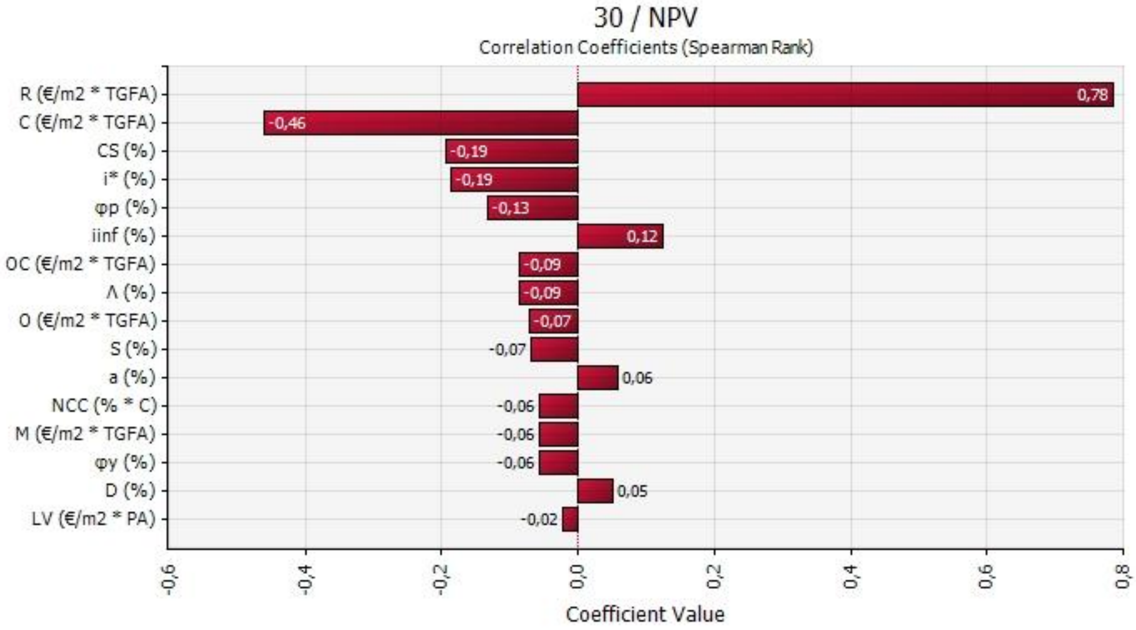


Fig. 5.25 NPV Correlation Coefficients – *PERT* distribution/Year-30

Most critical WLC negative input variable (coefficient value): Construction Cost (C) (-0,46)

Most critical WLC positive input variable (coefficient value): Rent (R) (0,78)

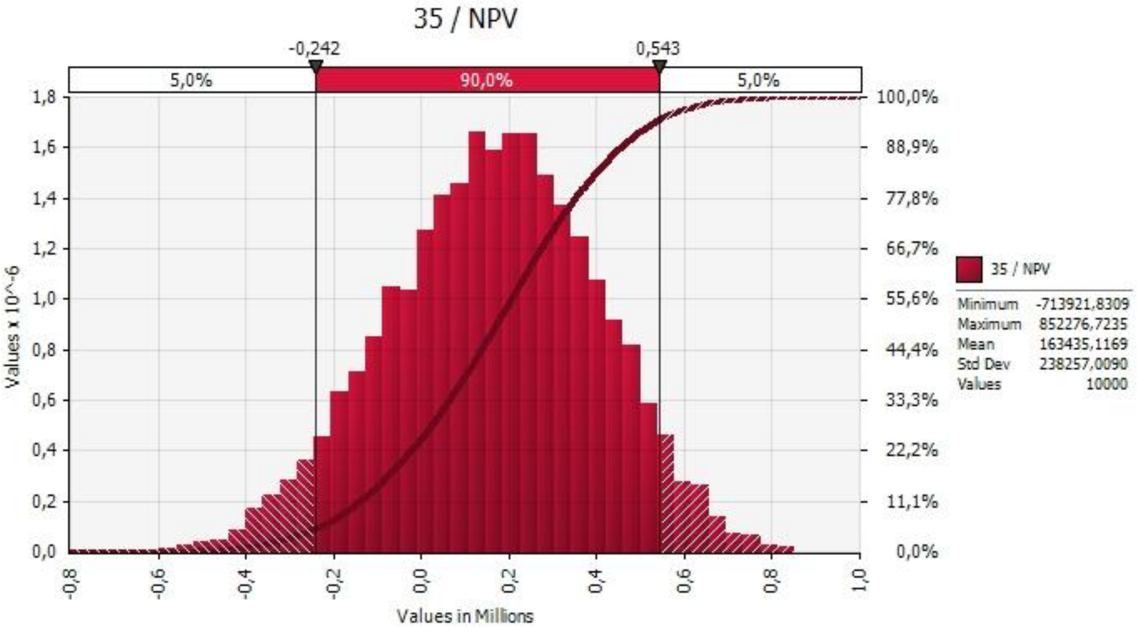


Fig. 5.26 NPV Histogram with Cumulative *S*-Curve – *PERT* distribution/Year-35

Mean estimated NPV: € 163.435,12

Standard deviation: € 238.257,00

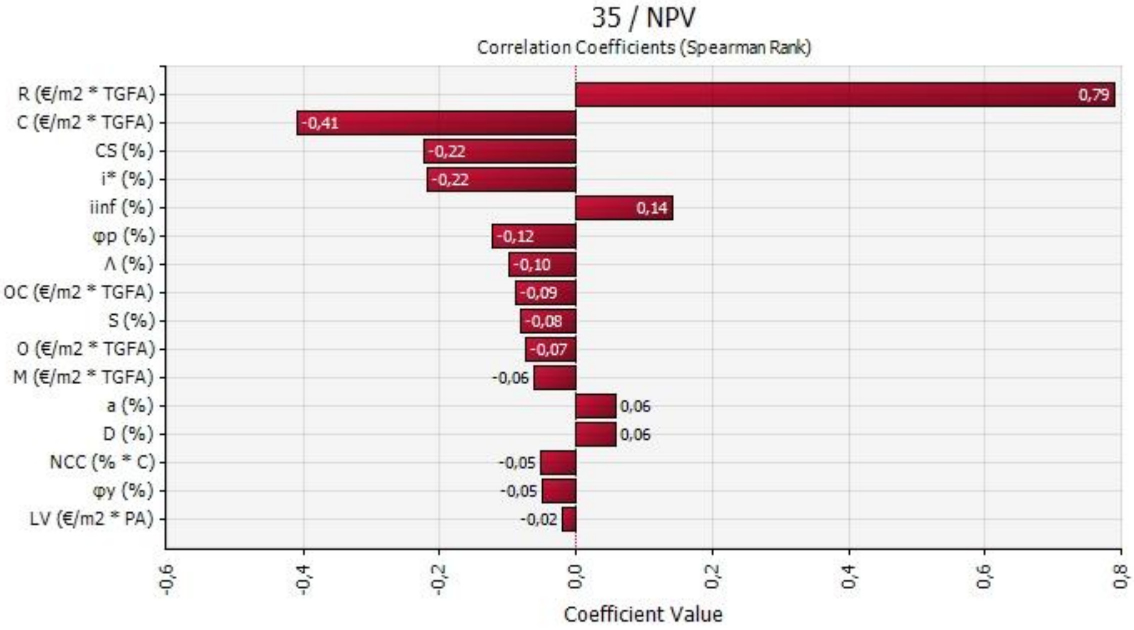


Fig. 5.27 NPV Correlation Coefficients – *PERT* distribution/Year-35

Most critical WLC negative input variable (coefficient value): Construction Cost (C) (-0,41)

Most critical WLC positive input variable (coefficient value): Rent (R) (0,79)

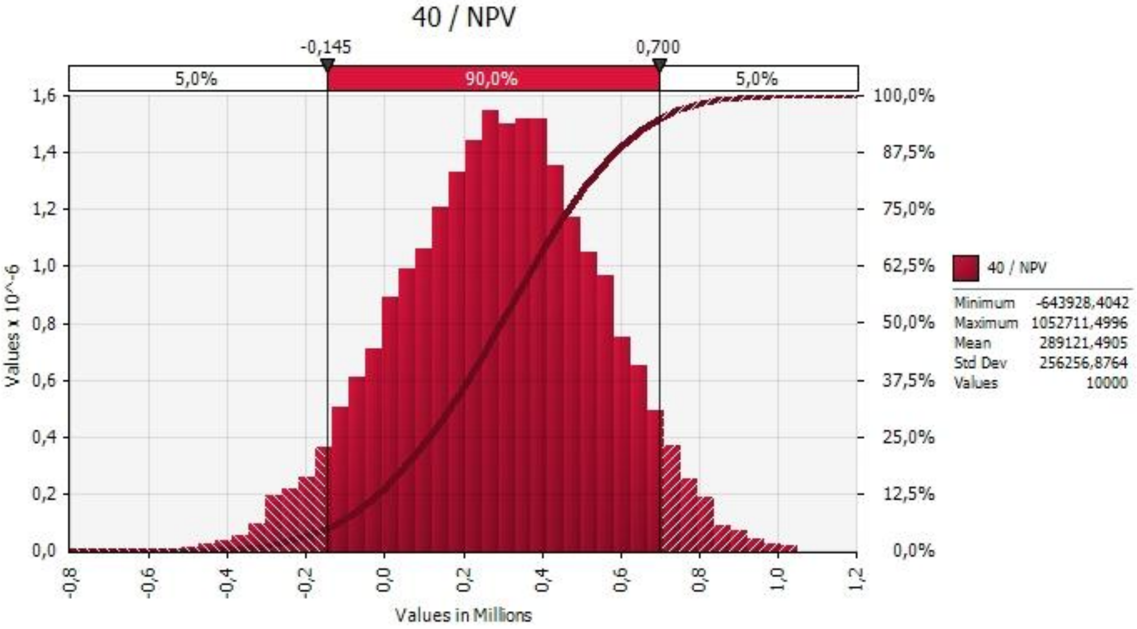


Fig. 5.28 NPV Histogram with Cumulative *S*-Curve – *PERT* distribution/Year-40

Mean estimated NPV: € 289.121,49

Standard deviation: € 256.256,88

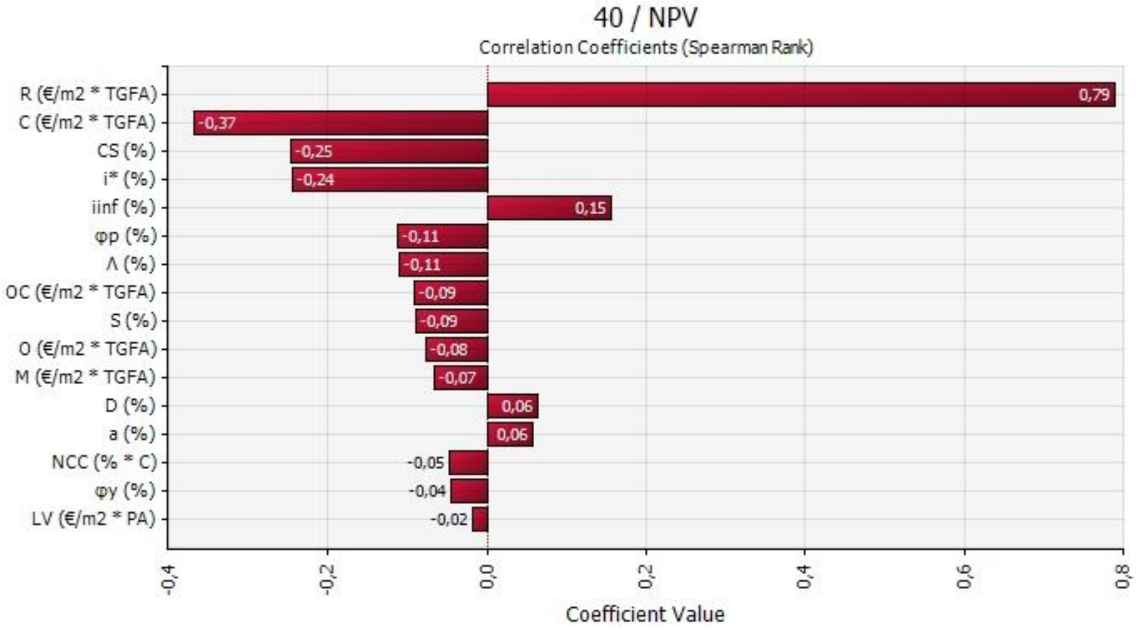


Fig. 5.29 NPV Correlation Coefficients – *PERT* distribution/Year-40

Most critical WLC negative input variable (coefficient value): Construction Cost (C) (-0,37)

Most critical WLC positive input variable (coefficient value): Rent (R) (0,79)

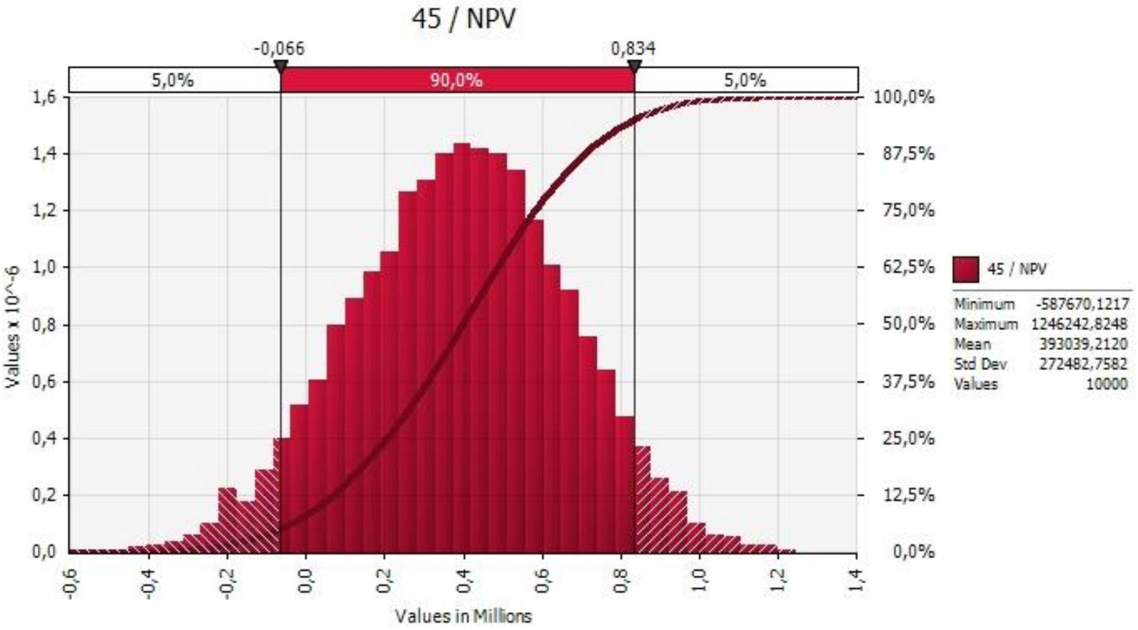


Fig. 5.30 NPV Histogram with Cumulative *S*-Curve – *PERT* distribution/Year-45

Mean estimated NPV: € 393.039,21

Standard deviation: € 272.482,76

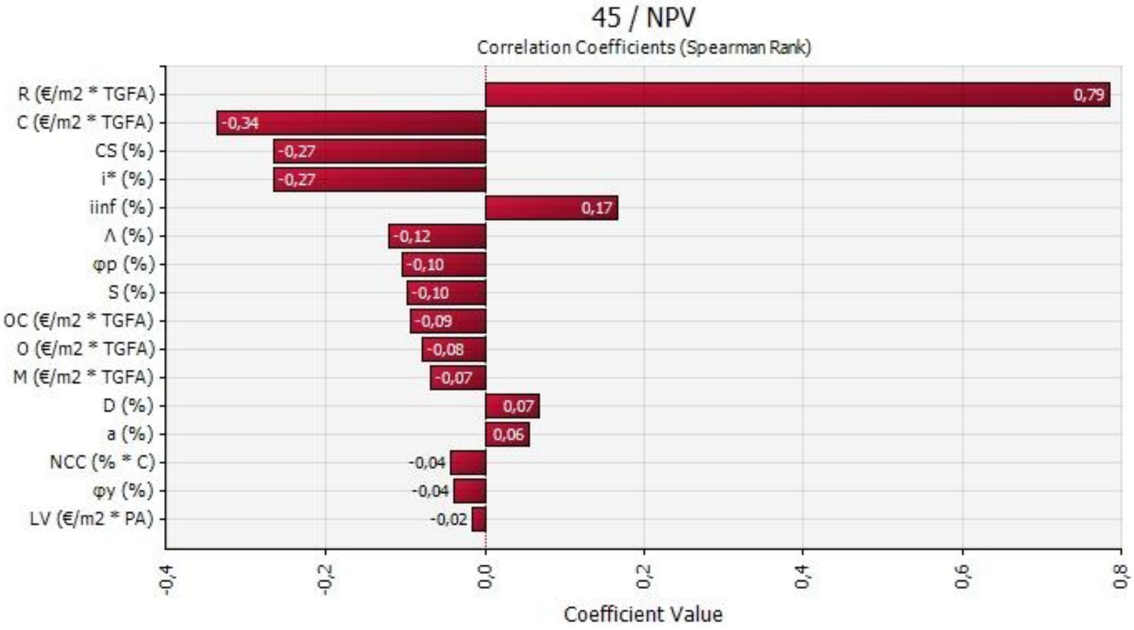


Fig. 5.31 NPV Correlation Coefficients – *PERT* distribution/Year-45

Most critical WLC negative input variable (coefficient value): Construction Cost (C) (-0,34)

Most critical WLC positive input variable (coefficient value): Rent (R) (0,79)

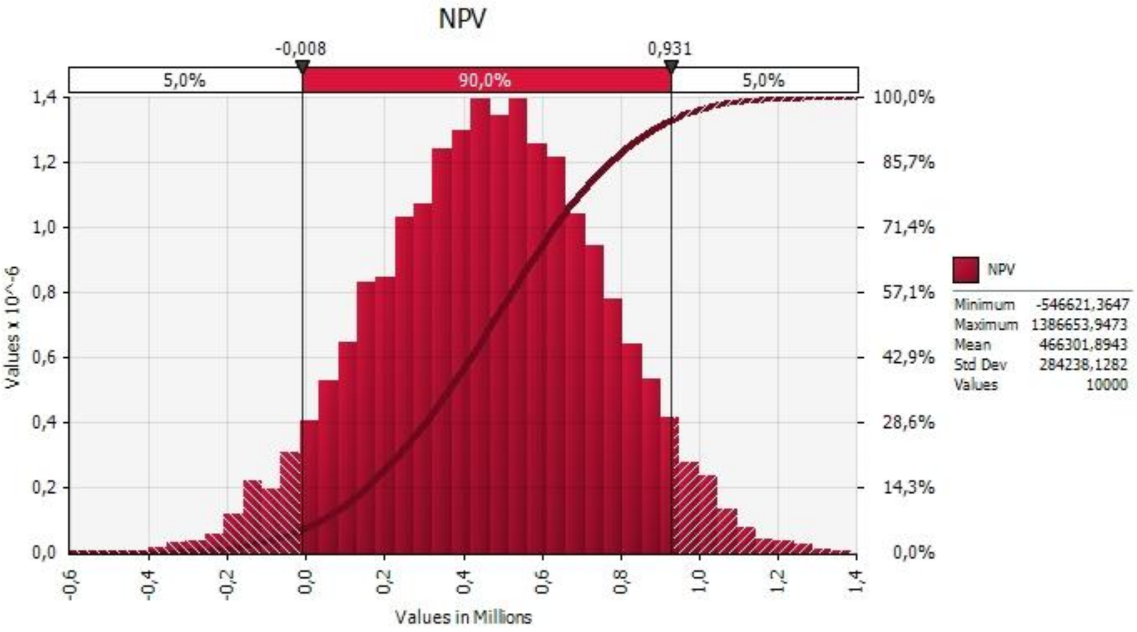


Fig. 5.32 NPV Histogram with Cumulative *S*-Curve – *PERT* distribution/Year-50

Mean estimated NPV: € 466.301,89

Standard deviation: € 284.238,13

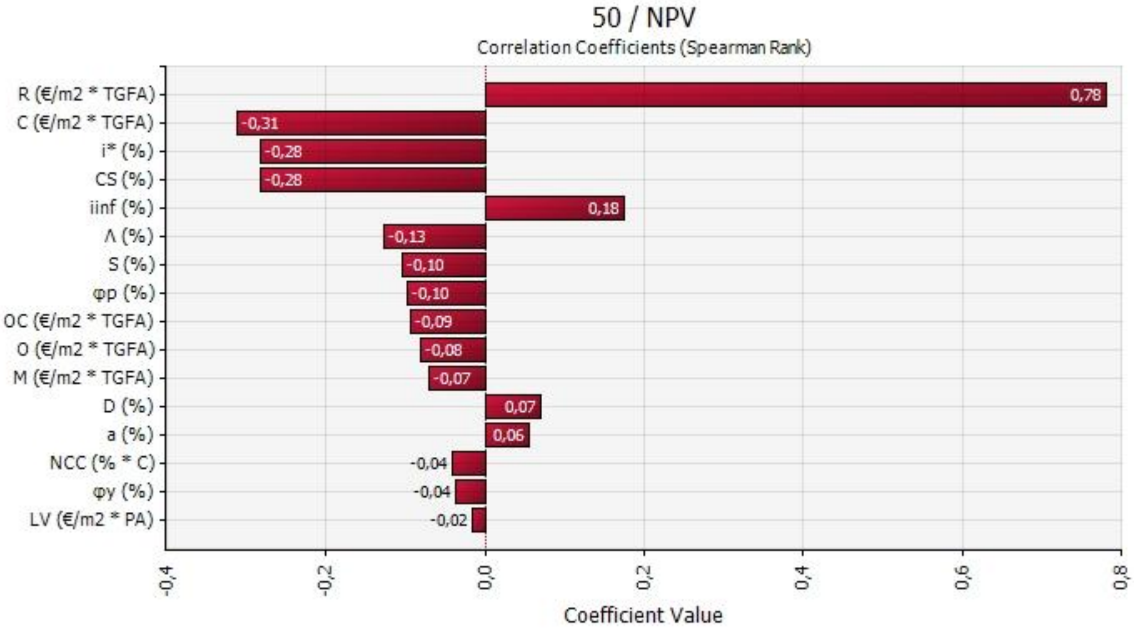


Fig. 5.33 NPV Correlation Coefficients – *PERT* distribution/Year-50

Most critical WLC negative input variable (coefficient value): Construction Cost (C) (-0,31)

Most critical WLC positive input variable (coefficient value): Rent (R) (0,78)

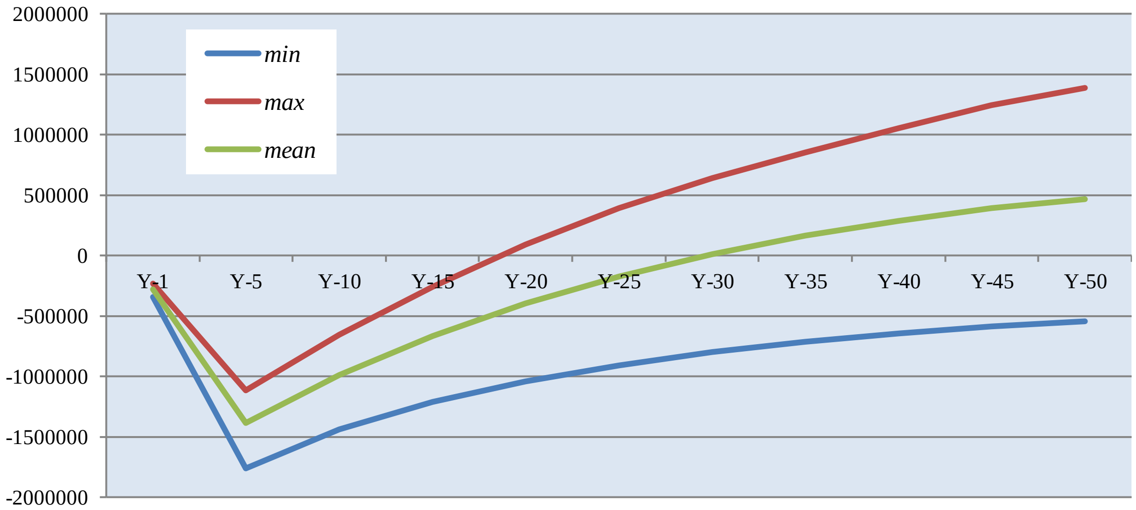


Fig. 5.34 Confidence Interval for NPV – *PERT* distribution

Furthermore, to estimate the built asset's Fair Value (product valuation) per year of life-cycle, a *sensitivity analysis* on Value output (dependent variable) is conducted in order to assess the *minimum*, *maximum* and *mean* estimates under uncertainty and a confidence interval for the commercial project's Fair Value over its life-cycle. The corresponding results per 5-year periods are summarised in the following Table 5.8 and Figures 5.35-5.56 (pages 338-348) illustrate the histograms with cumulative probability *S*-curves together with associated correlation coefficients for most critical WLC input variables. The estimated *confidence interval* for Value can be seen in Figure 5.57 (page 349).

Table 5.8 Value Results with Descriptive Statistics – *PERT* distribution

Value	Minimum	Maximum	Mean	Std. Dev.	Variance	Skewness	Kurtosis
Y-1	-351698	1822594	**787915**	293682	86249380000	-0,08018634	2,807876
Y-5	1277297	3557724	**2462135**	339365	1,15168E+11	-0,08713283	2,733708
Y-10	1318948	3763049	**2579740**	364369	1,32765E+11	-0,06068365	2,72277
Y-15	1342437	3922087	**2666384**	389832	1,51969E+11	-0,0326505	2,701081
Y-20	1340083	4007365	**2704816**	412441	1,70107E+11	-0,006617088	2,670668
Y-25	1301695	3990692	**2671292**	427060	1,8238E+11	0,01628843	2,635453
Y-30	1213797	3820232	**2533305**	426024	1,81496E+11	0,0364984	2,599547
Y-35	1058598	3441451	**2246548**	398114	1,58495E+11	0,05512642	2,566408
Y-40	808241	2726278	**1750817**	327128	1,07013E+11	0,07341631	2,538997
Y-45	422995	1551834	**964527**	190111	36142350000	0,09421065	2,525904
Y-49	-28666	161339	**53343**	27568	759980400	0,3768999	3,077473

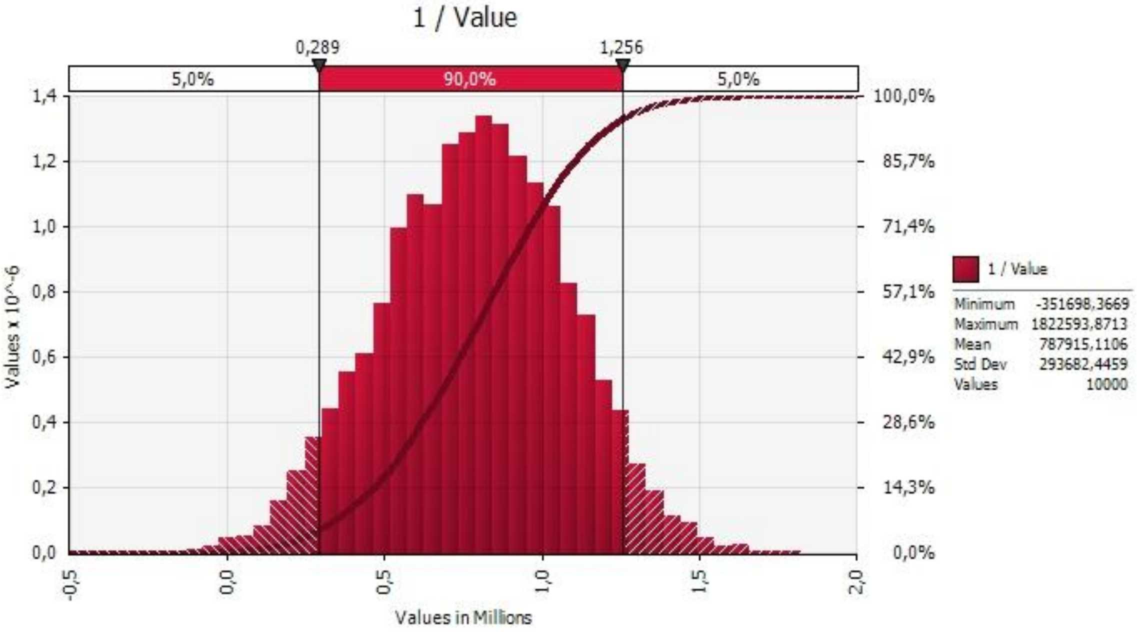


Fig. 5.35 Value Histogram with Cumulative *S*-Curve – *PERT* distribution/Year-1

Mean estimated Value: € 787.915,11

Standard deviation: € 293.682,45

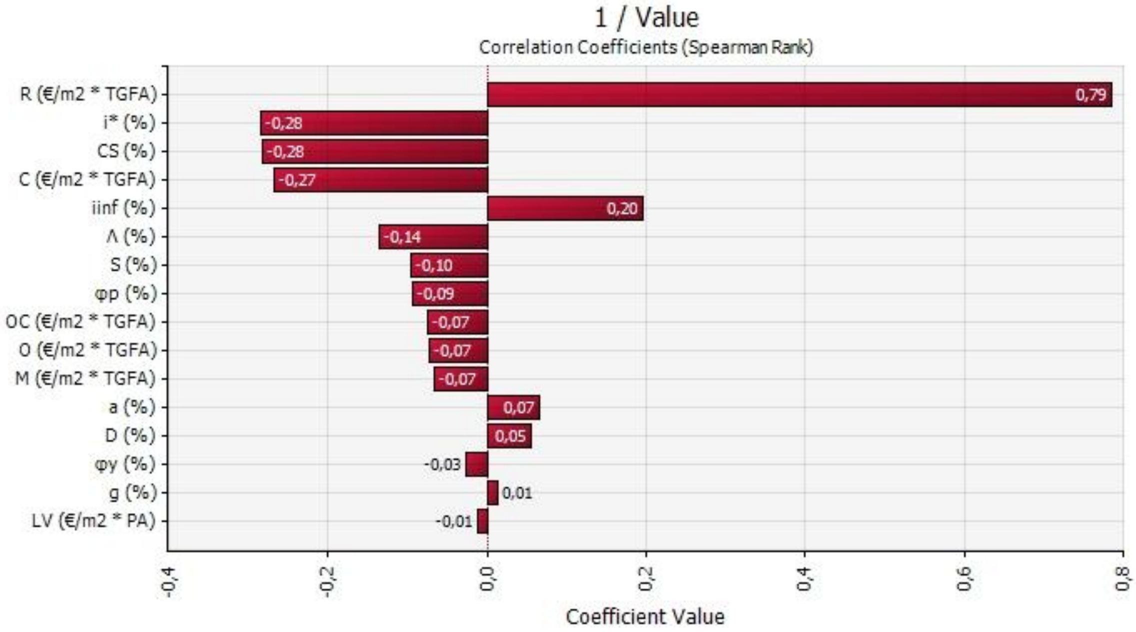


Fig. 5.36 Value Correlation Coefficients – *PERT* distribution/Year-1

Most critical WLC negative input variable (coefficient value): Free-Risk Rate (i_*) (-0,28)

Most critical WLC positive input variable (coefficient value): Rent (R) (0,79)

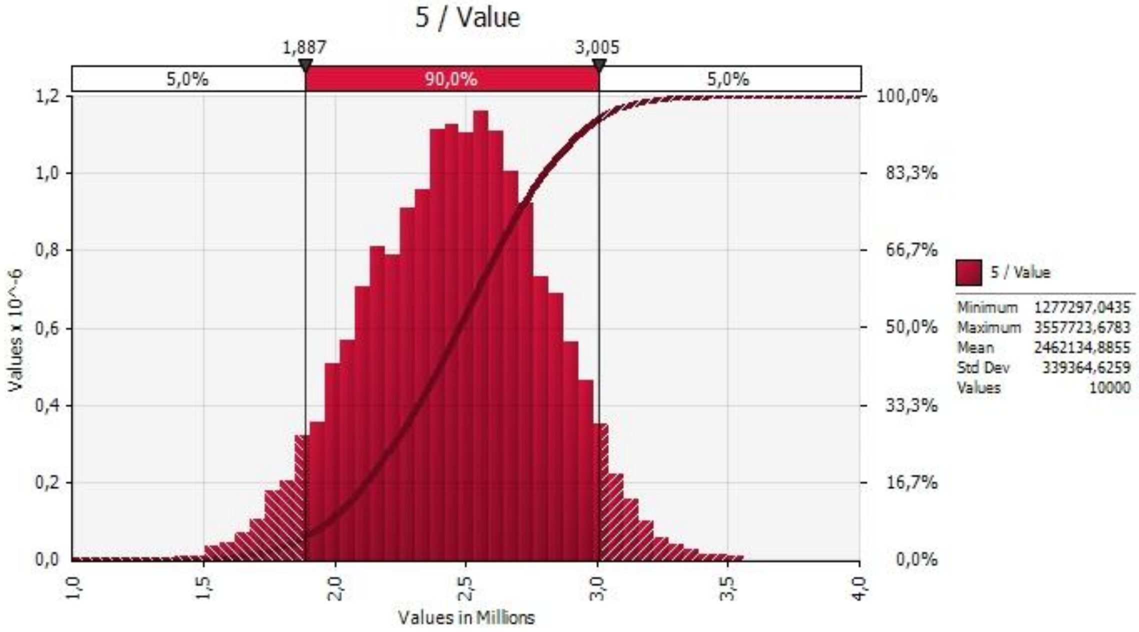


Fig. 5.37 Value Histogram with Cumulative *S*-Curve – *PERT* distribution/Year-5

Mean estimated Value: € 2.462.134,89

Standard deviation: € 339.364,63

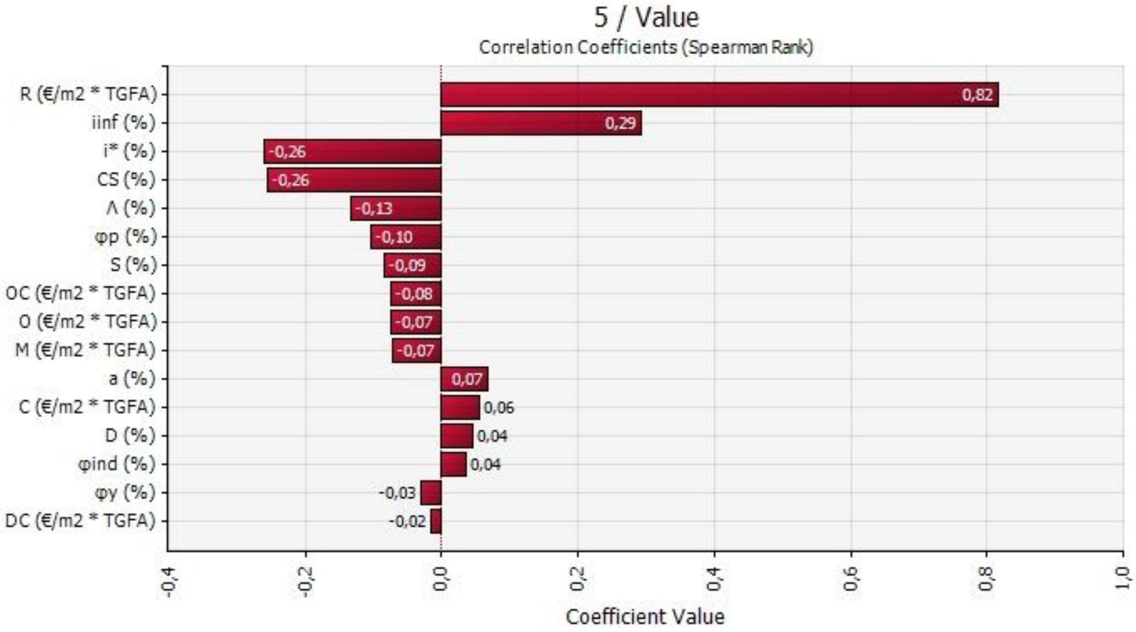


Fig. 5.38 Value Correlation Coefficients – *PERT* distribution/Year-5

Most critical WLC negative input variable (coefficient value): Free-Risk Rate (i_*) (-0,26)

Most critical WLC positive input variable (coefficient value): Rent (R) (0,82)

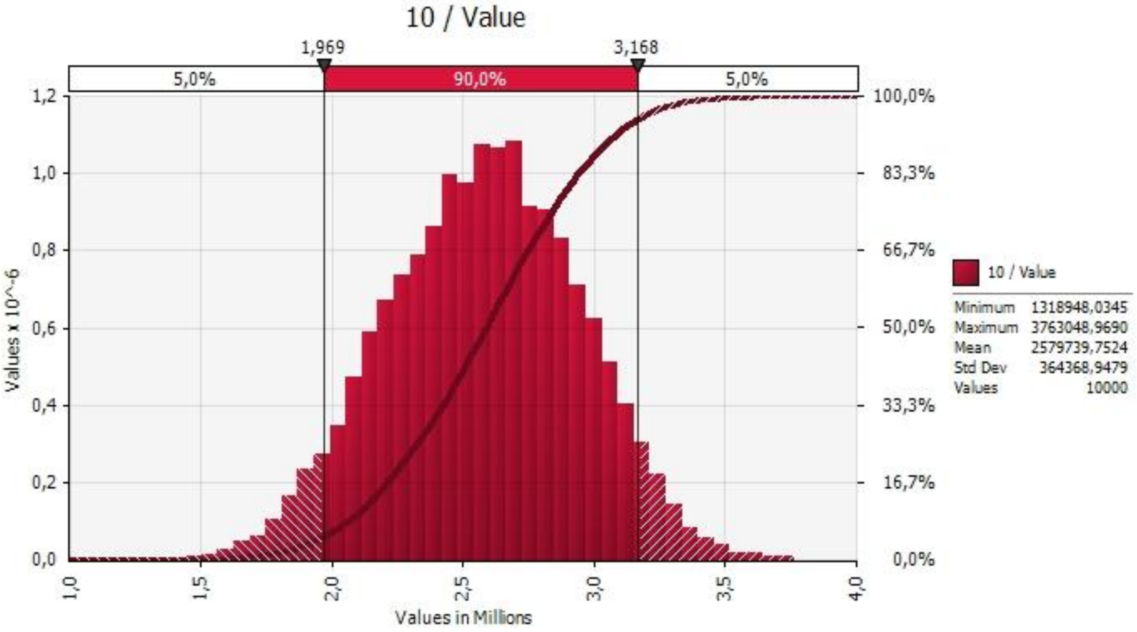


Fig. 5.39 Value Histogram with Cumulative *S*-Curve – *PERT* distribution/Year-10

Mean estimated Value: € 2.579.739,75

Standard deviation: € 364.368,95

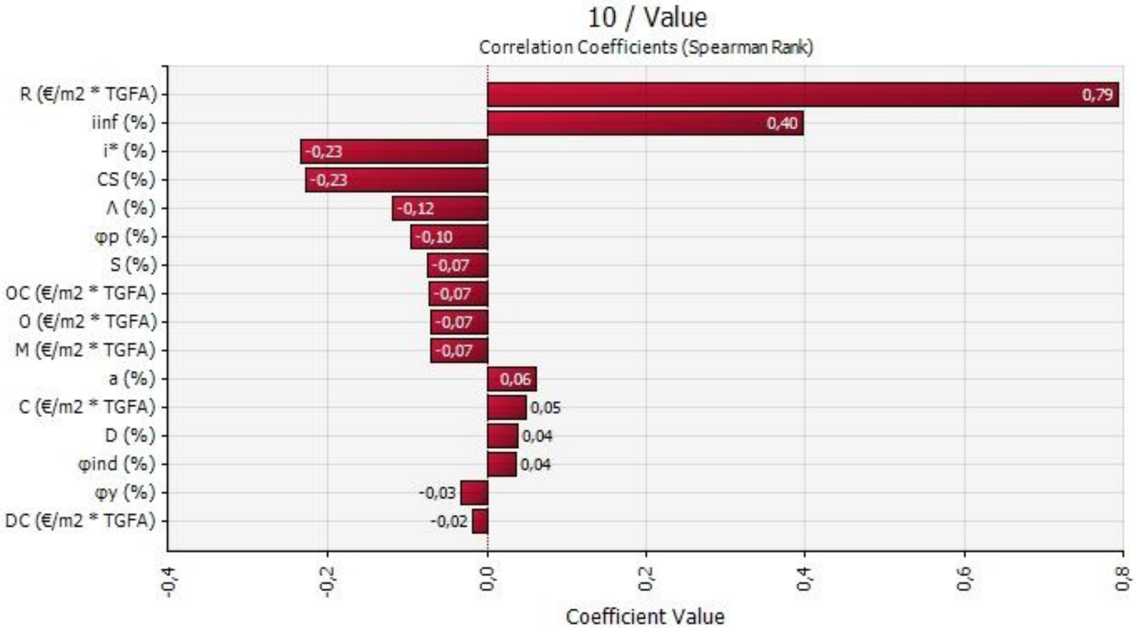


Fig. 5.40 Value Correlation Coefficients – *PERT* distribution/Year-10

Most critical WLC negative input variable (coefficient value): Free-Risk Rate (i_*) (-0,23)

Most critical WLC positive input variable (coefficient value): Rent (R) (0,79)

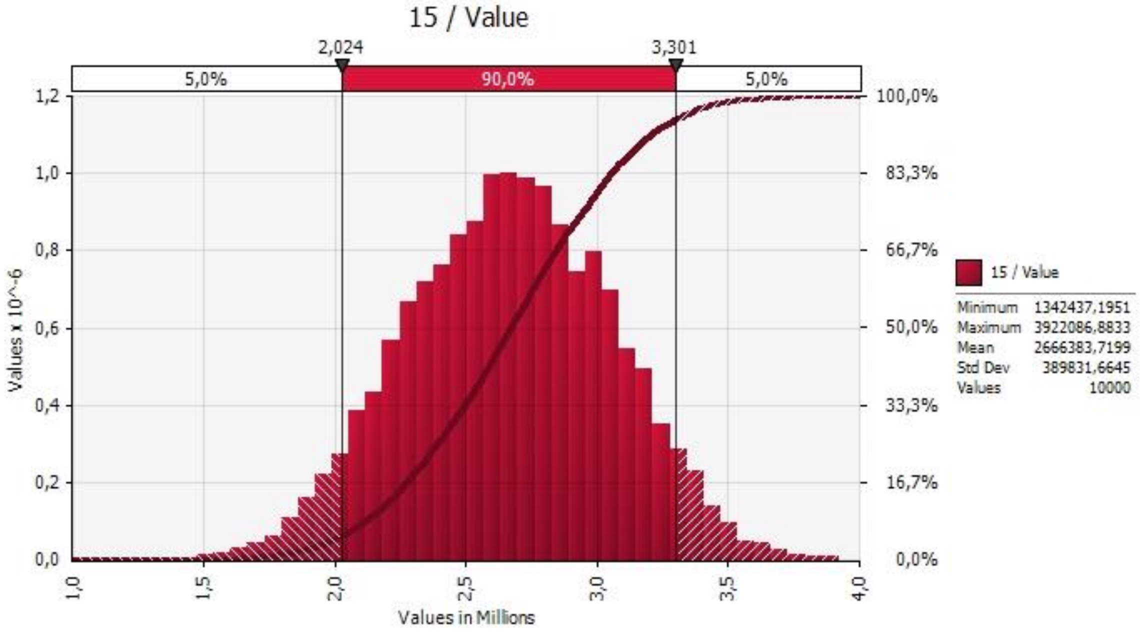


Fig. 5.41 Value Histogram with Cumulative *S*-Curve – *PERT* distribution/Year-15

Mean estimated Value: € 2.666.383,72

Standard deviation: € 389.831,66

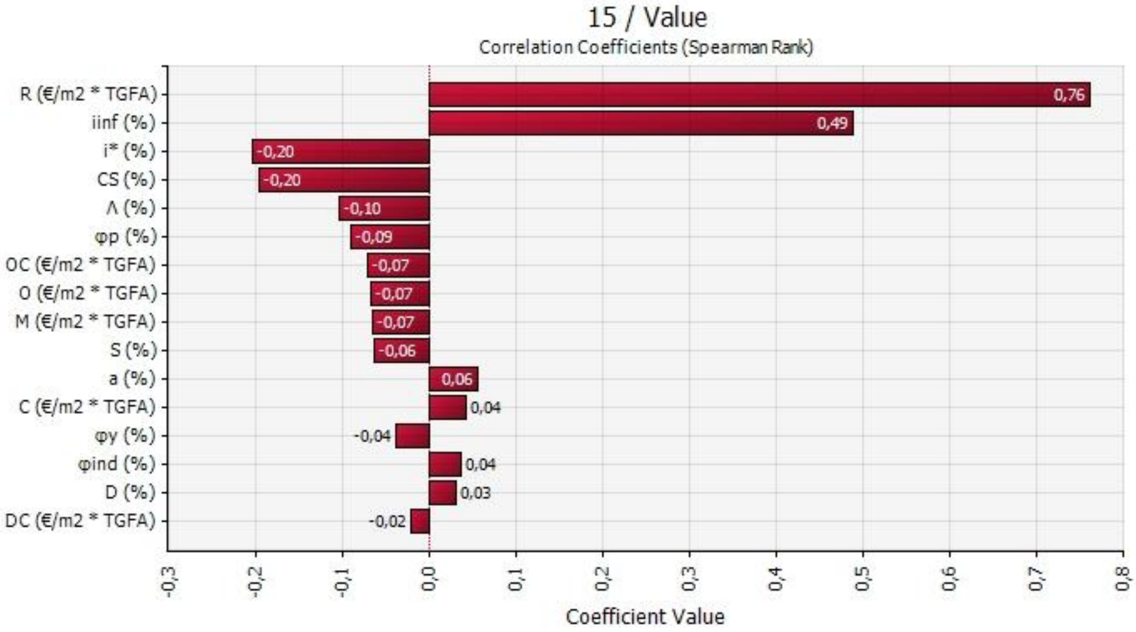


Fig. 5.42 Value Correlation Coefficients – *PERT* distribution/Year-15

Most critical WLC negative input variable (coefficient value): Free-Risk Rate (i_*) (-0,20)

Most critical WLC positive input variable (coefficient value): Rent (R) (0,76)

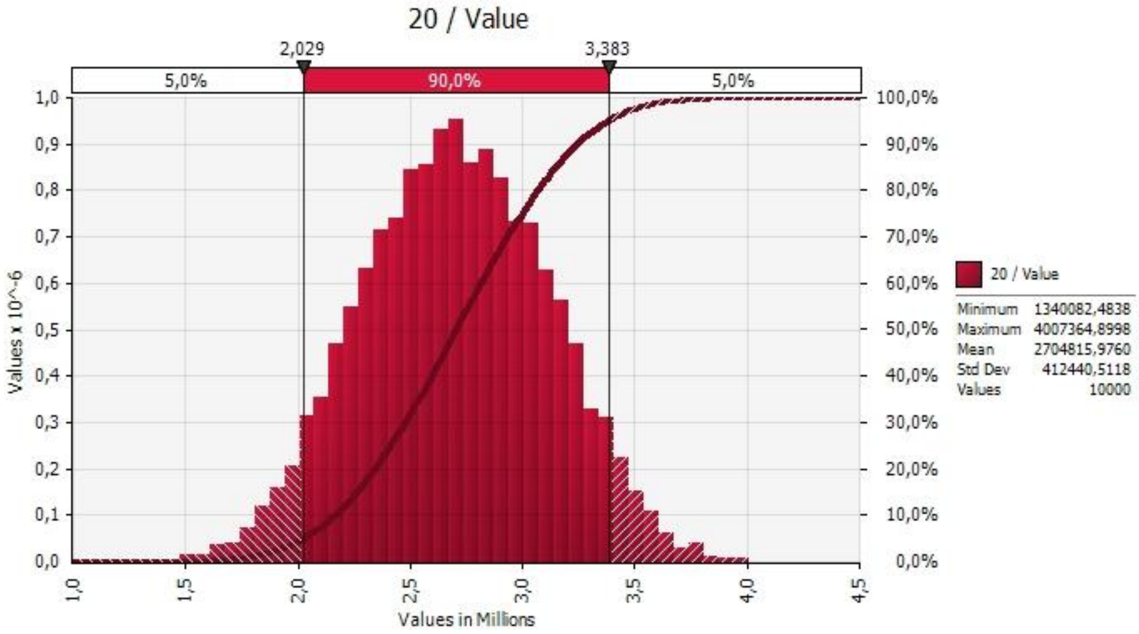


Fig. 5.43 Value Histogram with Cumulative *S*-Curve – *PERT* distribution/Year-20

Mean estimated Value: € 2.704.815,98

Standard deviation: € 412.440,51

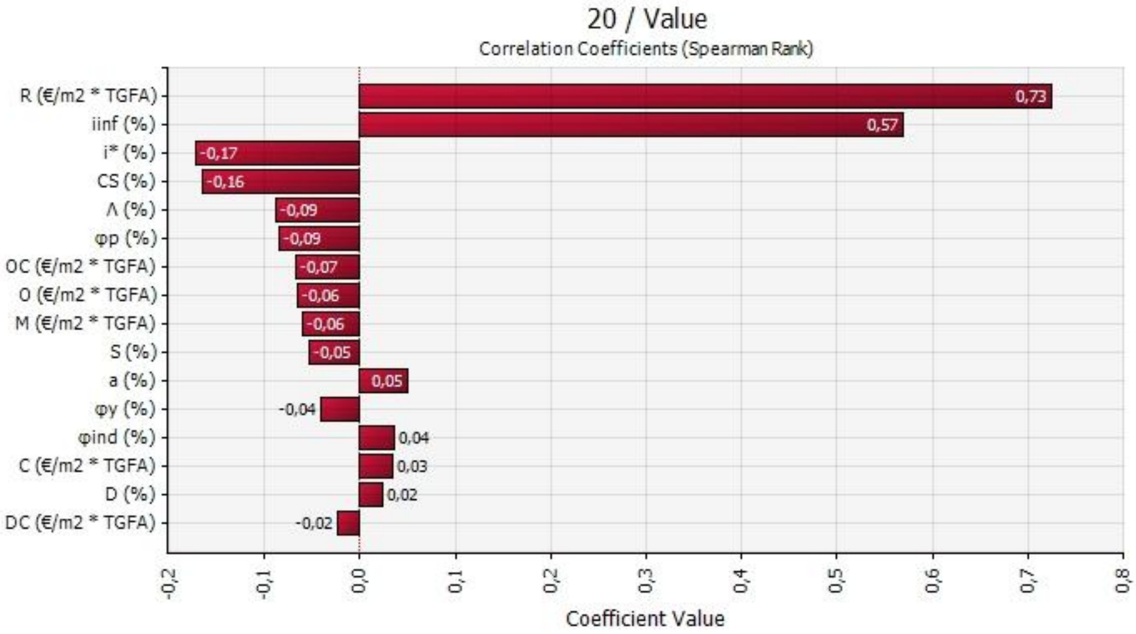


Fig. 5.44 Value Correlation Coefficients – *PERT* distribution/Year-20

Most critical WLC negative input variable (coefficient value): Free-Risk Rate (i_*) (-0,17)

Most critical WLC positive input variable (coefficient value): Rent (R) (0,73)

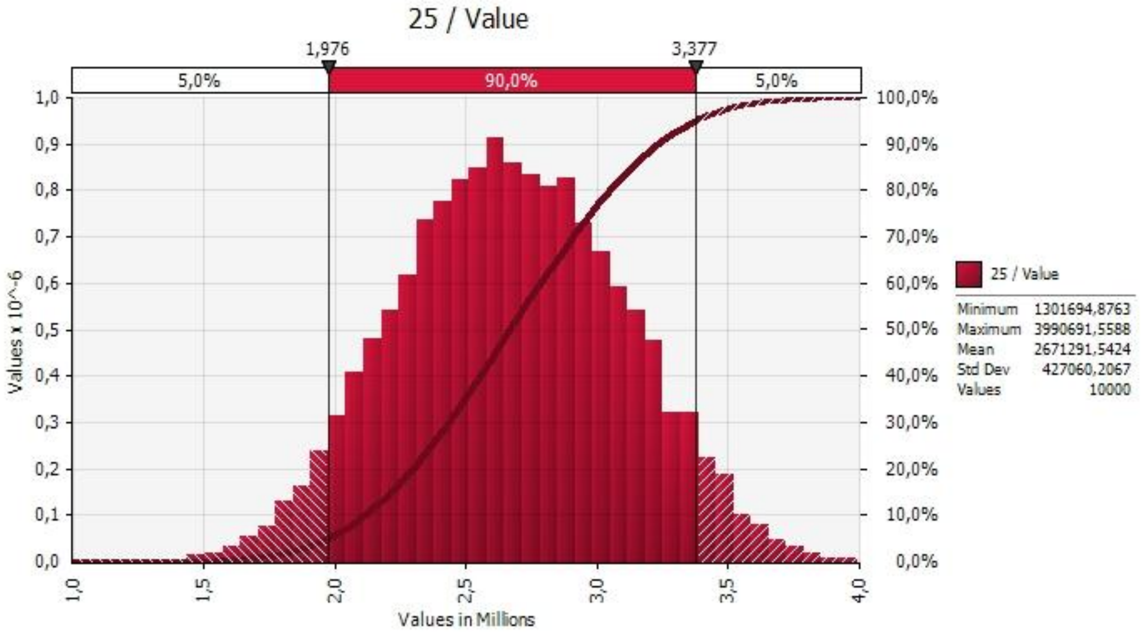


Fig. 5.45 Value Histogram with Cumulative *S*-Curve – *PERT* distribution/Year-25

Mean estimated Value: € 2.671.291,54

Standard deviation: € 427.060,21

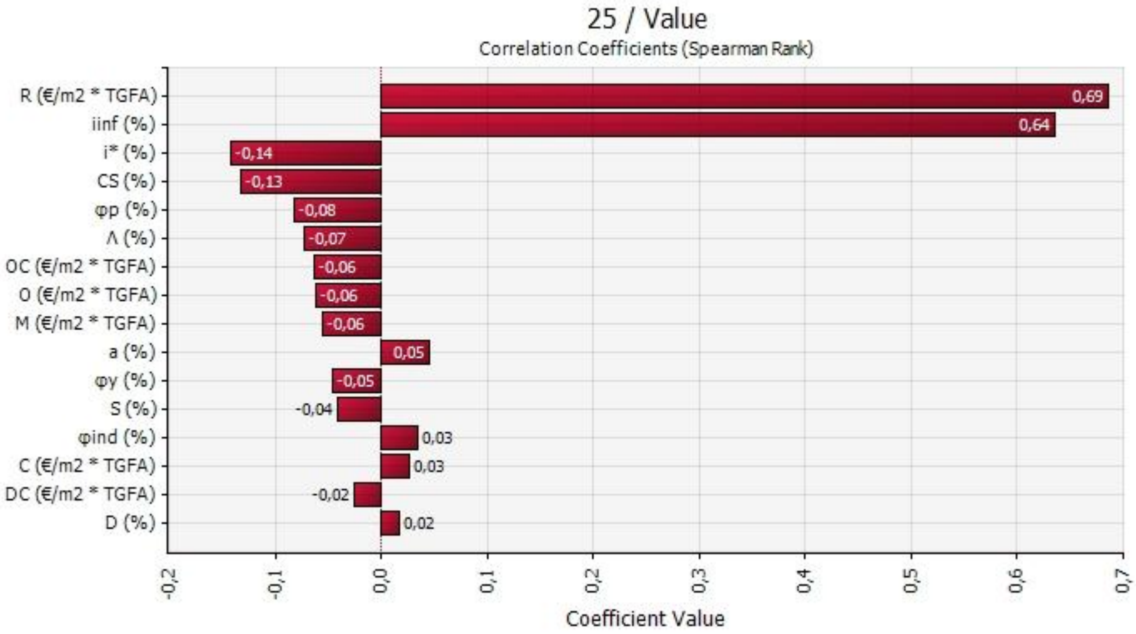


Fig. 5.46 Value Correlation Coefficients – *PERT* distribution/Year-25

Most critical WLC negative input variable (coefficient value): Free-Risk Rate (i_*) (-0,14)

Most critical WLC positive input variable (coefficient value): Rent (R) (0,69)

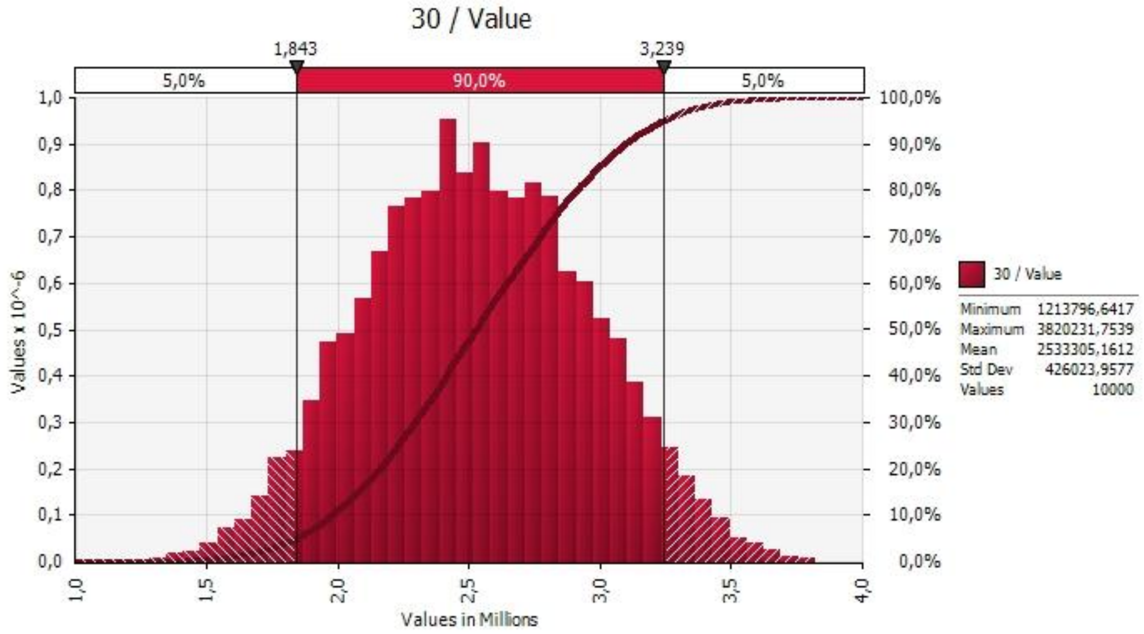


Fig. 5.47 Value Histogram with Cumulative *S*-Curve – *PERT* distribution/Year-30

Mean estimated Value: € 2.533.305,16

Standard deviation: € 426.023,96

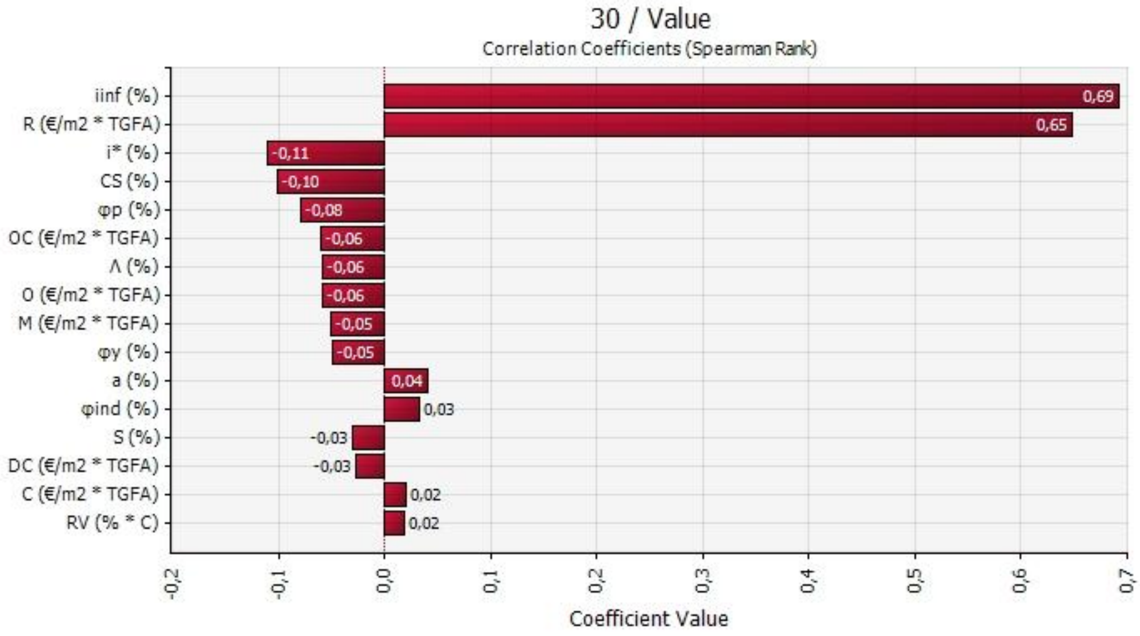


Fig. 5.48 Value Correlation Coefficients – *PERT* distribution/Year-30

Most critical WLC negative input variable (coefficient value): Free-Risk Rate (i_*) (-0,11)

Most critical WLC positive input variable (coefficient value): Inflation Rate (i_{inf}) (0,69)

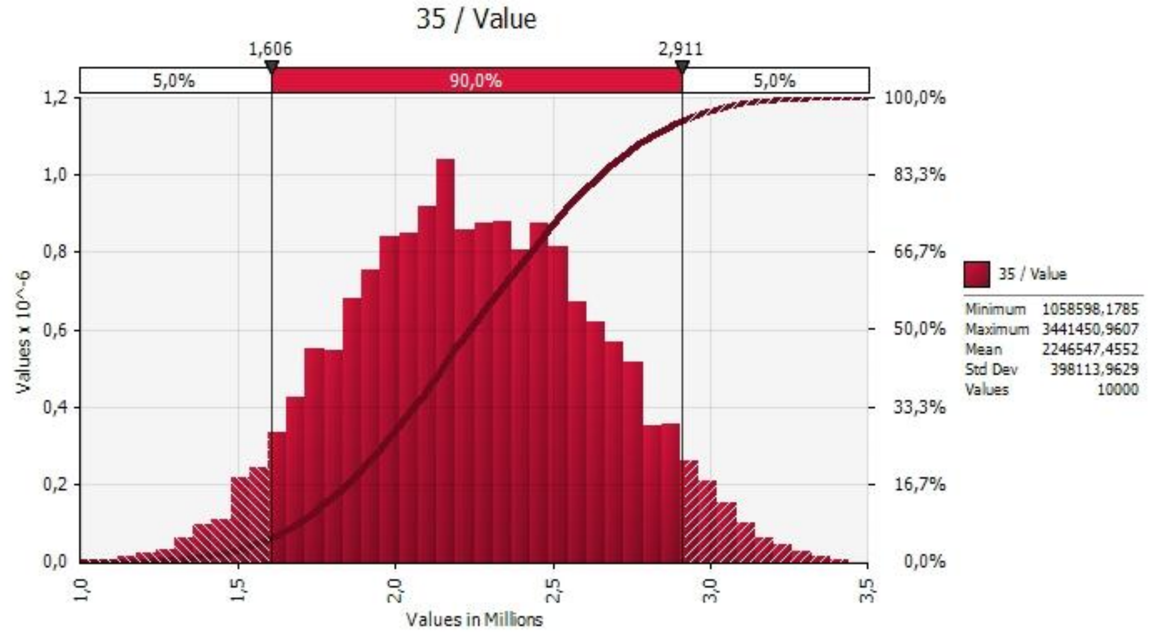


Fig. 5.49 Value Histogram with Cumulative *S*-Curve – *PERT* distribution/Year-35

Mean estimated Value: € 2.246.547,45

Standard deviation: € 398.113,96

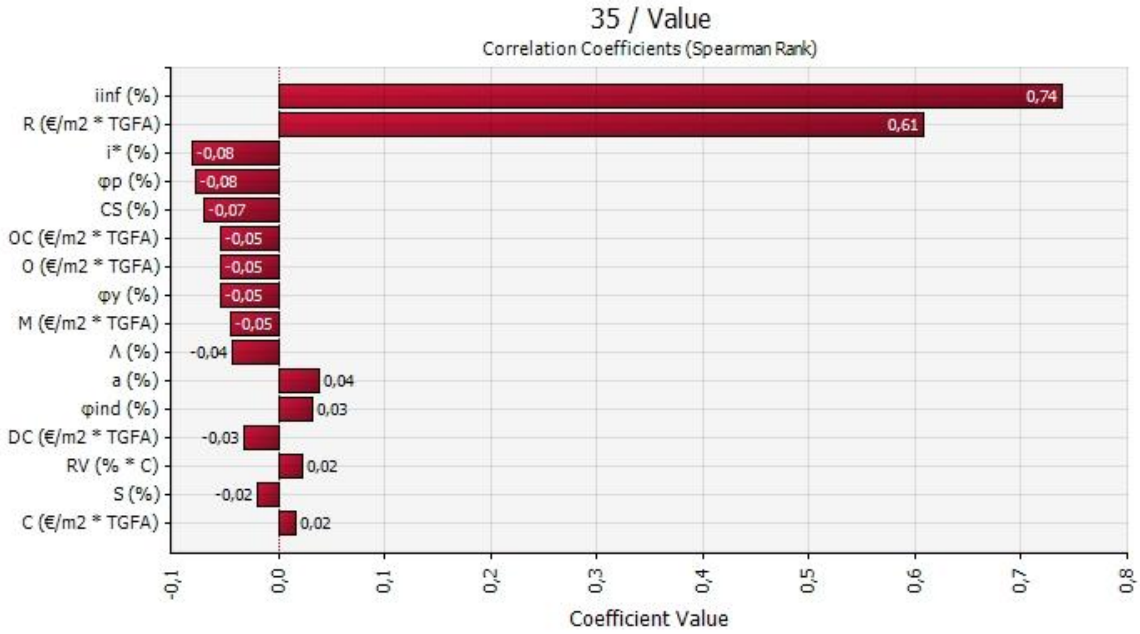


Fig. 5.50 Value Correlation Coefficients – *PERT* distribution/Year-35

Most critical WLC negative input variable (coefficient value): Free-Risk Rate (i_*) (-0,08)

Most critical WLC positive input variable (coefficient value): Inflation Rate (i_{inf}) (0,74)

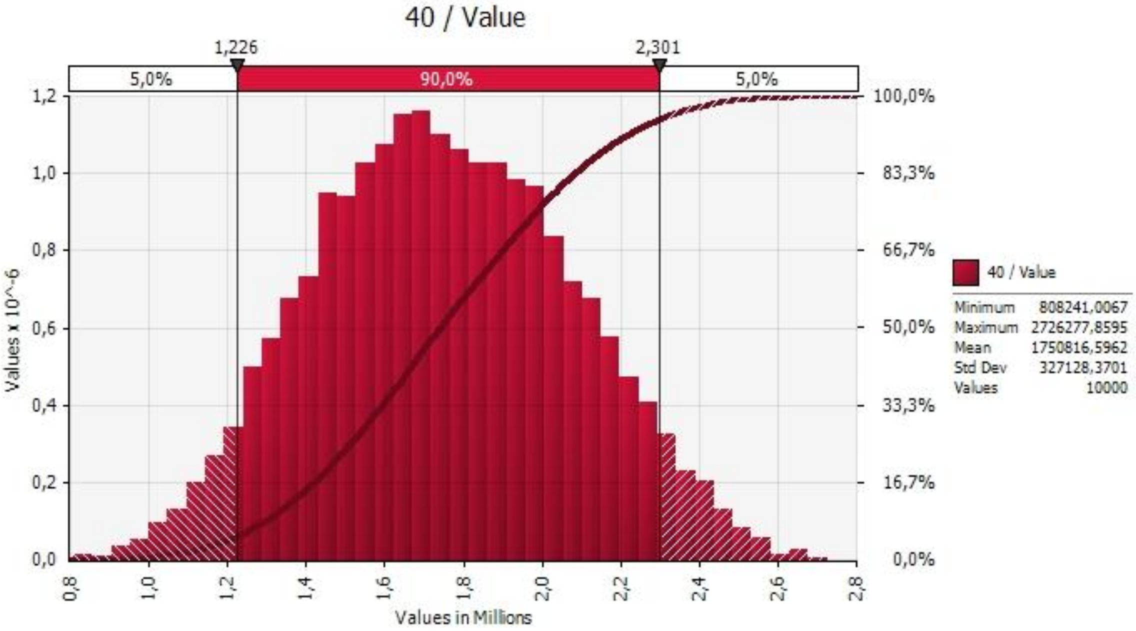


Fig. 5.51 Value Histogram with Cumulative *S*-Curve – *PERT* distribution/Year-40

Mean estimated Value: € 1.750.816,60

Standard deviation: € 327.128,37

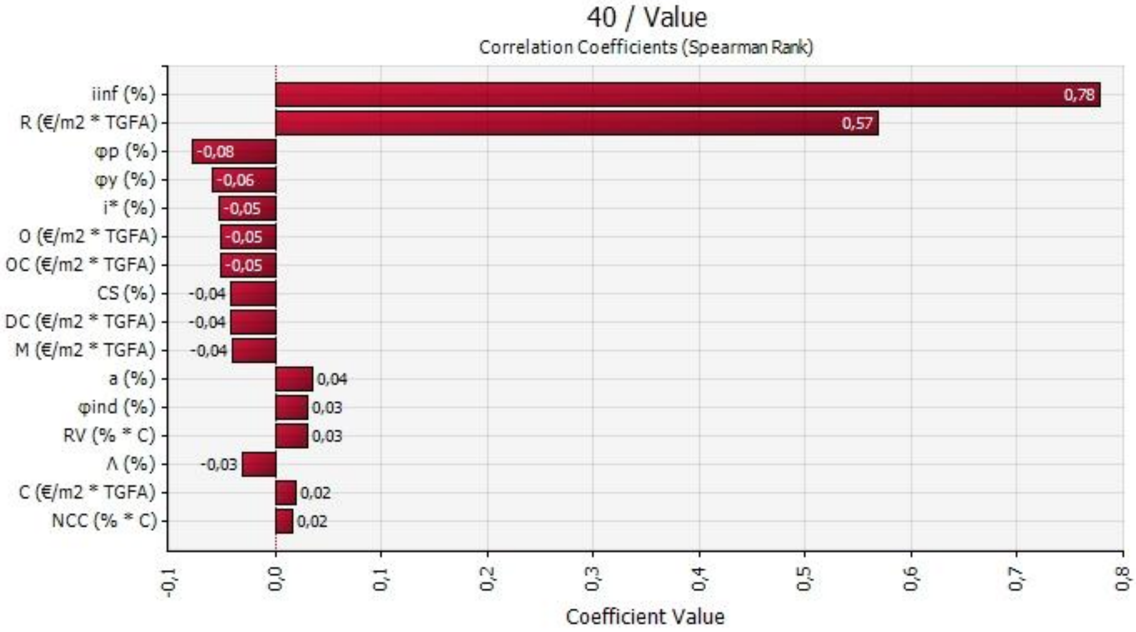


Fig. 5.52 Value Correlation Coefficients – *PERT* distribution/Year-40

Most critical WLC negative input variable (coefficient value): Property Tax (φ^p) (-0,08)

Most critical WLC positive input variable (coefficient value): Inflation Rate (i_{inf}) (0,78)

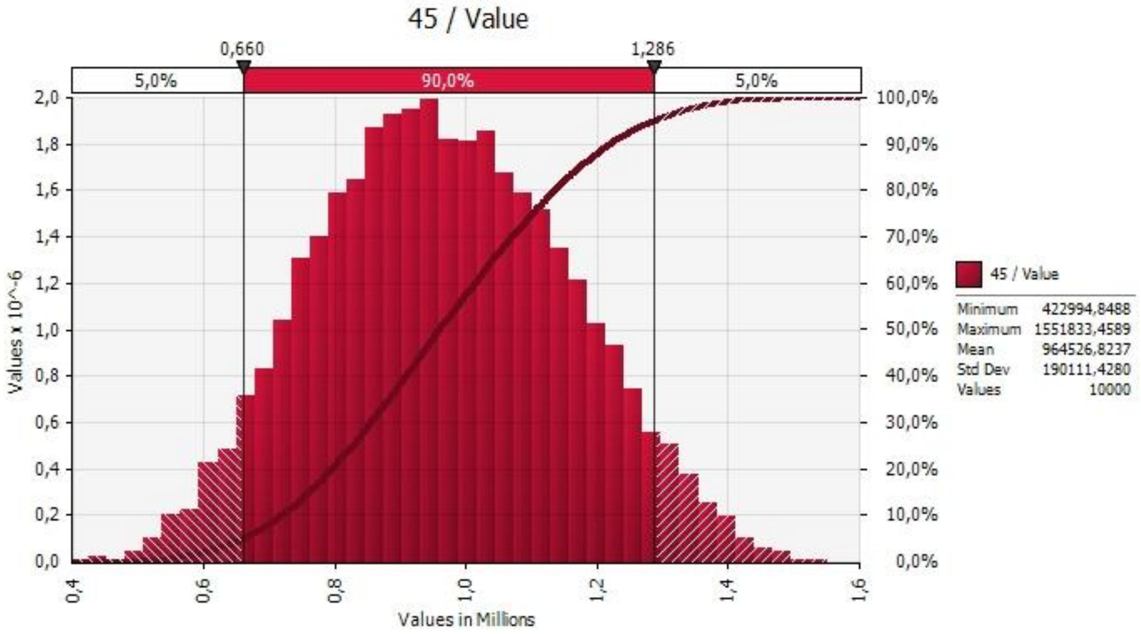


Fig. 5.53 Value Histogram with Cumulative *S*-Curve – *PERT* distribution/Year-45

Mean estimated Value: € 466.301,89

Standard deviation: € 284.238,13

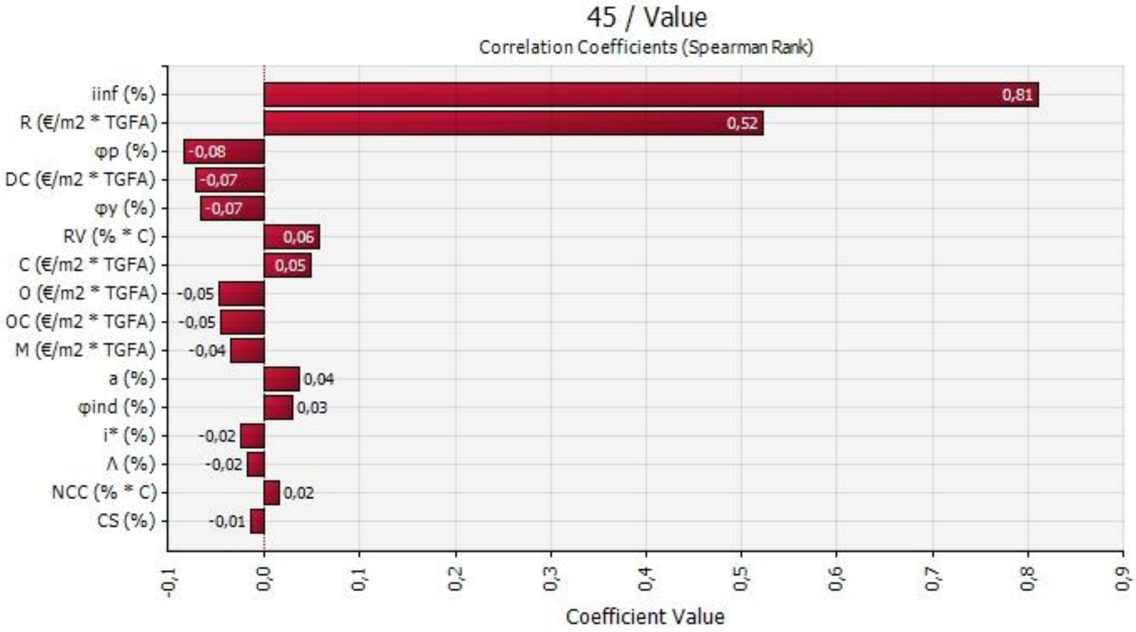


Fig. 5.54 Value Correlation Coefficients – *PERT* distribution/Year-45

Most critical WLC negative input variable (coefficient value): Property Tax (φ^p) (-0,08)

Most critical WLC positive input variable (coefficient value): Inflation Rate (i_{inf}) (0,81)

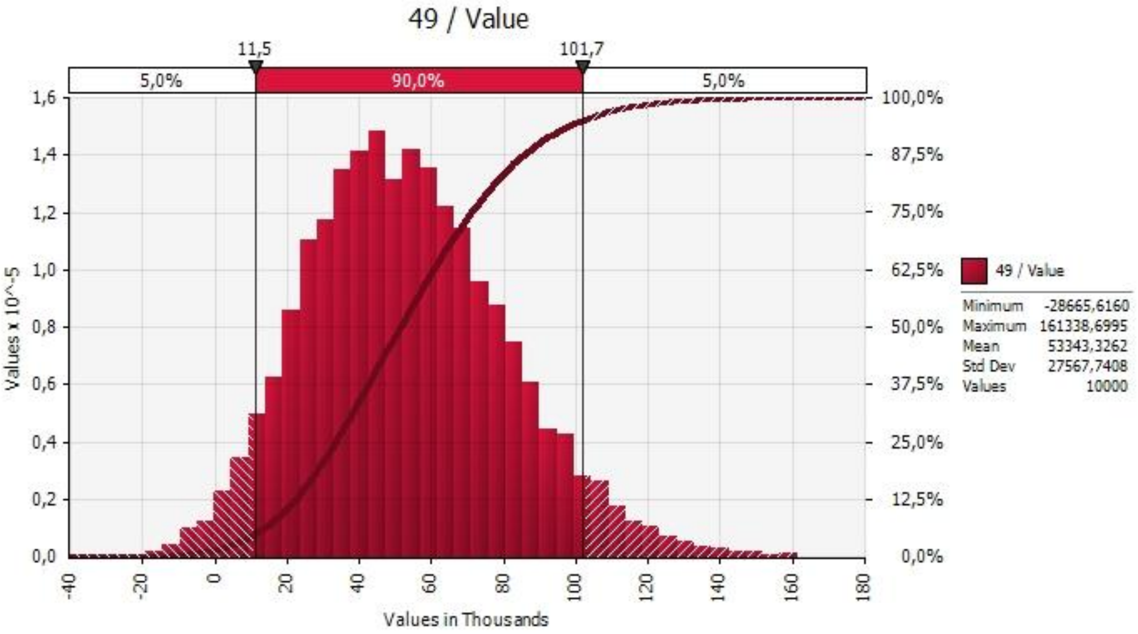


Fig. 5.55 Value Histogram with Cumulative *S*-Curve – *PERT* distribution/Year-49

Mean estimated Value: € 53.343,33

Standard deviation: € 27.567,74

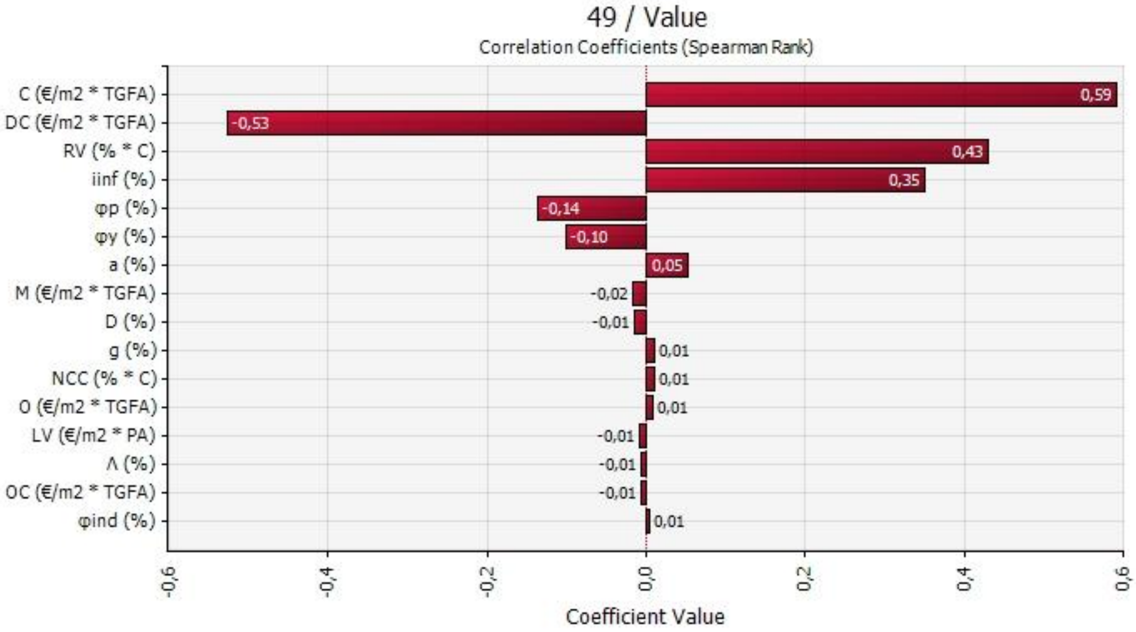


Fig. 5.56 Value Correlation Coefficients – *PERT* distribution/Year-49

Most critical WLC negative input variable (coefficient value): Disposal Cost (DC) (-0,53)

Most critical WLC positive input variable (coefficient value): Construction Cost (C) (0,59)

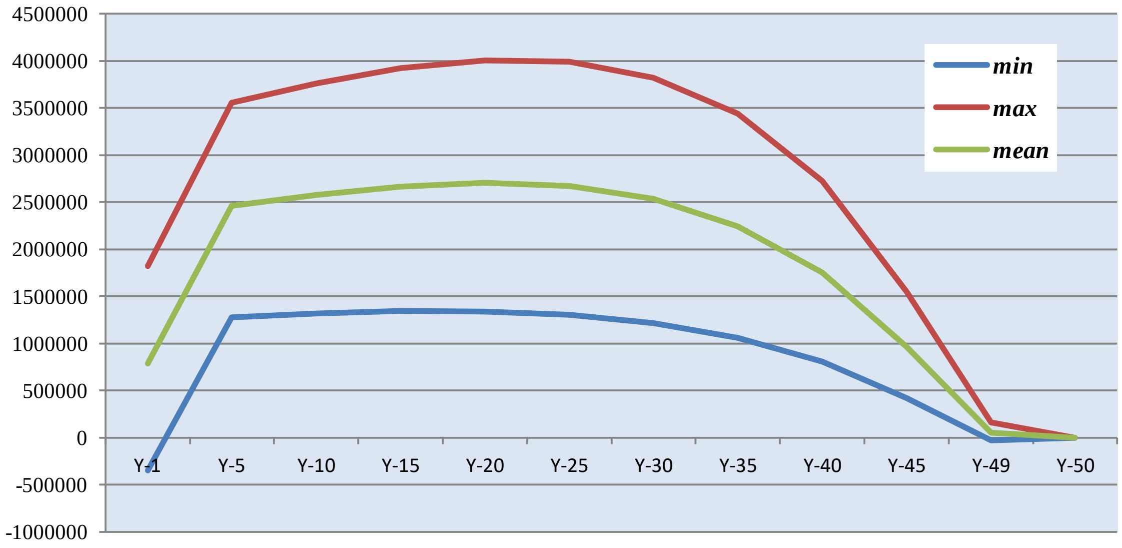


Fig. 5.57 Confidence Interval for Fair Value – *PERT* distribution

5.3.3 Amortised (Depreciated) Cost Accounting

Depreciation is the process of allocating costs to an asset over its entire life. This allocation is done in a way that the cost of the asset (depreciated expense) is charged to the accounting periods during the economic life of the asset and decreases the net value of fixed assets. The application of different depreciation accounting and valuation methods across firms or countries results in financial statements incomparable to each other. The objective of this third part of the case study is the application of the most commonly used depreciation methods (as fully described in Subsection 2.8.8) and the proposed by this thesis whole-life costing (WLC) methodology to the typical commercial built asset (office building project) in order to explore the relationship between these methods when applied to the valuation of fixed assets and to provide answers to the following questions: 'which depreciation method is more appropriate to be used as the accounting method for fixed assets?'; and 'in what way WLC methodology is associated with depreciation methods and generally with accounting methods?'. The basic assumptions and calculations are presented in the following Tables 5.9-5.11 (pages 350-355) (*AP = Acquisition Price).

Table 5.9 WLC Model's Inputs/Outputs for Building Acquisition under *Normal* Economy

INPUT VARIABLES:				
TGFA	m2	1.000		
PA	m2	1.250		
LV	€/m2 **PA**	0	0 €	
AP*	€/m2 **TGFA**	1.500	1.500.000 €	
C	€/m2 **TGFA**	0	0 €	
R	€/m2 **TGFA**	180	180.000 €	12,00%
O	€/m2 **TGFA**	10	10.000 €	0,67%
M	€/m2 **TGFA**	15	15.000 €	1,00%
OC	€/m2 **TGFA**	18	18.000 €	1,20%
RV	% NCC	10%	150.000 €	
DC	€/m2 **TGFA**	0	0 €	
i_{inf}	%	2%		
i_*	%	2%		
φ^p	%	1%		
φ^y	%	33%		
a	%	2%		
g	%	0,1%		
Λ	%	5%		
D	%	60%		
S	%	40%		
CS	%	3%		
φ^{ind}	%	24%		

T	years	50

	COST DISTRIBUTION:			
LV				
AP	100%			
C				
	Year 1	Year 2	Year 3	Year 4

CALCULATED INPUTS:		
δ	%	2,87%
SAV	€	150.000
i_{FR}	%	4%
AC	%	4,90%
i_S	%	7,06%
WACC	%	**5,64%**
i_D	%	7,00%

OUTPUT VARIABLES:		
NPV	€	**745.645**
IRR	%	**7,06%**

🟩	**Input Value**
🟧	**Value calculated by Model**

OTHER CALCULATIONS:	
ln(2) =	0,6931
ln(1+g) =	0,0010
(g/AC+Λ-g) =	0,0102
1+(g/AC+Λ-g) =	1,0102
ln[1+(g/AC+Λ-g)] =	0,0102
{ln(2)*ln(1+g)/ln[1+(g/AC+Λ-g)]} =	0,0682
exp{ln(2)*ln(1+g)/ln[1+(g/AC+Λ-g)]}-1 =	0,0706
$(1-\varphi^y)$ =	67%
D/(D+S) =	0,60
S/(D+S) =	0,40
$i_D*(1-\varphi^y)*[D/(D+S)]+i_S*[S/(D+S)]$ =	0,0564
$A1 = (R_{ot} + RV_T)$	Table 5.10
$A2 = (O_{ot} + M_{ot} + OC_{ot})$	Table 5.10
$A3 = (RV_T - DC_T)$	Table 5.10
$A4 = (C_{ct} + AP)$	Table 5.10
$A5 = (C_{ct} + AP + DC_T)$	Table 5.10
$A6 = (1 + \varphi^{ind})*(1 - \varphi^y)$	Table 5.10
A7 = (A1 - A2)*A6	Table 5.10
$A8 = (sumA4 - A3)*\varphi^y*a$	Table 5.10
$A9 = sumA4*\varphi^p$	Table 5.10
$A10 = A5*(1 + \varphi^{ind})$	Table 5.10
$NCF_t = A7 + A8 - A9 - A10$	Table 5.10
$DCF_t = NCF_t / (1 + WACC)^t$	Table 5.10

$$i_S = \exp\left(\frac{\ln 2 * \ln(1+g)}{\ln\left(1 + \frac{g}{AC_t + \Lambda_t - g}\right)}\right) - 1$$

$$WACC = i_D.\left(1 - \varphi_t^y\right).\left(\frac{D}{D+S}\right) + i_S.\left(\frac{S}{D+S}\right)$$

$$AC_t = \left[\left(i_{FR} - \varphi_t^p\right)\left(1 - \varphi_t^y + a.\varphi_t^y\right) + \delta_t\right]$$

$$NPV = \sum_{t=1}^{T} \frac{NCF_t}{(1+WACC)^t}$$

$$\mathbf{Value_t = \sum_{t=1}^{T} NCF_{t+1} / (1 + WACC)^{t+1}}$$

$$\mathbf{Cost_t = \sum_{t=1}^{T} NCF_{T-t}\ (1 + WACC)^t}$$

$$\mathbf{Profit_t = Value_t - Cost_t}$$

Table 5.10 WLC Model's Calculations for Building Acquisition under *Normal* Economy

t	pct	ct	ot	T	AP	C_{ct}	R_{ot}	RV_T	O_{ot}	M_{ot}	OC_{ot}	DC_T
1	0	0	0	0	1500000		180000		10000	15000	18000	
2	0	0	1	0			183600		10200	15300	18360	
3	0	0	2	0			187272		10404	15606	18727	
4	0	0	3	0			191017		10612	15918	19102	
5	0	0	4	0			194838		10824	16236	19484	
6	0	0	5	0			198735		11041	16561	19873	
7	0	0	6	0			202709		11262	16892	20271	
8	0	0	7	0			206763		11487	17230	20676	
9	0	0	8	0			210899		11717	17575	21090	
10	0	0	9	0			215117		11951	17926	21512	
11	0	0	10	0			219419		12190	18285	21942	
12	0	0	11	0			223807		12434	18651	22381	
13	0	0	12	0			228284		12682	19024	22828	
14	0	0	13	0			232849		12936	19404	23285	
15	0	0	14	0			237506		13195	19792	23751	
16	0	0	15	0			242256		13459	20188	24226	
17	0	0	16	0			247101		13728	20592	24710	
18	0	0	17	0			252043		14002	21004	25204	
19	0	0	18	0			257084		14282	21424	25708	
20	0	0	19	0			262226		14568	21852	26223	
21	0	0	20	0			267471		14859	22289	26747	
22	0	0	21	0			272820		15157	22735	27282	
23	0	0	22	0			278276		15460	23190	27828	
24	0	0	23	0			283842		15769	23653	28384	
25	0	0	24	0			289519		16084	24127	28952	
26	0	0	25	0			295309		16406	24609	29531	
27	0	0	26	0			301215		16734	25101	30122	
28	0	0	27	0			307240		17069	25603	30724	
29	0	0	28	0			313384		17410	26115	31338	
30	0	0	29	0			319652		17758	26638	31965	
31	0	0	30	0			326045		18114	27170	32605	
32	0	0	31	0			332566		18476	27714	33257	
33	0	0	32	0			339217		18845	28268	33922	
34	0	0	33	0			346002		19222	28833	34600	
35	0	0	34	0			352922		19607	29410	35292	
36	0	0	35	0			359980		19999	29998	35998	
37	0	0	36	0			367180		20399	30598	36718	
38	0	0	37	0			374523		20807	31210	37452	
39	0	0	38	0			382014		21223	31834	38201	
40	0	0	39	0			389654		21647	32471	38965	
41	0	0	40	0			397447		22080	33121	39745	
42	0	0	41	0			405396		22522	33783	40540	
43	0	0	42	0			413504		22972	34459	41350	
44	0	0	43	0			421774		23432	35148	42177	
45	0	0	44	0			430210		23901	35851	43021	
46	0	0	45	0			438814		24379	36568	43881	
47	0	0	46	0			447590		24866	37299	44759	
48	0	0	47	0			456542		25363	38045	45654	
49	0	0	48	0			465673		25871	38806	46567	
50	0	0	49	50			474986	395822	26388	39582	47499	
					1500000		15224292	395822	845794	1268691	1522429	

Table 5.10 WLC Model's Calculations for Building Acquisition under *Normal* Economy – *cont'd.*

A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
180000	43000	0	1500000	1500000	0,8308	113820	445500	15000	1860000
183600	43860	0	0	0	0,8308	116096	445500	15000	0
187272	44737	0	0	0	0,8308	118418	445500	15000	0
191017	45632	0	0	0	0,8308	120786	445500	15000	0
194838	46545	0	0	0	0,8308	123202	445500	15000	0
198735	47475	0	0	0	0,8308	125666	445500	15000	0
202709	48425	0	0	0	0,8308	128179	445500	15000	0
206763	49393	0	0	0	0,8308	130743	445500	15000	0
210899	50381	0	0	0	0,8308	133358	445500	15000	0
215117	51389	0	0	0	0,8308	136025	445500	15000	0
219419	52417	0	0	0	0,8308	138745	445500	15000	0
223807	53465	0	0	0	0,8308	141520	445500	15000	0
228284	54534	0	0	0	0,8308	144351	445500	15000	0
232849	55625	0	0	0	0,8308	147238	445500	15000	0
237506	56738	0	0	0	0,8308	150183	445500	15000	0
242256	57872	0	0	0	0,8308	153186	445500	15000	0
247101	59030	0	0	0	0,8308	156250	445500	15000	0
252043	60210	0	0	0	0,8308	159375	445500	15000	0
257084	61415	0	0	0	0,8308	162562	445500	15000	0
262226	62643	0	0	0	0,8308	165814	445500	15000	0
267471	63896	0	0	0	0,8308	169130	445500	15000	0
272820	65174	0	0	0	0,8308	172513	445500	15000	0
278276	66477	0	0	0	0,8308	175963	445500	15000	0
283842	67807	0	0	0	0,8308	179482	445500	15000	0
289519	69163	0	0	0	0,8308	183072	445500	15000	0
295309	70546	0	0	0	0,8308	186733	445500	15000	0
301215	71957	0	0	0	0,8308	190468	445500	15000	0
307240	73396	0	0	0	0,8308	194277	445500	15000	0
313384	74864	0	0	0	0,8308	198163	445500	15000	0
319652	76361	0	0	0	0,8308	202126	445500	15000	0
326045	77889	0	0	0	0,8308	206168	445500	15000	0
332566	79446	0	0	0	0,8308	210292	445500	15000	0
339217	81035	0	0	0	0,8308	214498	445500	15000	0
346002	82656	0	0	0	0,8308	218788	445500	15000	0
352922	84309	0	0	0	0,8308	223163	445500	15000	0
359980	85995	0	0	0	0,8308	227627	445500	15000	0
367180	87715	0	0	0	0,8308	232179	445500	15000	0
374523	89469	0	0	0	0,8308	236823	445500	15000	0
382014	91259	0	0	0	0,8308	241559	445500	15000	0
389654	93084	0	0	0	0,8308	246390	445500	15000	0
397447	94946	0	0	0	0,8308	251318	445500	15000	0
405396	96845	0	0	0	0,8308	256345	445500	15000	0
413504	98782	0	0	0	0,8308	261471	445500	15000	0
421774	100757	0	0	0	0,8308	266701	445500	15000	0
430210	102772	0	0	0	0,8308	272035	445500	15000	0
438814	104828	0	0	0	0,8308	277476	445500	15000	0
447590	106924	0	0	0	0,8308	283025	445500	15000	0
456542	109063	0	0	0	0,8308	288686	445500	15000	0
465673	111244	0	0	0	0,8308	294459	445500	15000	0
870808	113469	395822	0	0	0,8308	629197	445500	15000	0
			1500000	1500000					

Table 5.10 WLC Model's Calculations for Building Acquisition under *Normal* Economy – *cont'd.*

NCF	cumNCF	DCF	NPV	Cost	Value	Profit
-1752270	-1752270	-1658752	-1658752	1752270	2539954	787683
110006	-1642264	98577	-1560175	1741055	2573147	832092
112328	-1529936	95286	-1464889	1726885	2605889	879004
114696	-1415240	92102	-1372787	1709548	2638109	928561
117112	-1298128	89023	-1283763	1688818	2669730	980912
119576	-1178552	86045	-1197718	1664455	2700669	1036214
122089	-1056463	83165	-1114553	1636205	2730840	1094634
124653	-931810	80380	-1034173	1603799	2760147	1156348
127268	-804542	77686	-956488	1566951	2788493	1221542
129935	-674607	75081	-881406	1525358	2815769	1290410
132655	-541952	72562	-808844	1478700	2841862	1363162
135430	-406521	70126	-738718	1426637	2866652	1440015
138261	-268261	67771	-670947	1368808	2890009	1521201
141148	-127113	65494	-605453	1304832	2911795	1606964
144093	16980	63292	-542161	1234304	2931866	1697562
147096	164076	61163	-480998	1156796	2950064	1793268
150160	314236	59105	-421894	1071854	2966224	1894370
153285	467521	57115	-364779	978999	2980171	2001172
156472	623993	55191	-309588	877721	2991716	2113995
159724	783717	53331	-256258	767482	3000661	2233179
163040	946757	51533	-204725	647711	3006794	2359082
166423	1113179	49795	-154930	517806	3009890	2492084
169873	1283052	48114	-106816	377126	3009710	2632584
173392	1456444	46490	-60326	224996	3006001	2781005
176982	1633426	44920	-15406	60699	2998493	2937794
180643	1814069	43402	27996	0	2986901	2986901
184378	1998447	41935	69932	0	2970920	2970920
188187	2186634	40517	110449	0	2950229	2950229
192073	2378707	39147	149596	0	2924486	2924486
196036	2574743	37822	187418	0	2893328	2893328
200078	2774821	36542	223960	0	2856371	2856371
204202	2979023	35305	259265	0	2813208	2813208
208408	3187430	34109	293374	0	2763405	2763405
212698	3400128	32953	326327	0	2706504	2706504
217073	3617201	31836	358163	0	2642019	2642019
221537	3838738	30757	388920	0	2569436	2569436
226089	4064827	29714	418634	0	2488207	2488207
230733	4295560	28706	447339	0	2397756	2397756
235469	4531029	27731	475071	0	2297469	2297469
240300	4771330	26790	501861	0	2186696	2186696
245228	5016558	25880	527741	0	2064751	2064751
250255	5266812	25001	552742	0	1930904	1930904
255381	5522194	24152	576894	0	1784384	1784384
260611	5782805	23331	600225	0	1624374	1624374
265945	6048750	22538	622763	0	1450009	1450009
271386	6320135	21771	644534	0	1260373	1260373
276935	6597070	21031	665565	0	1054496	1054496
282596	6879666	20315	685880	0	831351	831351
288369	7168035	19624	705504	0	589852	589852
623107	7791142	40141	**745645**	0	0	0
		745645				

Table 5.11 Depreciation Calculations for Commercial Fixed Asset

YTR	YTUC	AP	YNCF (before φ^{y})	Deferred Tax Income	YNCF	NPV	Property Tax	NCF
(1)=A1	(2)=A2	(3)	(4)=(1)-(2)-(3)	(5)=-(4)*φ^{y}	(6)=(4)+(5)	(7)	(8)=(7)*φ^{p}	(9)=(6)-(8)
180000	43000	1500000	-1363000	449790	-913210	2129534	21295	-934505
183600	43860	0	139740	-46114	93626	2155969	21560	72066
187272	44737	0	142535	-47036	95498	2182021	21820	73678
191017	45632	0	145385	-47977	97408	2207632	22076	75332
194838	46545	0	148293	-48937	99356	2232738	22327	77029
198735	47475	0	151259	-49915	101344	2257273	22573	78771
202709	48425	0	154284	-50914	103370	2281164	22812	80559
206763	49393	0	157370	-51932	105438	2304335	23043	82395
210899	50381	0	160517	-52971	107547	2326704	23267	84280
215117	51389	0	163728	-54030	109698	2348182	23482	86216
219419	52417	0	167002	-55111	111891	2368678	23687	88205
223807	53465	0	170342	-56213	114129	2388091	23881	90248
228284	54534	0	173749	-57337	116412	2406316	24063	92349
232849	55625	0	177224	-58484	118740	2423241	24232	94508
237506	56738	0	180769	-59654	121115	2438744	24387	96728
242256	57872	0	184384	-60847	123537	2452700	24527	99010
247101	59030	0	188072	-62064	126008	2464972	24650	101358
252043	60210	0	191833	-63305	128528	2475415	24754	103774
257084	61415	0	195670	-64571	131099	2483877	24839	106260
262226	62643	0	199583	-65862	133721	2490193	24902	108819
267471	63896	0	203575	-67180	136395	2494192	24942	111453
272820	65174	0	207646	-68523	139123	2495687	24957	114166
278276	66477	0	211799	-69894	141905	2494485	24945	116961
283842	67807	0	216035	-71292	144744	2490377	24904	119840
289519	69163	0	220356	-72717	147638	2483142	24831	122807
295309	70546	0	224763	-74172	150591	2472547	24725	125866
301215	71957	0	229258	-75655	153603	2458343	24583	129020
307240	73396	0	233843	-77168	156675	2440265	24403	132272
313384	74864	0	238520	-78712	159809	2418035	24180	135628
319652	76361	0	243291	-80286	163005	2391356	23914	139091
326045	77889	0	248157	-81892	166265	2359912	23599	142666
332566	79446	0	253120	-83529	169590	2323370	23234	146356
339217	81035	0	258182	-85200	172982	2281376	22814	150168
346002	82656	0	263346	-86904	176442	2233555	22336	154106
352922	84309	0	268613	-88642	179970	2179509	21795	158175
359980	85995	0	273985	-90415	183570	2118817	21188	162382
367180	87715	0	279465	-92223	187241	2051032	20510	166731
374523	89469	0	285054	-94068	190986	1975680	19757	171229
382014	91259	0	290755	-95949	194806	1892260	18923	175883
389654	93084	0	296570	-97868	198702	1800241	18002	180700
397447	94946	0	302501	-99825	202676	1699060	16991	185685
405396	96845	0	308551	-101822	206729	1588121	15881	190848
413504	98782	0	314722	-103858	210864	1466793	14668	196196
421774	100757	0	321017	-105936	215081	1334407	13344	201737
430210	102772	0	327437	-108054	219383	1190256	11903	207480
438814	104828	0	333986	-110215	223771	1033590	10336	213435
447590	106924	0	340666	-112420	228246	863616	8636	219610
456542	109063	0	347479	-114668	232811	679495	6795	226016
465673	111244	0	354429	-116961	237467	480336	4803	232664
870808	113469	0	757339	-249922	507417	0	0	507417

Table 5.11 Depreciation Calculations for Commercial Fixed Asset – *cont'd.*

FV	DEP (SLM)	CAV (SLM)	DEP (WDV)	CAV (WDV)	DEP (SYD)	CAV (SYD)	DEP (SFM)	CAV (SFM)
(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
1755304	-27000	1473000	-67511	1432489	-52941	1447059	-5241	1494759
1782200	-27000	1446000	-64473	1368016	-51882	1395176	-5536	1489223
1809000	-27000	1419000	-61571	1306445	-50824	1344353	-5848	1483375
1835656	-27000	1392000	-58800	1247646	-49765	1294588	-6178	1477197
1862119	-27000	1365000	-56153	1191492	-48706	1245882	-6526	1470671
1888332	-27000	1338000	-53626	1137866	-47647	1198235	-6894	1463776
1914234	-27000	1311000	-51212	1086654	-46588	1151647	-7283	1456493
1939761	-27000	1284000	-48907	1037746	-45529	1106118	-7694	1448800
1964843	-27000	1257000	-46706	991040	-44471	1061647	-8127	1440673
1989402	-27000	1230000	-44604	946436	-43412	1018235	-8585	1432087
2013357	-27000	1203000	-42597	903839	-42353	975882	-9070	1423018
2036618	-27000	1176000	-40679	863160	-41294	934588	-9581	1413437
2059091	-27000	1149000	-38849	824311	-40235	894353	-10121	1403316
2080672	-27000	1122000	-37100	787211	-39176	855176	-10692	1392624
2101250	-27000	1095000	-35430	751781	-38118	817059	-11294	1381330
2120705	-27000	1068000	-33836	717945	-37059	780000	-11931	1369399
2138909	-27000	1041000	-32313	685632	-36000	744000	-12604	1356795
2155723	-27000	1014000	-30859	654774	-34941	709059	-13314	1343481
2171000	-27000	987000	-29470	625304	-33882	675176	-14065	1329416
2184579	-27000	960000	-28143	597161	-32824	642353	-14858	1314558
2196289	-27000	933000	-26877	570284	-31765	610588	-15696	1298862
2205947	-27000	906000	-25667	544617	-30706	579882	-16581	1282281
2213354	-27000	879000	-24512	520105	-29647	550235	-17515	1264766
2218300	-27000	852000	-23409	496697	-28588	521647	-18503	1246263
2220557	-27000	825000	-22355	474342	-27529	494118	-19546	1226717
2219883	-27000	798000	-21349	452993	-26471	467647	-20648	1206069
2216017	-27000	771000	-20388	432605	-25412	442235	-21812	1184257
2208681	-27000	744000	-19470	413134	-24353	417882	-23042	1161215
2197575	-27000	717000	-18594	394540	-23294	394588	-24341	1136874
2182380	-27000	690000	-17757	376783	-22235	372353	-25713	1111161
2162753	-27000	663000	-16958	359825	-21176	351176	-27163	1083998
2138330	-27000	636000	-16195	343630	-20118	331059	-28694	1055304
2108717	-27000	609000	-15466	328164	-19059	312000	-30312	1024992
2073498	-27000	582000	-14770	313394	-18000	294000	-32021	992971
2032223	-27000	555000	-14105	299289	-16941	277059	-33826	959145
1984415	-27000	528000	-13470	285819	-15882	261176	-35733	923412
1929562	-27000	501000	-12864	272955	-14824	246353	-37748	885664
1867119	-27000	474000	-12285	260670	-13765	232588	-39876	845788
1796501	-27000	447000	-11732	248938	-12706	219882	-42124	803663
1717086	-27000	420000	-11204	237734	-11647	208235	-44499	759164
1628207	-27000	393000	-10700	227034	-10588	197647	-47008	712156
1529155	-27000	366000	-10218	216816	-9529	188118	-49658	662498
1419170	-27000	339000	-9758	207058	-8471	179647	-52458	610040
1297444	-27000	312000	-9319	197739	-7412	172235	-55415	554625
1163111	-27000	285000	-8900	188839	-6353	165882	-58540	496086
1015251	-27000	258000	-8499	180340	-5294	160588	-61840	434246
852880	-27000	231000	-8117	172223	-4235	156353	-65326	368919
674948	-27000	204000	-7751	164472	-3176	153176	-69009	299910
480336	-27000	177000	-7402	157069	-2118	151059	-72900	227010
0	**-27000**	**150000**	**-7069**	**150000**	**-1059**	**150000**	**-77010**	**150000**

Table 5.12 summarises the numerical results of the analysis per five years, i.e. the fair value of the fixed asset based on the whole-life calculations and the current (amortised) accounting value per depreciation method employed (Subsection 2.8.8, Chapter 2).

Table 5.12 Results for Fair Value and Current Accounting (Depreciated) Values (T = 50 years)

t	Fair Value	Current Accounting Value of Commercial Fixed Asset per Depreciation Method			
		SLM	WDV	SYD	SFM
1	1755304	1473000	1432489	1447059	1494759
5	1862119	1365000	1191492	1245882	1470671
10	1989402	1230000	946436	1018235	1432087
15	2101250	1095000	751781	817059	1381330
20	2184579	960000	597161	642353	1314558
25	2220557	825000	474342	494118	1226717
30	2182380	690000	376783	372353	1111161
35	2032223	555000	299289	277059	959145
40	1717086	420000	237734	208235	759164
45	1163111	285000	188839	165882	496086
50	0	150000	150000	150000	150000

Finally, Figure 5.58 illustrates graphical results of the depreciated (amortised) cost accounting analysis for the purchased commercial building through its entire useful life, i.e. fair valuation curve and current cost accounting curves per depreciation method used.

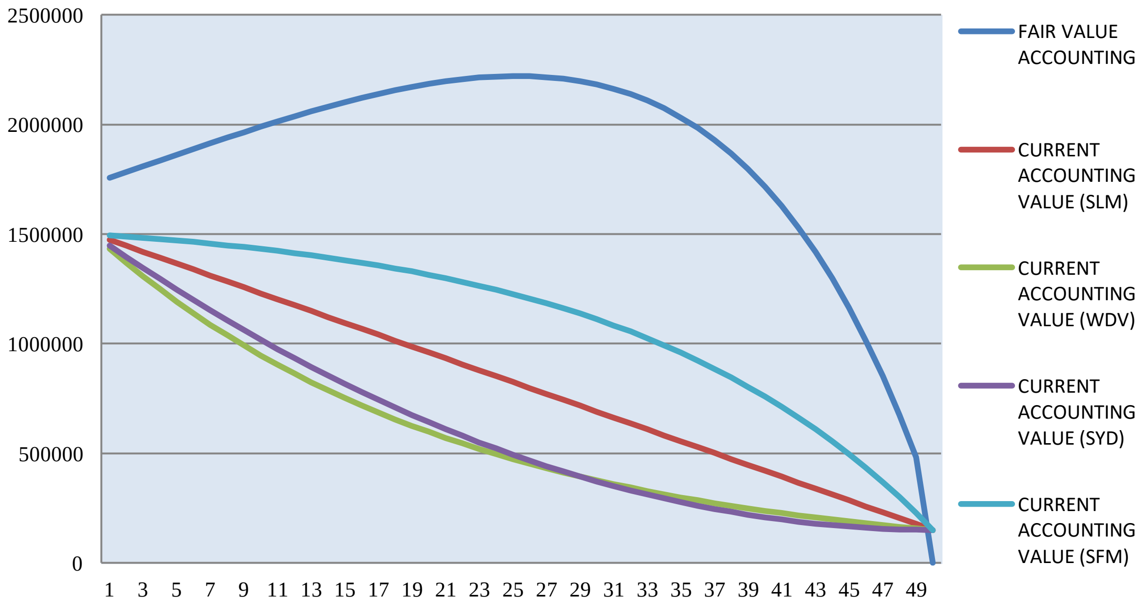


Fig. 5.58 Commercial Fixed Asset Valuation, LCC and Depreciation Methods

This page intentionally left blank

CHAPTER 6

SYNTHESIS TO AN INTEGRATED PROJECT MANAGEMENT WHOLE-LIFE METHODOLOGY

6.1 Introduction

This Chapter synthesises the previously analysed in Chapters 4 and 5 project management processes in order to develop an integrated whole-life methodology for building products.

6.2 Integrating the Cost Management Process

In Chapters 4 and 5 of the thesis, a number of modelling methodologies and processes, both *deterministic* and *stochastic*, concerning the project overall *construction production* process have been developed; these can be separated into an initial (early stage) *pre-construction* period and a subsequent *physical construction* period. Pre-construction starts with a *feasibility study* to assess project's viability with respect to client's needs and preliminary project scope requirements in relation to cost and time constraints, followed by an *evaluation and selection* of the project(s) under consideration whereas a *'go/no go'* decision is made. After the decision to proceed with the capital investment is justified, the *design* stage begins, having a significant influence on the costs incurred at subsequent project stages. To assist owners with early stage decision-making at the pre-construction period, *cost and time forecasting tools* were developed from *historical data* obtained from actual building projects by using the *linear regression* statistical technique; an indication of the *building design morphology complexity* was also derived from the calculation of relevant *plan shape indices*. Physical construction commences after the architectural and engineering design drawings have been agreed by all parties involved. For *time and cost estimation* and *cost budgeting* (cost baseline) purposes, PERT/CPM *network analysis* technique is used together with an *activity-oriented costing* methodology based on activity resource consumption following the *managerial accounting* procedures. For *cost control* reasons and in order to *monitor project performance*, the *earned-value analysis* technique can be used and an *integer linear programming tool* is presented to tackle the *time-cost trade-off* (optimisation) problem. For the *useful life* period of the constructed product, the modelling methodologies and processes, both *deterministic* and *stochastic*, are presented. The procedure adopted entails: at first, the development of a unique *whole-life costing* (WLC) mathematical model as a practical and easy to implement decision-making tool to assist owners and construction professionals in the evaluation and financial control of building investment projects throughout the product *whole-life cycle*; and, secondly, the use of the above *holistic* management technique in *fair value accounting* and *amortised (depreciated) cost accounting* for capital building projects. The uniqueness of the herein proposed WLC methodology is founded on the *integration* of the *life-cycle costing* (LCC) fundamental concepts with the widely used *investment appraisal* techniques. Through the analysis of capital requirements, owners and/or building developers can assess the net contribution of the investment project to their *equity* and the effects of potential changes in the cost and value of main decision parameters and financing schemes. As accounting elements, built assets are ruled by a set of basic aspects, such as: cost (cost of land, construction cost etc.), residual value, useful life estimation and depreciation impact. The above elements are correlated with type and the use form of the asset. Asset accounting is subject to the accounting framework instituted by the Accounting Board of each country. The accounting framework provides a general set of accounting principles. *Depreciation* is the process of allocating costs to an asset over its entire life. In this thesis, different depreciation accounting and valuation methods for built assets, like SL, WDV, SF, SYD, and Fair Value Accounting, are applied to investigate their effect on the value of built assets.

6.3 Case Study (III): *The Effect of Time-Cost Trade-off (TCT) at Construction Production on Whole-Life Appraisal of a Commercial Built Asset*

In this third case study of the thesis, an attempt is made to integrate the time-discrete building project construction production and built asset useful life periods, as previously have extensively been analysed, taking into account the different available from the TCT analysis *time-cost options* for executing the project and their overall effect on the whole-life appraisal of the commercial constructed fixed asset (Chapter 4). The study period T is now shortened from fifty (50) to thirty (30) years (or 1560 weeks). Table 6.1 summarises the TCT results for *contract deadline*, *normal*, *optimum* and *crashed* conditions (Table 4.20, page 280). The *total useful life* of the built fixed asset is assumed to follow (in weeks): a *uniform* (1560, 1589) distribution (contract deadline/crashed duration); a *PERT* (1560, 1576, 1589) distribution (contract deadline/optimum duration/crashed duration); and a *Poisson* (1589) distribution (crashed duration). Respectively, the *total construction cost* follows (in €): a *uniform* (955500, 1048280) distribution (contract deadline normal cost/ crashed cost); a *PERT* (926080, 955500, 1048280) distribution (optimum cost/contract deadline normal cost/crashed cost); and a *Poisson* (1048280) distribution (crashed cost).

Table 6.1 Summary Results from Construction TCT for the Commercial Building Project

	Project Duration	Normal Cost	Total Overheads	Crash Cost	Total Cost
Crashed	53	545500	265000	237780	1048280
Optimum	66	545500	330000	50580	926080
Normal	79	545500	395000	0	940500
Contract Deadline	82	545500	410000	0	955500

The rest of the assumptions for the WLC model's input (independent) variables are the same with those in Table 5.9 (page 350) with the exception of the depreciation rate a = 1/T = 1/30 = 3,33% (instead of a = 1/50 = 2%). In order to assess the effect of TCT alternatives on fair value (FV) accounting as well as on depreciated (DEP) current accounting valuations (CAV) of the commercial building, the above input values remain constant throughout the three analyses that follow. Tables 6.2-6.7 (pages 361-366) present the WLC model’s required calculations and numerical results for fixed asset whole-life appraisal for each one of the TCT options under uncertainty (as previously described).

Table 6.2 TCT/Whole-Life Appraisal Integration (*uniform* time-cost distributions)

YTR	**YTUC**	**TC**	**YNCF (before φ^y)**	**Deferred Tax Income**	**YNCF**	**NPV**	**Property Tax**	**NCF**
(1)	(2)	(3)	(4)=(1)-(2)-(3)	(5)=-(4)*φ^y	(6)=(4)+(5)	(7)	(8)=(7)*φ^p	(9)=(6)-(8)
180000	43000	1001890	-864890	285414	-579476	1561352	15614	-595090
183600	43860	0	139740	-46114	93626	1562449	15624	78001
187272	44737	0	142535	-47036	95498	1561739	15617	79881
191017	45632	0	145385	-47977	97408	1559076	15591	81818
194838	46545	0	148293	-48937	99356	1554303	15543	83813
198735	47475	0	151259	-49915	101344	1547254	15473	85871
202709	48425	0	154284	-50914	103370	1537750	15377	87993
206763	49393	0	157370	-51932	105438	1525602	15256	90182
210899	50381	0	160517	-52971	107547	1510608	15106	92441
215117	51389	0	163728	-54030	109698	1492554	14926	94772
219419	52417	0	167002	-55111	111891	1471211	14712	97179
223807	53465	0	170342	-56213	114129	1446335	14463	99666
228284	54534	0	173749	-57337	116412	1417667	14177	102235
232849	55625	0	177224	-58484	118740	1384932	13849	104891
237506	56738	0	180769	-59654	121115	1347836	13478	107637
242256	57872	0	184384	-60847	123537	1306067	13061	110477
247101	59030	0	188072	-62064	126008	1259294	12593	113415
252043	60210	0	191833	-63305	128528	1207162	12072	116457
257084	61415	0	195670	-64571	131099	1149298	11493	119606
262226	62643	0	199583	-65862	133721	1085301	10853	122868
267471	63896	0	203575	-67180	136395	1014748	10147	126248
272820	65174	0	207646	-68523	139123	937186	9372	129751
278276	66477	0	211799	-69894	141905	852136	8521	133384
283842	67807	0	216035	-71292	144744	759089	7591	137153
289519	69163	0	220356	-72717	147638	657502	6575	141063
295309	70546	0	224763	-74172	150591	546799	5468	145123
301215	71957	0	229258	-75655	153603	426368	4264	149339
307240	73396	0	233843	-77168	156675	295559	2956	153720
313384	74864	0	238520	-78712	159809	153681	1537	158272
319652	76361	0	243291	-80286	163005	0	0	163005

Table 6.2 TCT/Whole-Life Appraisal Integration (*uniform* time-cost distributions) – *cont'd.*

FV	DEP (SLM)	CAV (SLM)	DEP (WDV)	CAV (WDV)	DEP (SYD)	CAV (SYD)	DEP (SFM)	CAV (SFM)
(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
1384477	-27480	974410	-59532	942347	-53243	948647	-9924	991966
1390476	-27480	946929	-55995	886344	-51526	897121	-10526	981441
1394961	-27480	919449	-52668	833670	-49808	847313	-11164	970277
1397780	-27480	891969	-49538	784126	-48091	799223	-11841	958435
1398776	-27480	864488	-46594	737528	-46373	752850	-12560	945875
1397774	-27480	837008	-43826	693699	-44656	708194	-13322	932553
1394589	-27480	809528	-41222	652475	-42938	665256	-14130	918423
1389022	-27480	782047	-38772	613701	-41220	624036	-14987	903436
1380859	-27480	754567	-36468	577232	-39503	584533	-15896	887540
1369870	-27480	727087	-34302	542931	-37785	546747	-16861	870679
1355806	-27480	699606	-32263	510668	-36068	510679	-17884	852795
1338402	-27480	672126	-30346	480323	-34350	476329	-18969	833826
1317374	-27480	644646	-28543	451781	-32633	443696	-20119	813707
1292414	-27480	617165	-26847	424936	-30915	412781	-21340	792367
1263193	-27480	589685	-25252	399686	-29198	383583	-22635	769732
1229361	-27480	562205	-23751	375937	-27480	356102	-24008	745724
1190536	-27480	534725	-22340	353599	-25763	330340	-25464	720260
1146315	-27480	507244	-21013	332589	-24045	306294	-27009	693251
1096262	-27480	479764	-19764	312827	-22328	283967	-28648	664603
1039910	-27480	452284	-18590	294240	-20610	263356	-30386	634218
976759	-27480	424803	-17485	276757	-18893	244464	-32229	601989
906272	-27480	397323	-16446	260314	-17175	227288	-34184	567804
827876	-27480	369843	-15469	244847	-15458	211831	-36258	531546
740955	-27480	342362	-14550	230300	-13740	198091	-38458	493088
644850	-27480	314882	-13685	216617	-12023	186068	-40791	452298
538853	-27480	287402	-12872	203747	-10305	175763	-43265	409032
422209	-27480	259921	-12107	191642	-8588	167175	-45890	363142
294107	-27480	232441	-11388	180256	-6870	160305	-48674	314468
153680	-27480	204961	-10711	169547	-5153	155153	-51627	262840
0	-27480	177480	-10075	159474	-3435	151718	-54759	208081

Table 6.3 Fair Value and Current Accounting Values for TCT/Whole-Life Appraisal – *uniform*

t	Fair Value	Current Accounting Value of Commercial Fixed Asset per Depreciation Method			
		SLM	WDV	SYD	SFM
0	1384602	974410	942347	948647	991966
4	1398892	864488	737528	752850	945875
9	1369968	727087	542931	546747	870679
14	1263267	589685	399686	383583	769732
19	1039954	452284	294240	263356	634218
24	644866	314882	216617	186068	452298
29	0	177480	159474	151718	208081

Figures 6.1-6.3 (pages 367-368) present graphical results for the whole-life appraisal of the fixed asset under study for each one of the TCT alternatives under uncertainty (for *uniform*, *PERT* and *Poisson* probability distribution functions assigned to the critical inputs, i.e. the total useful life of the built product and the total construction cost at the construction production phase).

Table 6.4 TCT/Whole-Life Appraisal Integration (*PERT* time-cost distributions)

YTR	**YTUC**	**TC**	**YNCF (before φ^y)**	**Deferred Tax Income**	**YNCF**	**NPV**	**Property Tax**	**NCF**
(1)	(2)	(3)	(4)=(1)-(2)-(3)	(5)=-(4)*φ^y	(6)=(4)+(5)	(7)	(8)=(7)*φ^p	(9)=(6)-(8)
180000	43000	966060	-829060	273590	-555470	1552734	15527	-570998
183600	43860	0	139740	-46114	93626	1554048	15540	78085
187272	44737	0	142535	-47036	95498	1553570	15536	79963
191017	45632	0	145385	-47977	97408	1551153	15512	81897
194838	46545	0	148293	-48937	99356	1546640	15466	83890
198735	47475	0	151259	-49915	101344	1539864	15399	85945
202709	48425	0	154284	-50914	103370	1530647	15306	88064
206763	49393	0	157370	-51932	105438	1518798	15188	90250
210899	50381	0	160517	-52971	107547	1504117	15041	92505
215117	51389	0	163728	-54030	109698	1486386	14864	94834
219419	52417	0	167002	-55111	111891	1465378	14654	97238
223807	53465	0	170342	-56213	114129	1440847	14408	99721
228284	54534	0	173749	-57337	116412	1412534	14125	102287
232849	55625	0	177224	-58484	118740	1380162	13802	104939
237506	56738	0	180769	-59654	121115	1343435	13434	107681
242256	57872	0	184384	-60847	123537	1302041	13020	110517
247101	59030	0	188072	-62064	126008	1255644	12556	113452
252043	60210	0	191833	-63305	128528	1203891	12039	116489
257084	61415	0	195670	-64571	131099	1146403	11464	119635
262226	62643	0	199583	-65862	133721	1082777	10828	122893
267471	63896	0	203575	-67180	136395	1012587	10126	126269
272820	65174	0	207646	-68523	139123	935378	9354	129769
278276	66477	0	211799	-69894	141905	850665	8507	133399
283842	67807	0	216035	-71292	144744	757934	7579	137164
289519	69163	0	220356	-72717	147638	656638	6566	141072
295309	70546	0	224763	-74172	150591	546196	5462	145129
301215	71957	0	229258	-75655	153603	425990	4260	149343
307240	73396	0	233843	-77168	156675	295361	2954	153721
313384	74864	0	238520	-78712	159809	153612	1536	158272
319652	76361	0	243291	-80286	163005	0	0	163005

Table 6.4 TCT/Whole-Life Appraisal Integration (*PERT* time-cost distributions) – *cont'd.*

FV	DEP (SLM)	CAV (SLM)	DEP (WDV)	CAV (WDV)	DEP (SYD)	CAV (SYD)	DEP (SFM)	CAV (SFM)
(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
1377328	-26325	939735	-56335	977608	-51004	984975	-9423	1030174
1383465	-26325	913411	-53050	918394	-49358	931106	-9999	1019077
1388100	-26325	887086	-49956	862767	-47713	879032	-10611	1007313
1391084	-26325	860762	-47043	810508	-46068	828754	-11260	994841
1392257	-26325	834437	-44300	761416	-44423	780272	-11948	981618
1391447	-26325	808113	-41717	715296	-42777	733585	-12679	967599
1388469	-26325	781788	-39284	671970	-41132	688694	-13454	952736
1383122	-26325	755464	-36993	631269	-39487	645598	-14276	936979
1375194	-26325	729139	-34836	593033	-37841	604298	-15149	920273
1364452	-26325	702815	-32804	557112	-36196	564794	-16076	902562
1350649	-26325	676490	-30891	523368	-34551	527086	-17059	883785
1333520	-26325	650166	-29090	491667	-32906	491173	-18102	863877
1312777	-26325	623841	-27394	461887	-31260	457055	-19208	842772
1288114	-26325	597517	-25796	433910	-29615	424734	-20383	820396
1259201	-26325	571192	-24292	407628	-27970	394208	-21629	796673
1225683	-26325	544868	-22875	382938	-26325	365478	-22952	771523
1187182	-26325	518543	-21541	359743	-24679	338543	-24355	744859
1143288	-26325	492219	-20285	337953	-23034	313404	-25844	716590
1093565	-26325	465894	-19102	317483	-21389	290060	-27424	686620
1037544	-26325	439570	-17988	298253	-19743	268513	-29101	654845
974720	-26325	413245	-16939	280188	-18098	248761	-30881	621158
904555	-26325	386921	-15952	263217	-16453	230804	-32769	585444
826469	-26325	360596	-15021	247274	-14808	214643	-34772	547580
739844	-26325	334272	-14145	232296	-13162	200278	-36899	507438
644013	-26325	307947	-13321	218226	-11517	187709	-39155	464879
538265	-26325	281623	-12544	205008	-9872	176935	-41549	419758
421837	-26325	255298	-11812	192590	-8226	167957	-44089	371922
293911	-26325	228974	-11123	180925	-6581	160774	-46785	321207
153611	-26325	202649	-10475	169966	-4936	155387	-49646	267439
0	-26325	176325	-9864	159671	-3291	151796	-52681	210435

Table 6.5 Fair Value and Current Accounting Values for TCT/Whole-Life Appraisal – *PERT*

t	Fair Value	Current Accounting Value of Commercial Fixed Asset per Depreciation Method			
		SLM	WDV	SYD	SFM
0	1377328	939735	977608	984975	1030174
4	1392257	834437	761416	780272	981618
9	1364452	702815	557112	564794	902562
14	1259201	571192	407628	394208	796673
19	1037544	439570	298253	268513	654845
24	644013	307947	218226	187709	464879
29	0	176325	159671	151796	210435

In addition, in pages 368-378 a selection of graphical results is illustrated for the whole-life appraisal of the fixed asset under study for each one of the TCT alternatives under uncertainty. The outputs entail *minimum*, *mean* and *maximum* fair and depreciated current accounting values as well as associated *standard deviations* for the four different ways of calculating depreciation of the built product, for the years 1, 2, 4, 15 and 20.

Table 6.6 TCT/Whole-Life Appraisal Integration (*Poisson* time-cost distributions)

YTR	**YTUC**	**TC**	**YNCF (before φ^y)**	**Deferred Tax Income**	**YNCF**	**NPV**	**Property Tax**	**NCF**
(1)	(2)	(3)	(4)=(1)-(2)-(3)	(5)=-(4)*φ^y	(6)=(4)+(5)	(7)	(8)=(7)*φ^p	(9)=(6)-(8)
180000	43000	1048280	-911280	300722	-610558	1571736	15717	-626275
183600	43860	0	139740	-46114	93626	1572566	15726	77900
187272	44737	0	142535	-47036	95498	1571574	15716	79783
191017	45632	0	145385	-47977	97408	1568613	15686	81722
194838	46545	0	148293	-48937	99356	1563525	15635	83721
198735	47475	0	151259	-49915	101344	1556145	15561	85782
202709	48425	0	154284	-50914	103370	1546294	15463	87908
206763	49393	0	157370	-51932	105438	1533783	15338	90100
210899	50381	0	160517	-52971	107547	1518412	15184	92362
215117	51389	0	163728	-54030	109698	1499967	15000	94698
219419	52417	0	167002	-55111	111891	1478219	14782	97109
223807	53465	0	170342	-56213	114129	1452926	14529	99600
228284	54534	0	173749	-57337	116412	1423830	14238	102174
232849	55625	0	177224	-58484	118740	1390658	13907	104834
237506	56738	0	180769	-59654	121115	1353117	13531	107584
242256	57872	0	184384	-60847	123537	1310898	13109	110428
247101	59030	0	188072	-62064	126008	1263671	12637	113371
252043	60210	0	191833	-63305	128528	1211085	12111	116417
257084	61415	0	195670	-64571	131099	1152769	11528	119571
262226	62643	0	199583	-65862	133721	1088326	10883	122837
267471	63896	0	203575	-67180	136395	1017336	10173	126222
272820	65174	0	207646	-68523	139123	939352	9394	129729
278276	66477	0	211799	-69894	141905	853898	8539	133366
283842	67807	0	216035	-71292	144744	760471	7605	137139
289519	69163	0	220356	-72717	147638	658535	6585	141053
295309	70546	0	224763	-74172	150591	547520	5475	145116
301215	71957	0	229258	-75655	153603	426821	4268	149335
307240	73396	0	233843	-77168	156675	295796	2958	153717
313384	74864	0	238520	-78712	159809	153764	1538	158271
319652	76361	0	243291	-80286	163005	0	0	163005

Table 6.6 TCT/Whole-Life Appraisal Integration (*Poisson* time-cost distributions) – *cont'd.*

FV	DEP (SLM)	CAV (SLM)	DEP (WDV)	CAV (WDV)	DEP (SYD)	CAV (SYD)	DEP (SFM)	CAV (SFM)
(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
1394738	-28977	1019328	-63727	984607	-56143	992185	-10574	1037722
1400681	-28977	990376	-59853	924804	-54331	937900	-11209	1026529
1405099	-28977	961424	-56214	868636	-52520	885423	-11883	1014663
1407846	-28977	932472	-52797	815882	-50709	834756	-12597	1002084
1408760	-28977	903520	-49587	766333	-48898	785898	-13354	988750
1407669	-28977	874568	-46573	719796	-47087	738849	-14157	974614
1404390	-28977	845616	-43742	676086	-45276	693610	-15008	959628
1398723	-28977	816664	-41082	635033	-43465	650179	-15909	943742
1390454	-28977	787713	-38585	596474	-41654	608558	-16866	926901
1379356	-28977	758761	-36239	560257	-39843	568746	-17879	909048
1365181	-28977	729809	-34036	526242	-38032	530743	-18954	890122
1347667	-28977	700857	-31967	494292	-36221	494549	-20093	870059
1326528	-28977	671905	-30024	464284	-34410	460165	-21300	848790
1301462	-28977	642953	-28199	436099	-32599	427589	-22580	826243
1272142	-28977	614001	-26484	409626	-30788	396823	-23937	802341
1238219	-28977	585049	-24874	384761	-28977	367866	-25376	777002
1199317	-28977	556097	-23362	361406	-27166	340718	-26901	750140
1155034	-28977	527145	-21942	339470	-25355	315380	-28517	721665
1104941	-28977	498193	-20608	318866	-23544	291850	-30231	691478
1048574	-28977	469241	-19355	299514	-21733	270130	-32048	659476
985439	-28977	440289	-18179	281337	-19922	250219	-33974	625552
915006	-28977	411337	-17073	264263	-18110	232117	-36016	589589
836709	-28977	382385	-16036	248227	-16299	215824	-38180	551464
749938	-28977	353433	-15061	233164	-14488	201341	-40475	511049
654043	-28977	324481	-14145	219016	-12677	188666	-42907	468204
548328	-28977	295529	-13285	205727	-10866	177801	-45486	422785
432047	-28977	266577	-12478	193245	-9055	168745	-48219	374636
304465	-28977	237566	-11719	181460	-7244	161438	-51117	323533
167702	-28977	205611	-11007	167437	-5433	152985	-54189	266435
51341	-28977	145967	-10337	125939	-3622	117991	-57446	179146

Table 6.7 Fair Value and Current Accounting Values for TCT/Whole-Life Appraisal – *Poisson*

t	Fair Value	Current Accounting Value of Commercial Fixed Asset per Depreciation Method			
		SLM	WDV	SYD	SFM
0	1394738	1019328	984607	992185	1037722
4	1408760	903520	766333	785898	988750
9	1379356	758761	560257	568746	909048
14	1272142	614001	409626	396823	802341
19	1048574	469241	299514	270130	659476
24	654043	324481	219016	188666	468204
29	51341	145967	125939	117991	179146

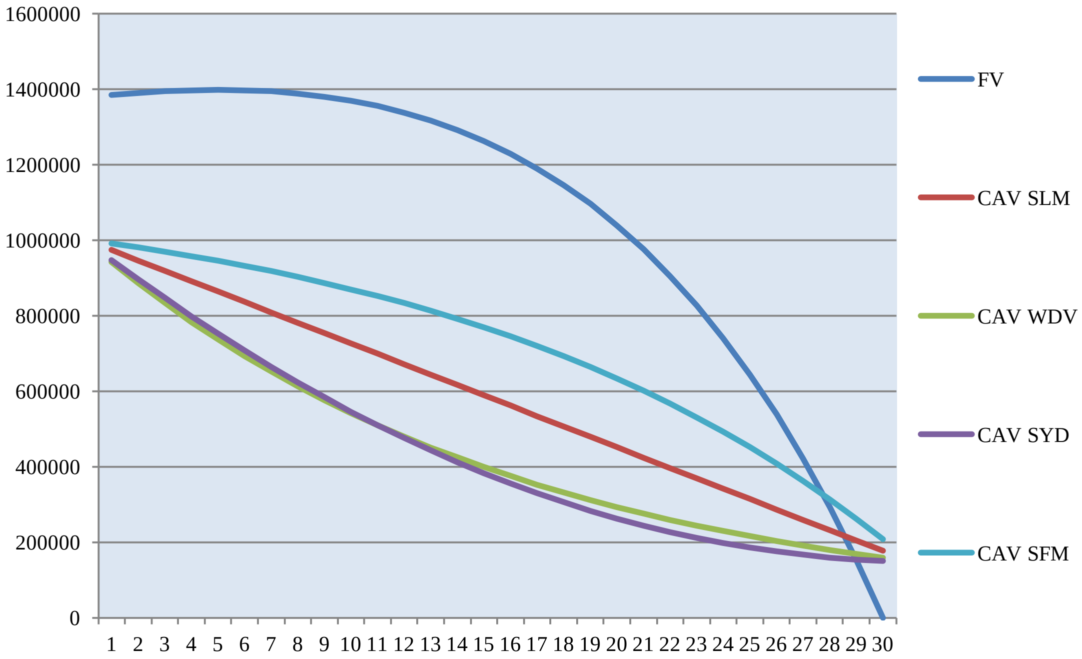


Fig. 6.1 Graphical Results for TCT/Whole-Life Appraisal Integration – *uniform*

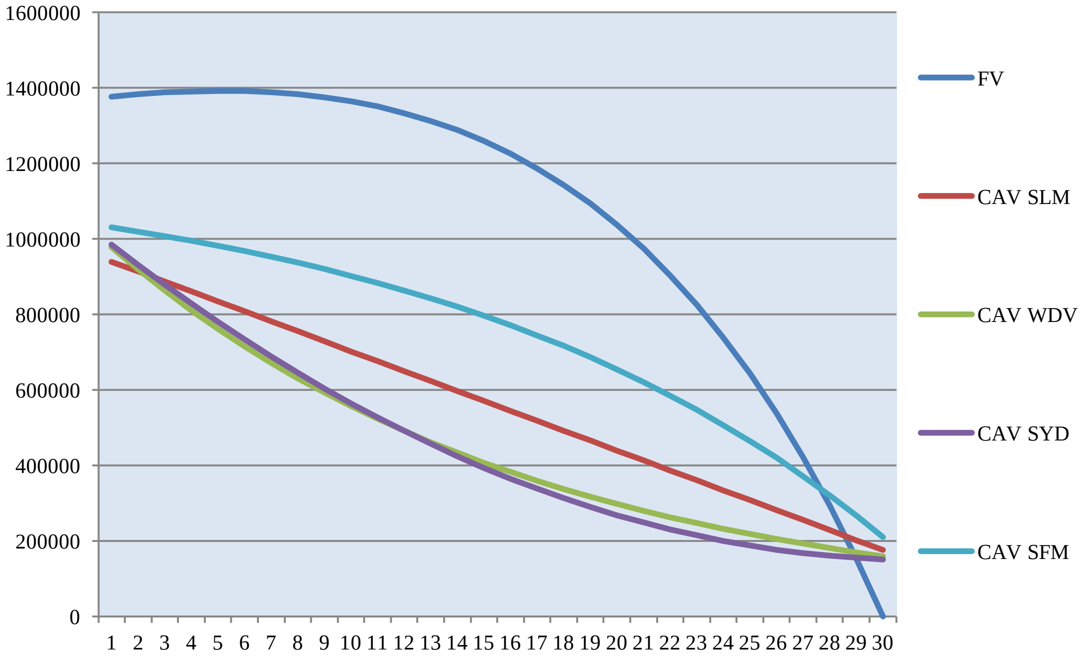


Fig. 6.2 Graphical Results for TCT/Whole-Life Appraisal Integration – *PERT*

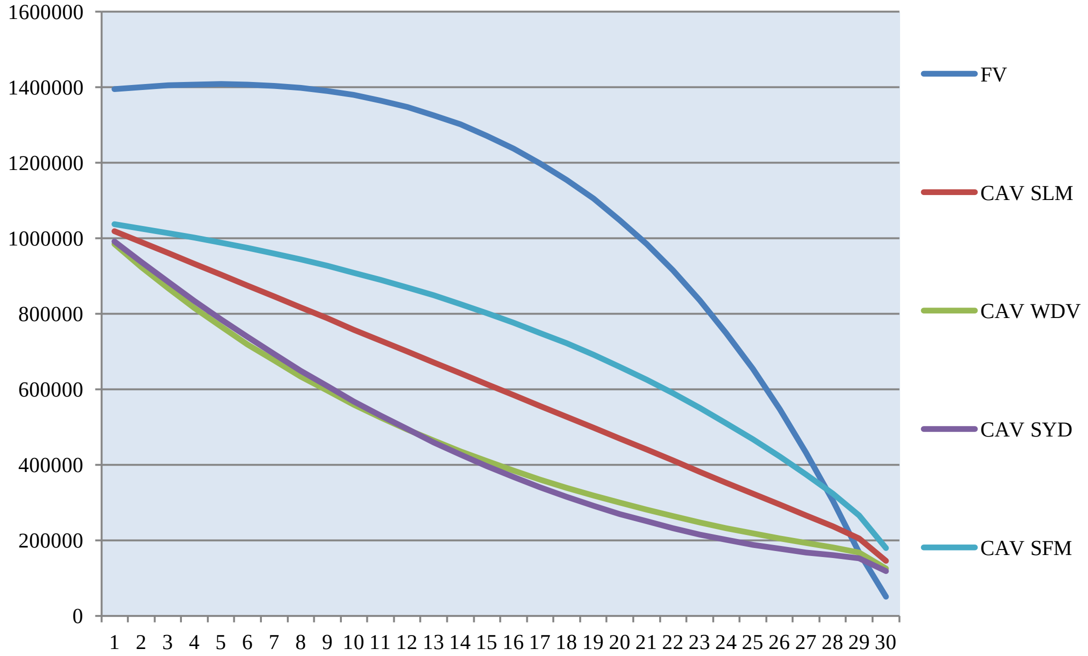
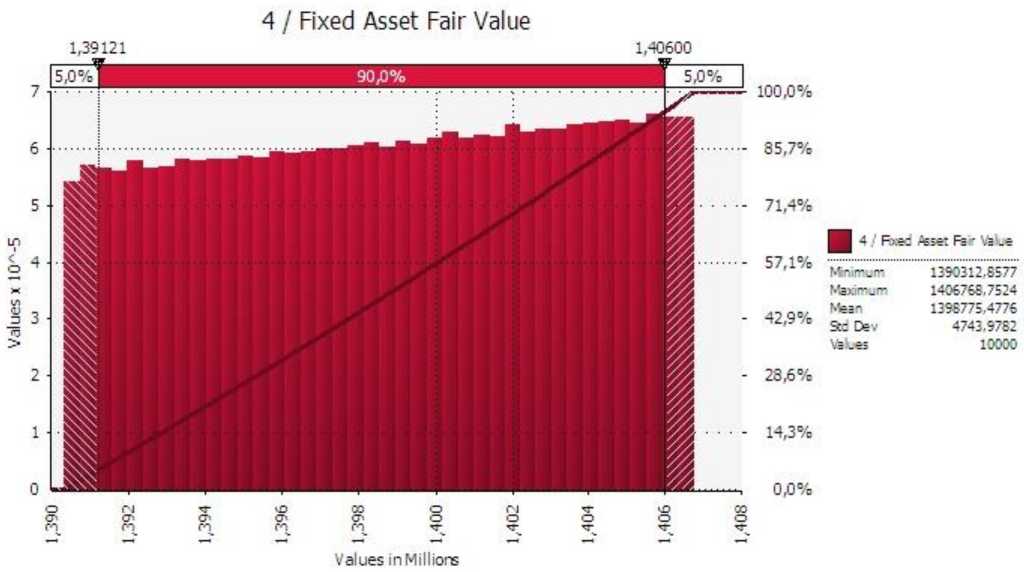
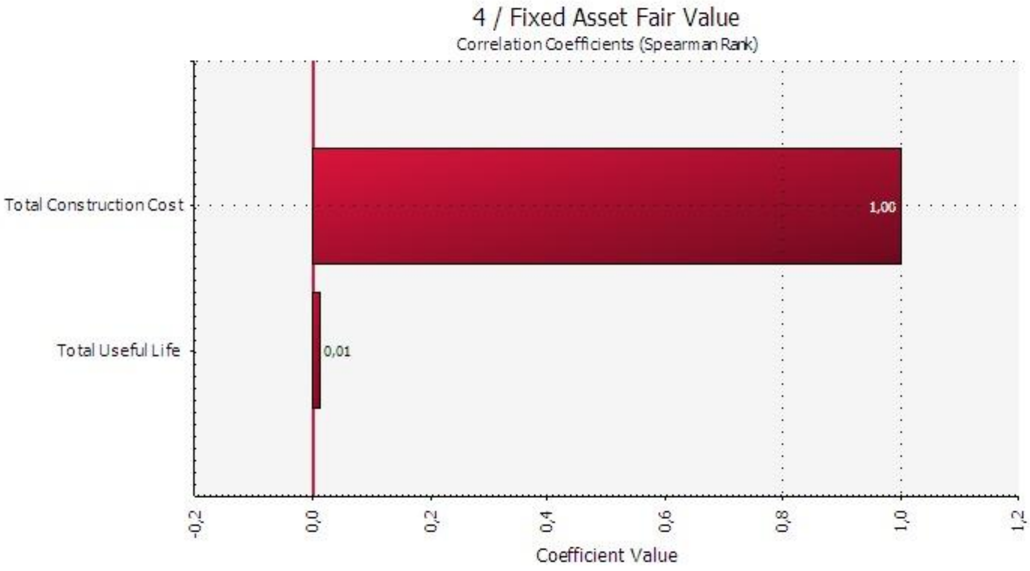


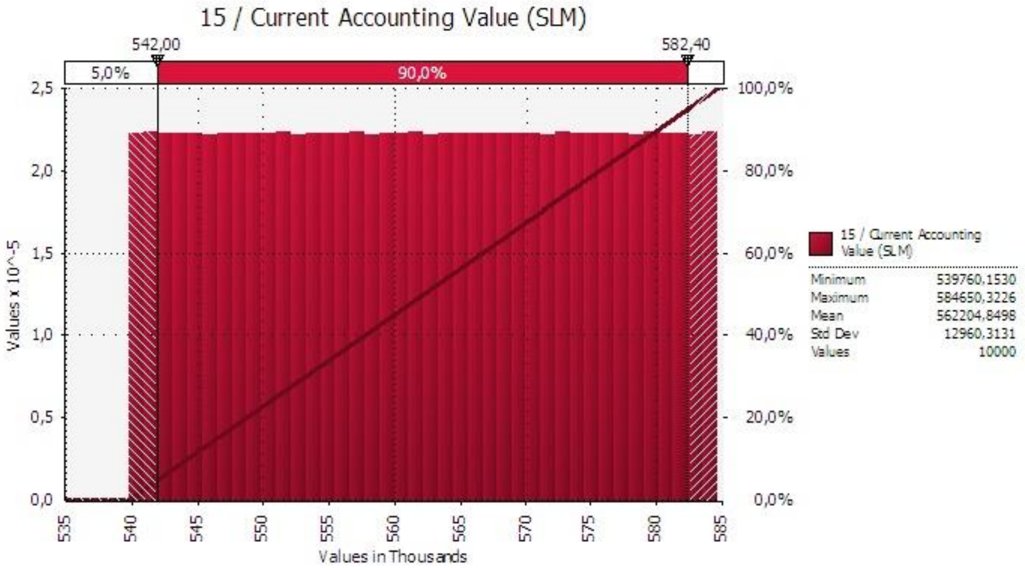
Fig. 6.3 Graphical Results for TCT/Whole-Life Appraisal Integration – *Poisson*

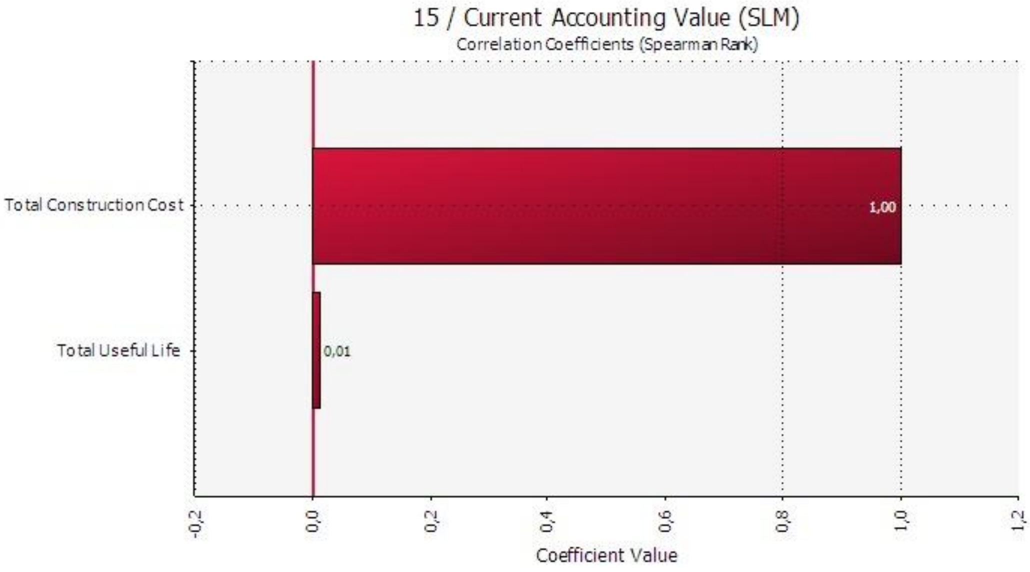
Summary of selective (for years 1, 2, 4, 15 and 20 of total useful life) graphical results (histograms with cumulative *S*-curves and Spearman's rank correlation coefficients charts for inputs criticality) for constructed asset fair value and amortised current accounting values under different TCT decisions at construction production stage (10.000 trials):

Uniform

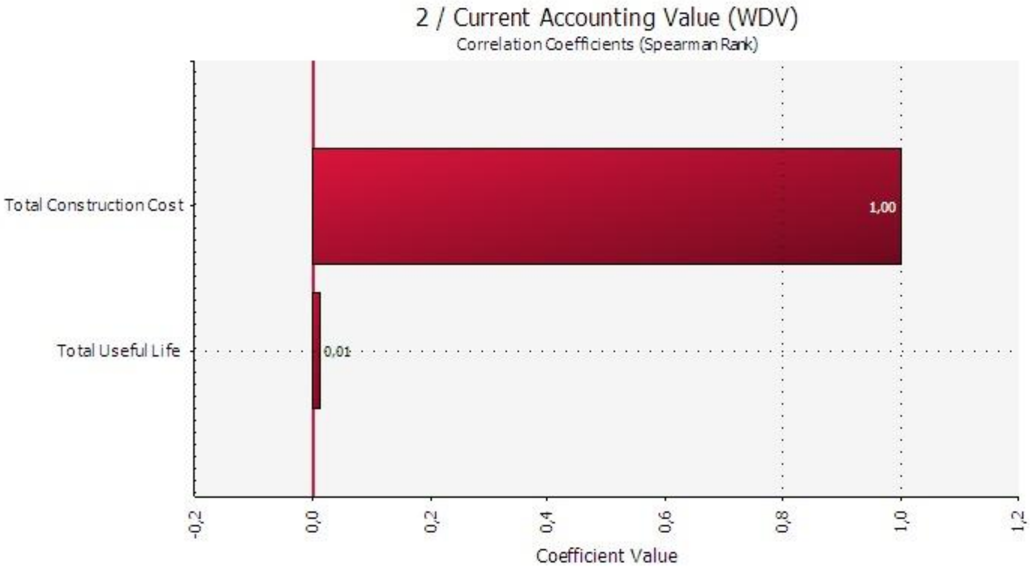


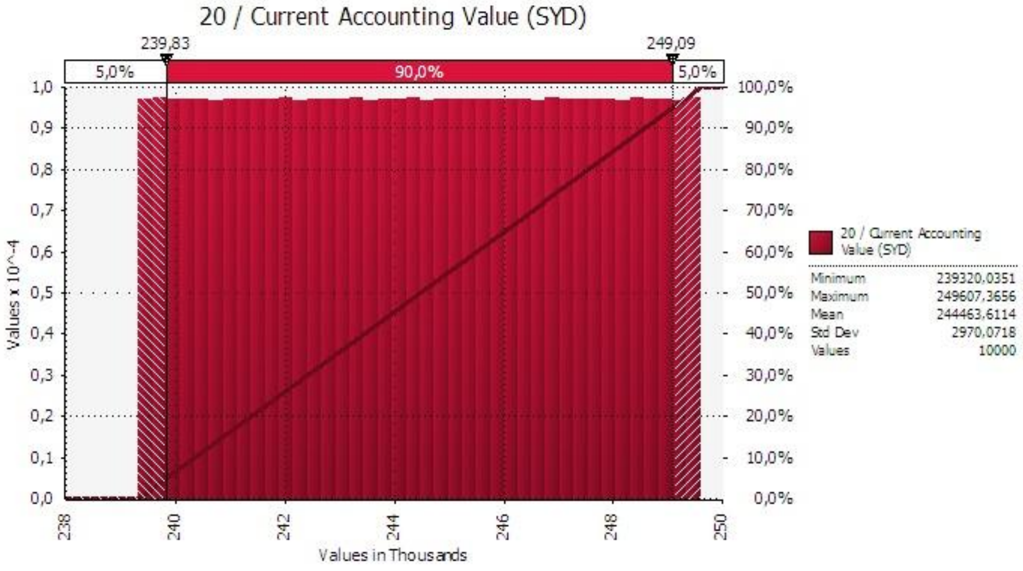

4 / Fixed Asset Fair Value
Correlation Coefficients (Spearman Rank)
Total Construction Cost
Total Useful Life
1,00
0,01
-0,2
0,0
0,2
0,4
0,6
0,8
1,0
1,2
Coefficient Value

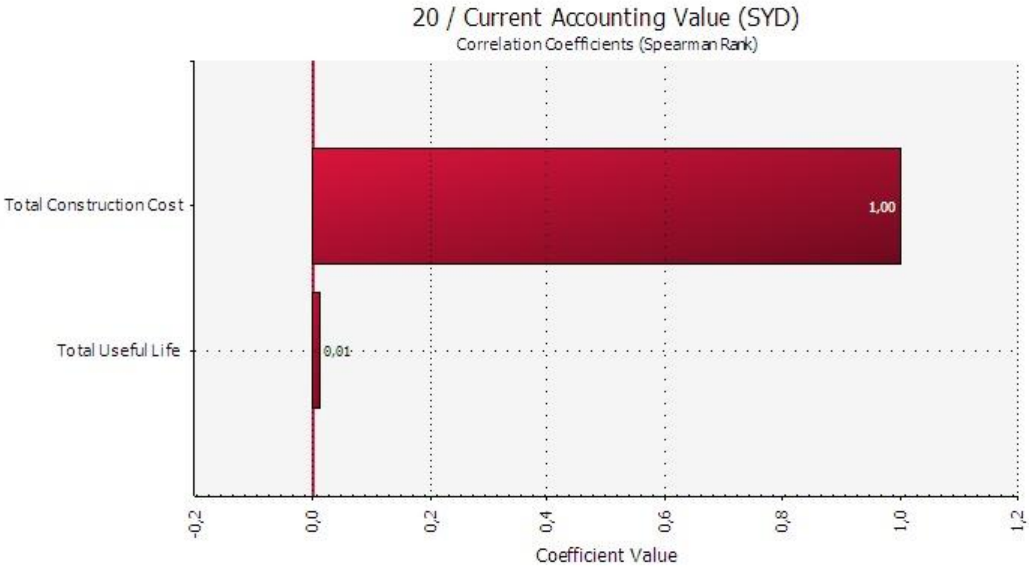

15 / Current Accounting Value (SLM)
542,00
582,40
5,0%
90,0%
2,5
2,0
1,5
1,0
0,5
0,0
Values x 10^-5
100,0%
80,0%
60,0%
40,0%
20,0%
0,0%
535
540
545
550
555
560
565
570
575
580
585
Values in Thousands
15 / Current Accounting Value (SLM)
Minimum 539760,1530
Maximum 584650,3226
Mean 562204,8498
Std Dev 12960,3131
Values 10000

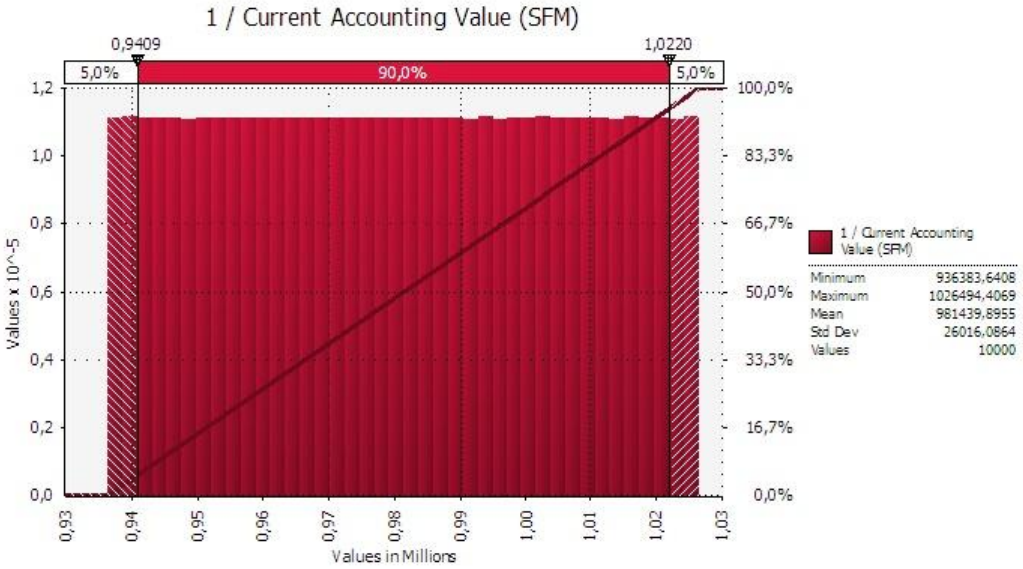

15 / Current Accounting Value (SLM)
Correlation Coefficients (Spearman Rank)
Total Construction Cost
Total Useful Life
1,00
0,01
-0,2
0,0
0,2
0,4
0,6
0,8
1,0
1,2
Coefficient Value

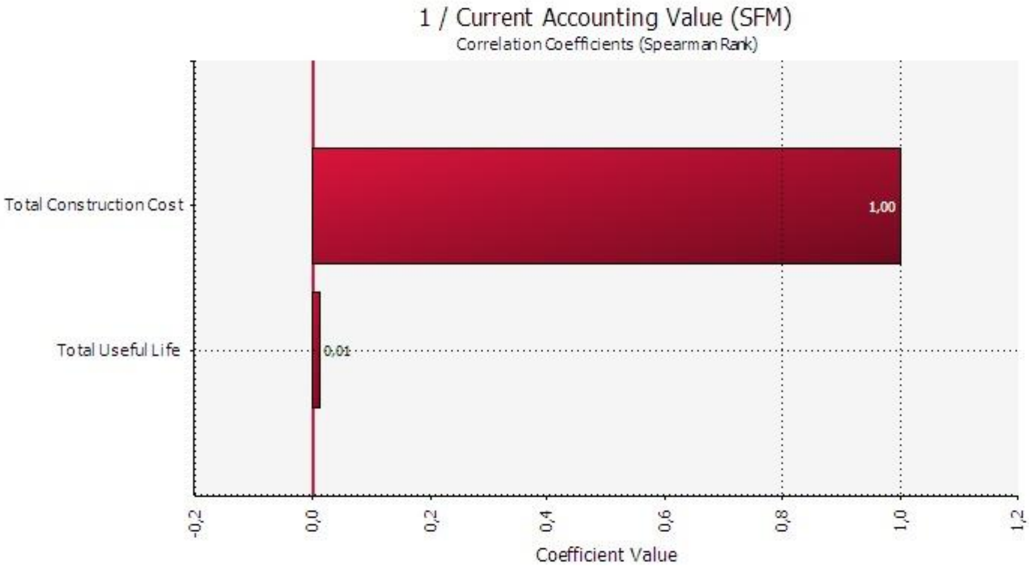

2 / Current Accounting Value (WDV)
802,2
865,0
5,0%
90,0%
5,0%
Values x 10^-5
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
100,0%
87,5%
75,0%
62,5%
50,0%
37,5%
25,0%
12,5%
0,0%
790
800
810
820
830
840
850
860
870
Values in Thousands
2 / Current Accounting Value (WDV)
Minimum 798753,0294
Maximum 868483,4043
Mean 833669,7056
Std Dev 20131,6783
Values 10000


2 / Current Accounting Value (WDV)
Correlation Coefficients (Spearman Rank)
Total Construction Cost
1,00
Total Useful Life
0,01
-0,2
0,0
0,2
0,4
0,6
0,8
1,0
1,2
Coefficient Value

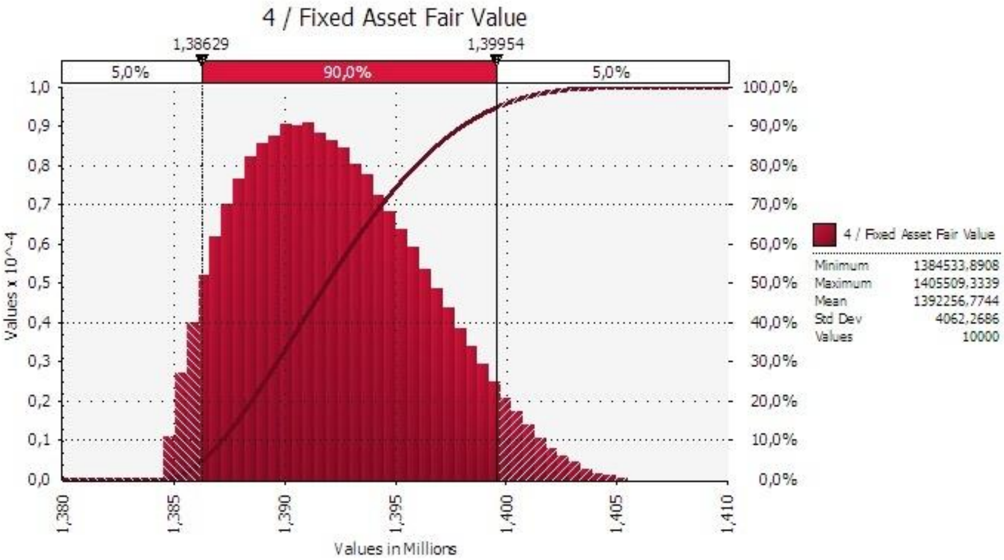

20 / Current Accounting Value (SYD)
239,83
249,09
5,0%
90,0%
5,0%
Values x 10^-4
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
100,0%
90,0%
80,0%
70,0%
60,0%
50,0%
40,0%
30,0%
20,0%
10,0%
0,0%
238
240
242
244
246
248
250
Values in Thousands
20 / Current Accounting Value (SYD)
Minimum 239320,0351
Maximum 249607,3656
Mean 244463,6114
Std Dev 2970,0718
Values 10000

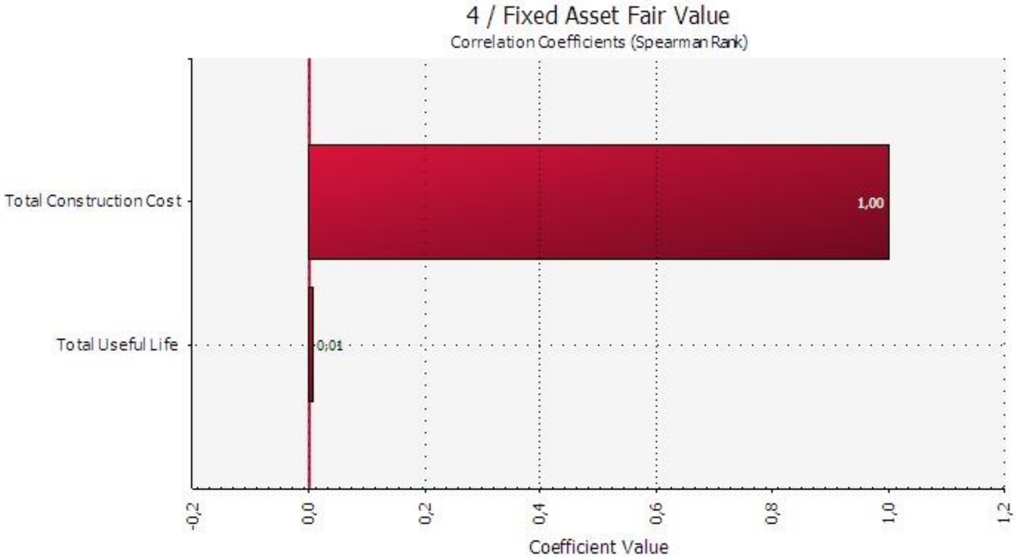

20 / Current Accounting Value (SYD)
Correlation Coefficients (Spearman Rank)
Total Construction Cost
1,00
Total Useful Life
0,01
-0,2
0,0
0,2
0,4
0,6
0,8
1,0
1,2
Coefficient Value

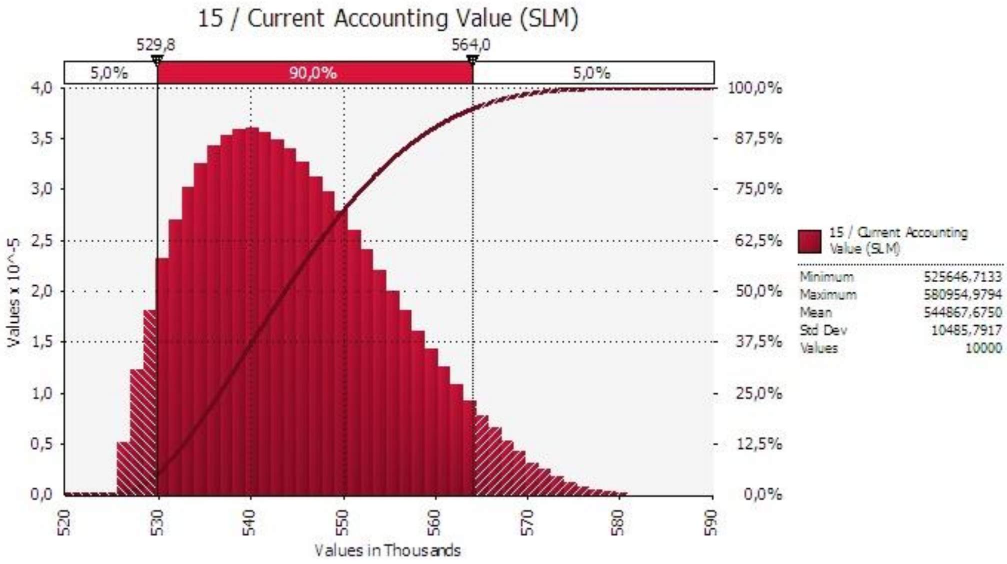

1 / Current Accounting Value (SFM)
0,9409
1,0220
5,0%
90,0%
5,0%
1,2
1,0
0,8
0,6
0,4
0,2
0,0
Values x 10^-5
100,0%
83,3%
66,7%
50,0%
33,3%
16,7%
0,0%
0,93
0,94
0,95
0,96
0,97
0,98
0,99
1,00
1,01
1,02
1,03
Values in Millions
1 / Current Accounting Value (SFM)
Minimum 936383,6408
Maximum 1026494,4069
Mean 981439,8955
Std Dev 26016,0864
Values 10000

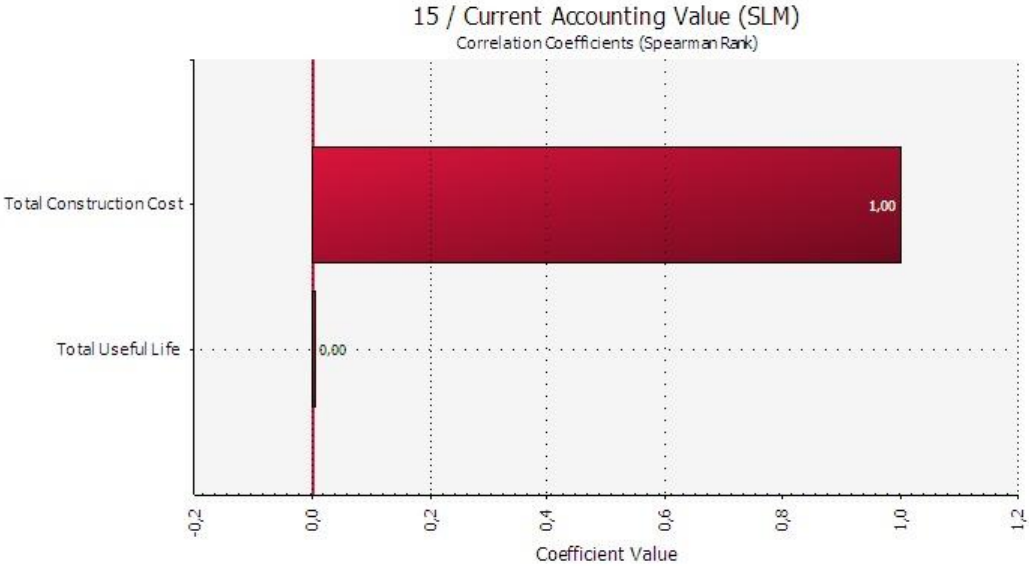

1 / Current Accounting Value (SFM)
Correlation Coefficients (Spearman Rank)
Total Construction Cost
1,00
Total Useful Life
0,01
-0,2
0,0
0,2
0,4
0,6
0,8
1,0
1,2
Coefficient Value

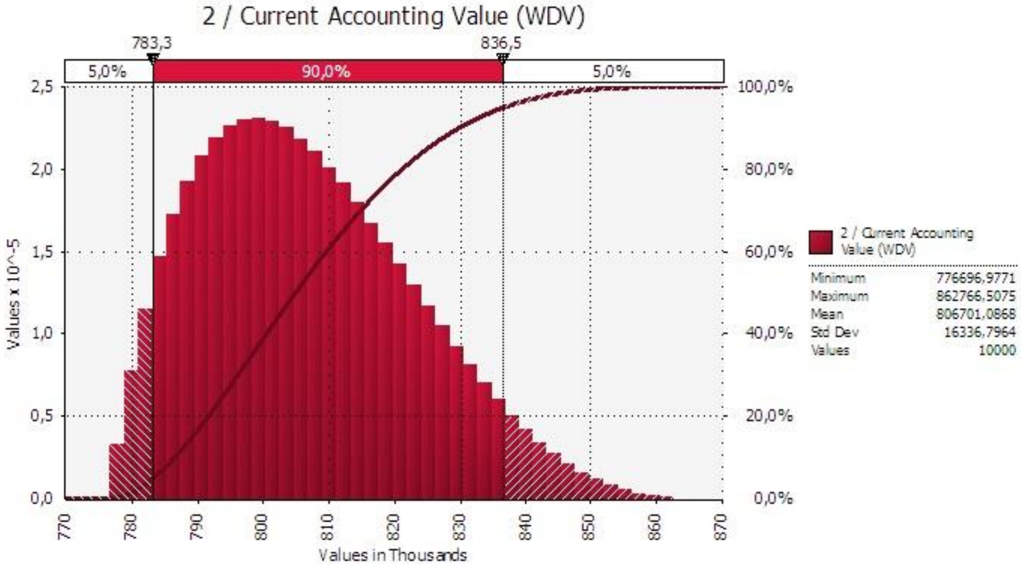
PERT

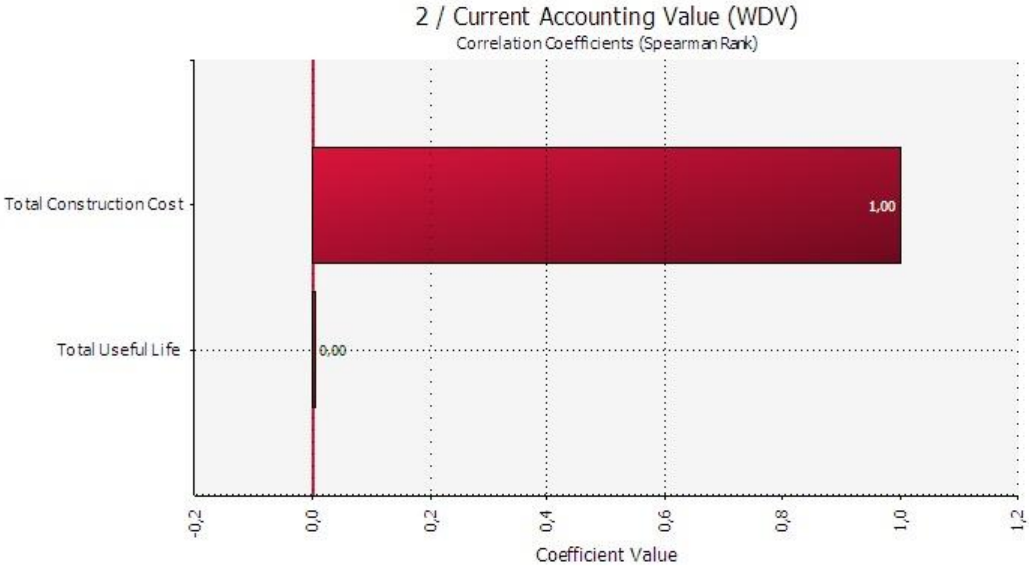

4 / Fixed Asset Fair Value
1,38629
1,39954
5,0%
90,0%
5,0%
1,0
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
Values x 10^-4
100,0%
90,0%
80,0%
70,0%
60,0%
50,0%
40,0%
30,0%
20,0%
10,0%
0,0%
1,380
1,385
1,390
1,395
1,400
1,405
1,410
Values in Millions
4 / Fixed Asset Fair Value
Minimum 1384533,8908
Maximum 1405509,3339
Mean 1392256,7744
Std Dev 4062,2686
Values 10000

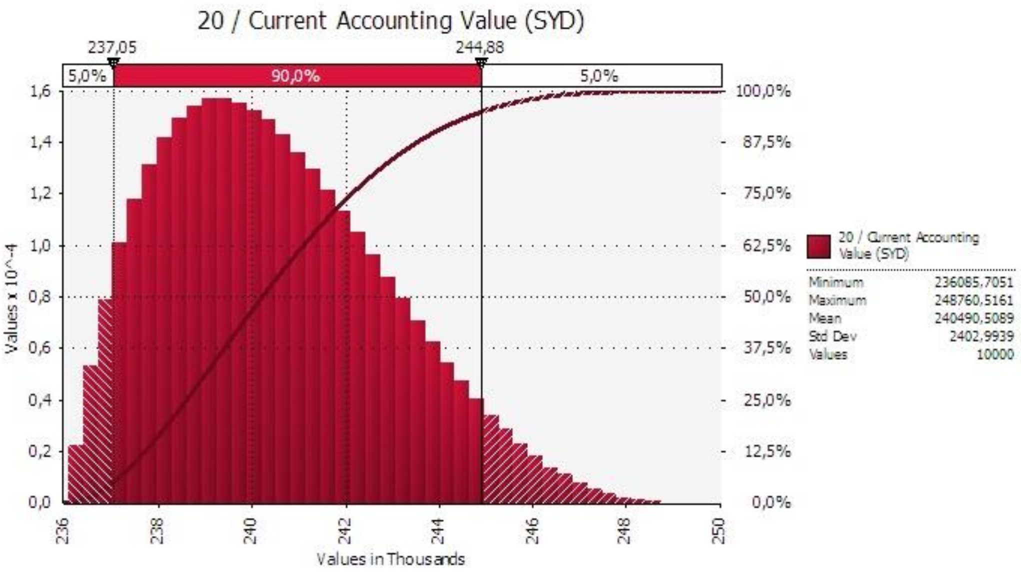

4 / Fixed Asset Fair Value
Correlation Coefficients (Spearman Rank)
Total Construction Cost
Total Useful Life
1,00
0,01
-0,2
0,0
0,2
0,4
0,6
0,8
1,0
1,2
Coefficient Value

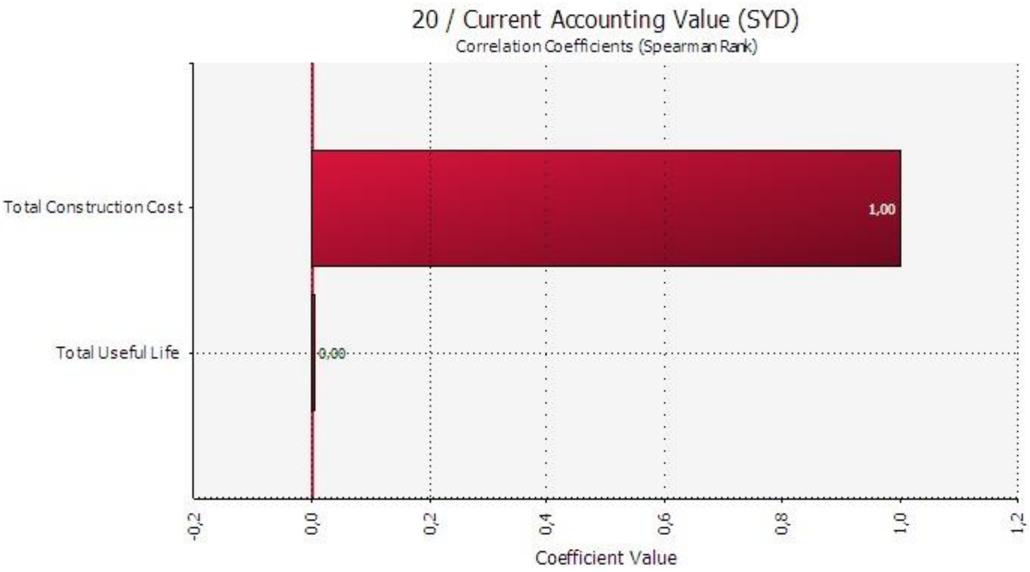

15 / Current Accounting Value (SLM)
529,8
564,0
5,0%
90,0%
5,0%
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
Values x 10^-5
100,0%
87,5%
75,0%
62,5%
50,0%
37,5%
25,0%
12,5%
0,0%
520
530
540
550
560
570
580
590
Values in Thousands
15 / Current Accounting Value (SLM)
Minimum 525646,7133
Maximum 580954,9794
Mean 544867,6750
Std Dev 10485,7917
Values 10000

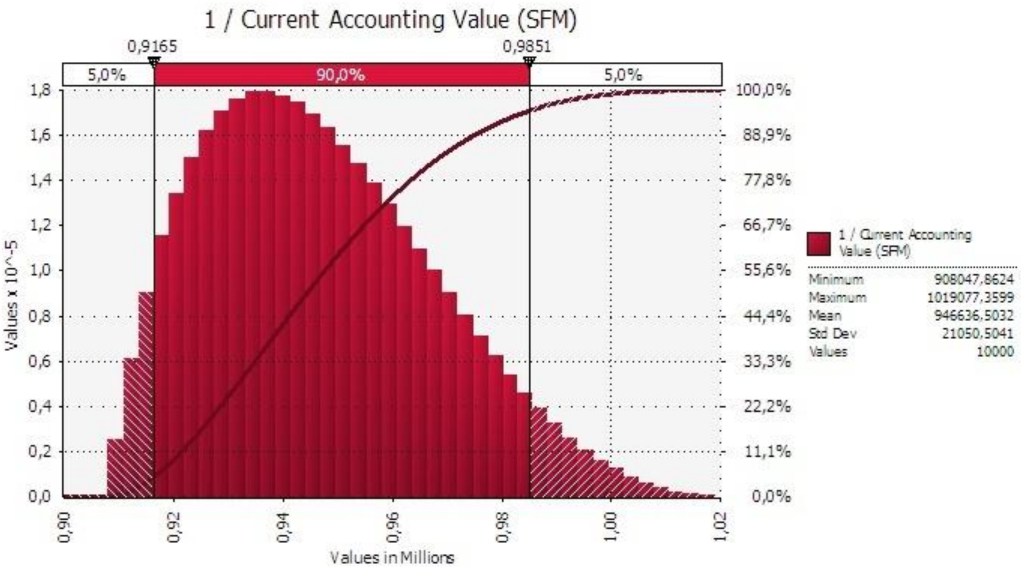

15 / Current Accounting Value (SLM)
Correlation Coefficients (Spearman Rank)
Total Construction Cost
1,00
Total Useful Life
0,00
-0,2
0,0
0,2
0,4
0,6
0,8
1,0
1,2
Coefficient Value

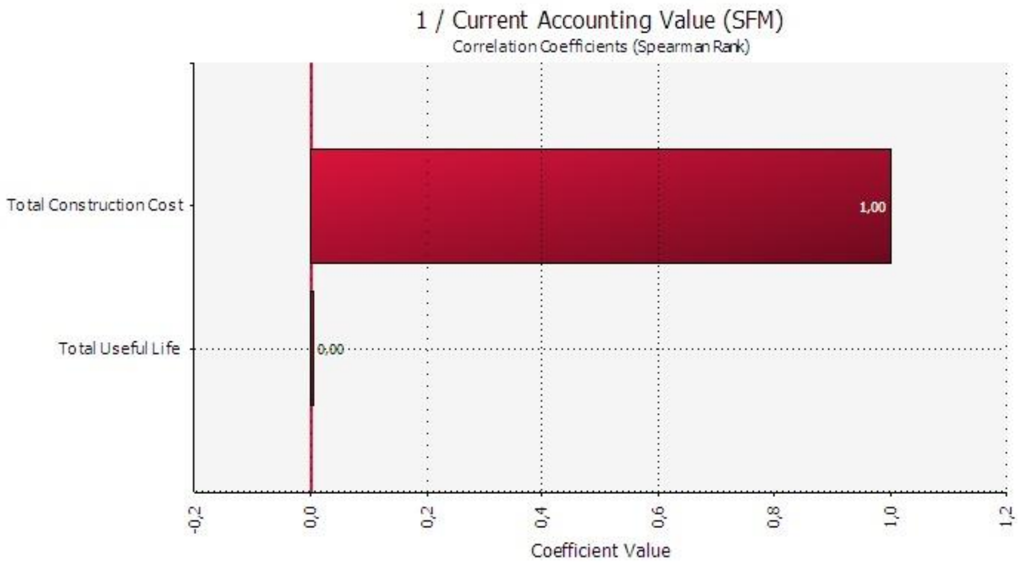

2 / Current Accounting Value (WDV)
783,3
836,5
5,0%
90,0%
5,0%
2,5
2,0
1,5
1,0
0,5
0,0
Values x 10^-5
100,0%
80,0%
60,0%
40,0%
20,0%
0,0%
770
780
790
800
810
820
830
840
850
860
870
Values in Thousands
2 / Current Accounting Value (WDV)
Minimum 776696,9771
Maximum 862766,5075
Mean 806701,0868
Std Dev 16336,7964
Values 10000


2 / Current Accounting Value (WDV)
Correlation Coefficients (Spearman Rank)
Total Construction Cost
1,00
Total Useful Life
0,00
-0,2
0,0
0,2
0,4
0,6
0,8
1,0
1,2
Coefficient Value

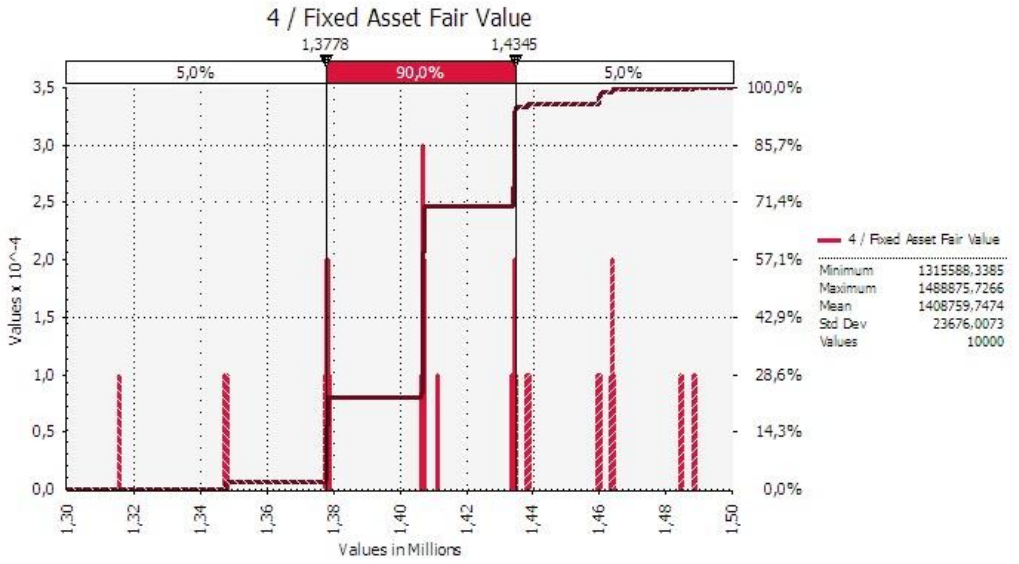

20 / Current Accounting Value (SYD)
237,05
244,88
5,0%
90,0%
5,0%
Values x 10^-4
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
100,0%
87,5%
75,0%
62,5%
50,0%
37,5%
25,0%
12,5%
0,0%
236
238
240
242
244
246
248
250
Values in Thousands
20 / Current Accounting Value (SYD)
Minimum 236085,7051
Maximum 248760,5161
Mean 240490,5089
Std Dev 2402,9939
Values 10000

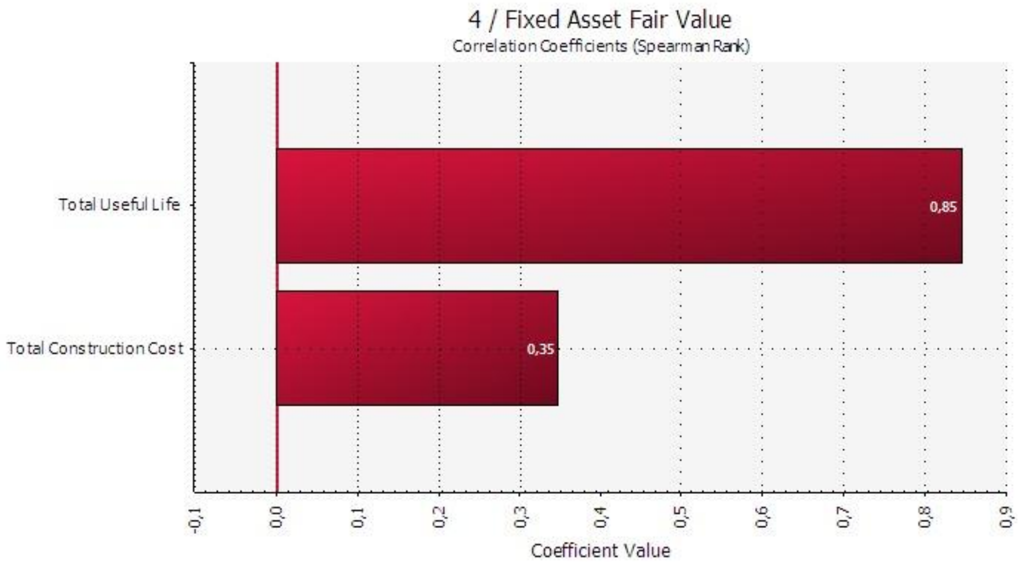

20 / Current Accounting Value (SYD)
Correlation Coefficients (Spearman Rank)
Total Construction Cost
Total Useful Life
1,00
0,00
-0,2
0,0
0,2
0,4
0,6
0,8
1,0
1,2
Coefficient Value

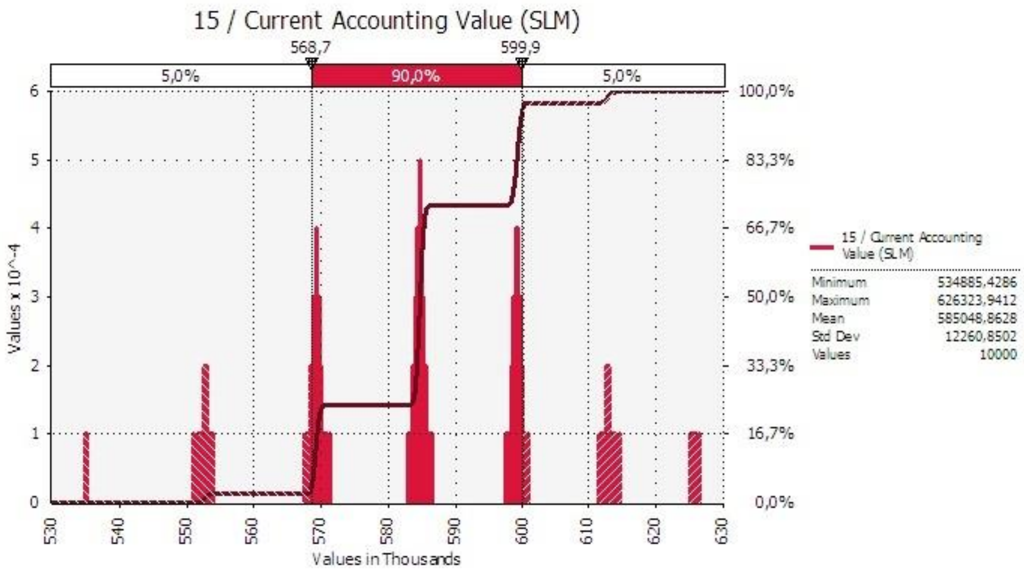

1 / Current Accounting Value (SFM)
0,9165
0,9851
5,0%
90,0%
5,0%
Values x 10^-5
1,8
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
100,0%
88,9%
77,8%
66,7%
55,6%
44,4%
33,3%
22,2%
11,1%
0,0%
0,90
0,92
0,94
0,96
0,98
1,00
1,02
Values in Millions
1 / Current Accounting Value (SFM)
Minimum 908047,8624
Maximum 1019077,3599
Mean 946636,5032
Std Dev 21050,5041
Values 10000

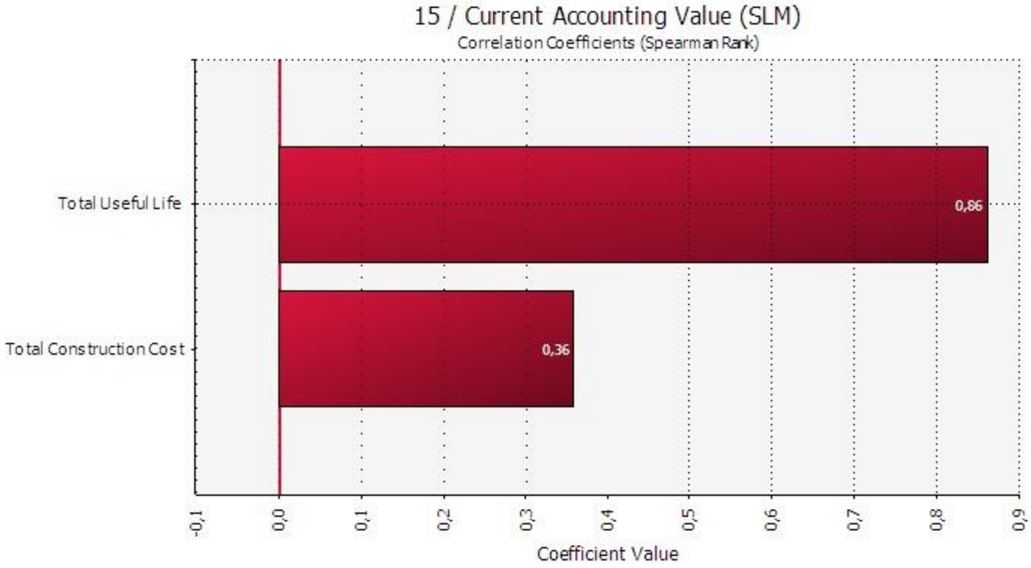

1 / Current Accounting Value (SFM)
Correlation Coefficients (Spearman Rank)
Total Construction Cost
Total Useful Life
1,00
0,00
-0,2
0,0
0,2
0,4
0,6
0,8
1,0
1,2
Coefficient Value

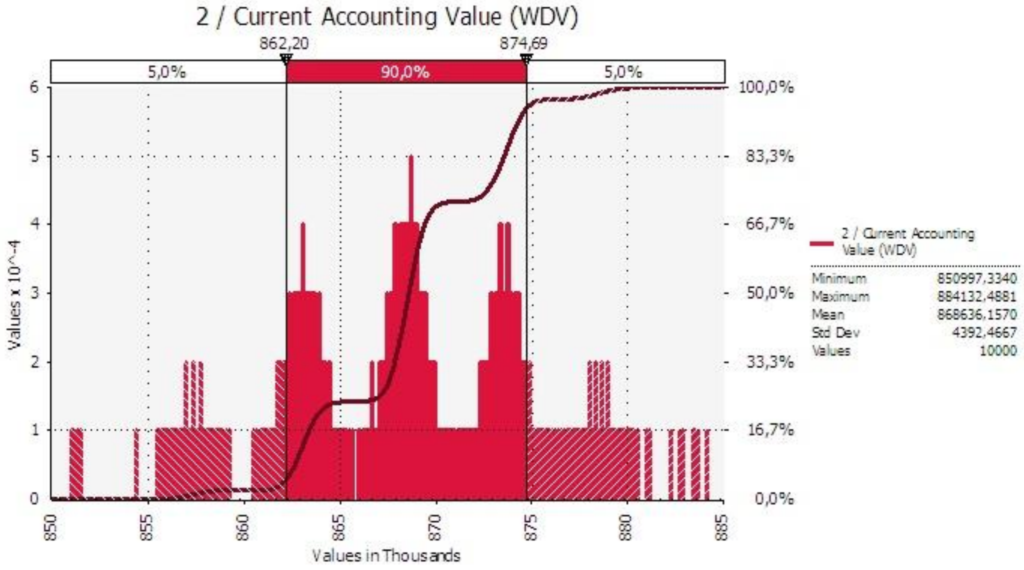
Poisson

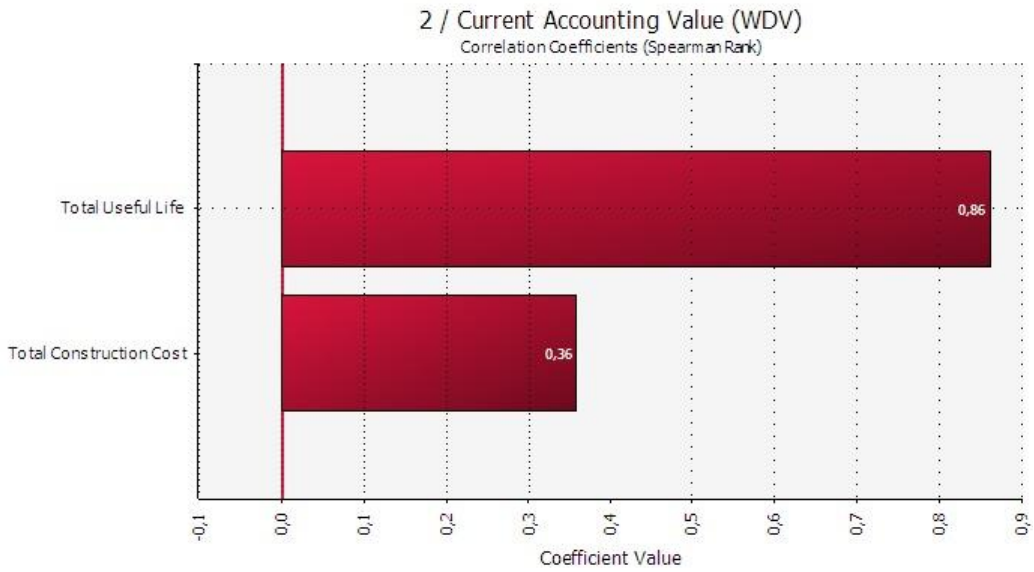

4 / Fixed Asset Fair Value
1,3778
1,4345
5,0%
90,0%
5,0%
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
Values x 10^-4
100,0%
85,7%
71,4%
57,1%
42,9%
28,6%
14,3%
0,0%
1,30
1,32
1,34
1,36
1,38
1,40
1,42
1,44
1,46
1,48
1,50
Values in Millions
4 / Fixed Asset Fair Value
Minimum 1315588,3385
Maximum 1488875,7266
Mean 1408759,7474
Std Dev 23676,0073
Values 10000

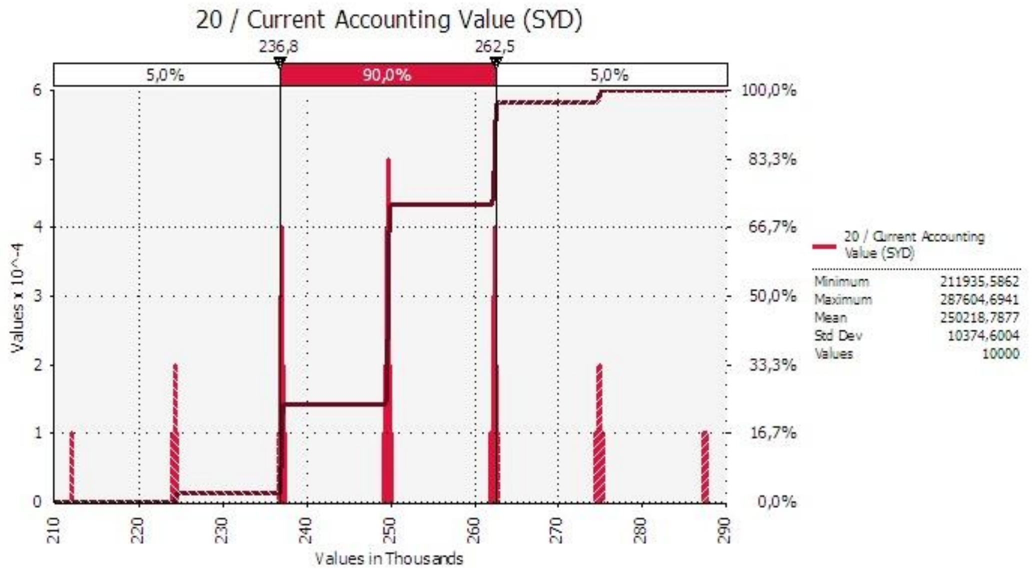

4 / Fixed Asset Fair Value
Correlation Coefficients (Spearman Rank)
Total Useful Life
Total Construction Cost
0,85
0,35
-0,1
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
Coefficient Value

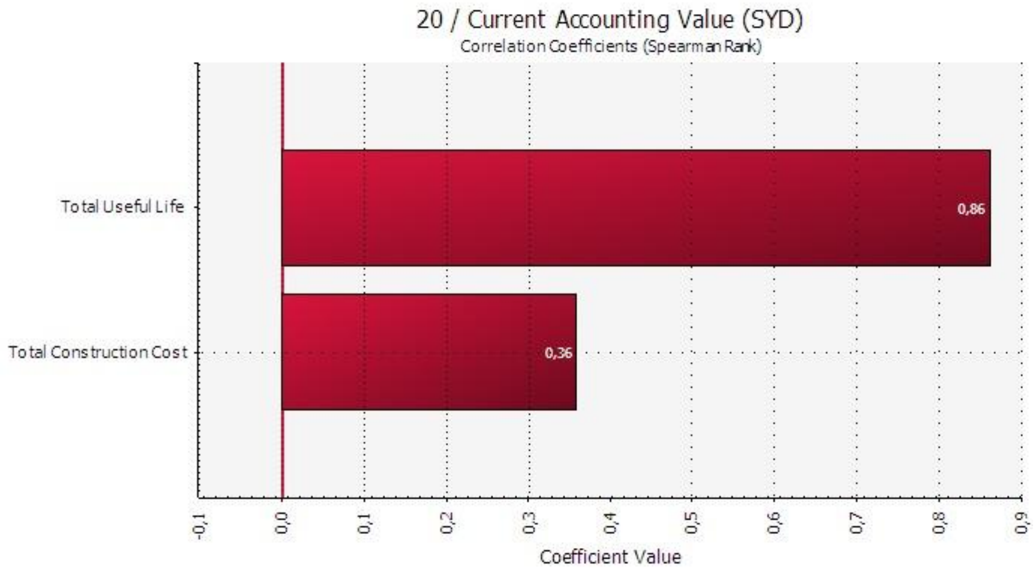

15 / Current Accounting Value (SLM)
568,7
599,9
5,0%
90,0%
5,0%
Values x 10^-4
0
1
2
3
4
5
6
0,0%
16,7%
33,3%
50,0%
66,7%
83,3%
100,0%
530
540
550
560
570
580
590
600
610
620
630
Values in Thousands
15 / Current Accounting Value (SLM)
Minimum 534885,4286
Maximum 626323,9412
Mean 585048,8628
Std Dev 12260,8502
Values 10000

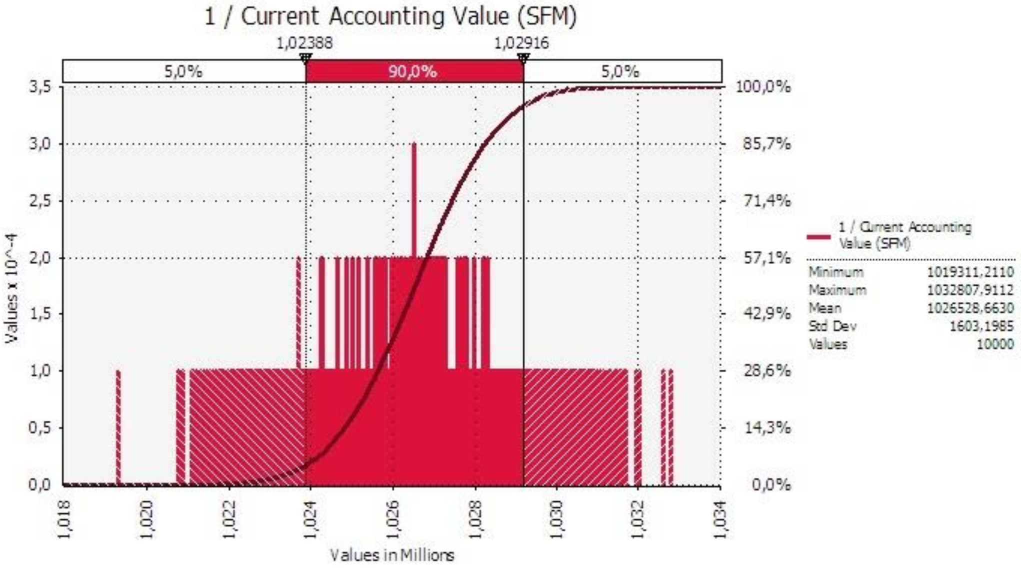

15 / Current Accounting Value (SLM)
Correlation Coefficients (Spearman Rank)
Total Useful Life
0,86
Total Construction Cost
0,36
-0,1
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
Coefficient Value

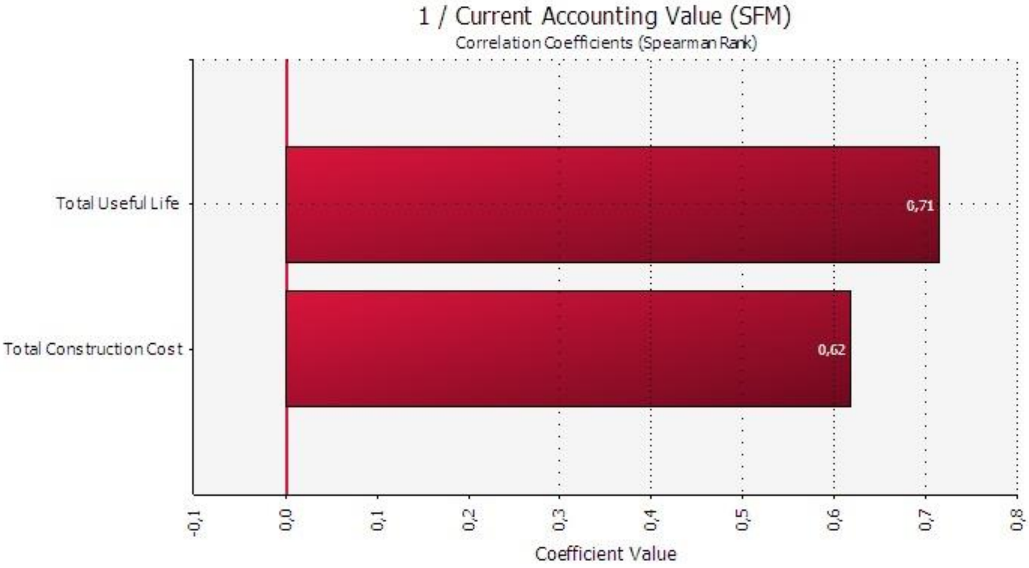

2 / Current Accounting Value (WDV)
862,20
874,69
5,0%
90,0%
5,0%
Values x 10^-4
0
1
2
3
4
5
6
0,0%
16,7%
33,3%
50,0%
66,7%
83,3%
100,0%
850
855
860
865
870
875
880
885
Values in Thousands
2 / Current Accounting Value (WDV)
Minimum 850997,3340
Maximum 884132,4881
Mean 868636,1570
Std Dev 4392,4667
Values 10000


2 / Current Accounting Value (WDV)
Correlation Coefficients (Spearman Rank)
Total Useful Life
Total Construction Cost
0,86
0,36
-0,1
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
Coefficient Value


20 / Current Accounting Value (SYD)
236,8
262,5
5,0%
90,0%
5,0%
6
5
4
3
2
1
0
Values x 10^-4
100,0%
83,3%
66,7%
50,0%
33,3%
16,7%
0,0%
210
220
230
240
250
260
270
280
290
Values in Thousands
20 / Current Accounting Value (SYD)
Minimum 211935,5862
Maximum 287604,6941
Mean 250218,7877
Std Dev 10374,6004
Values 10000


20 / Current Accounting Value (SYD)
Correlation Coefficients (Spearman Rank)
Total Useful Life
Total Construction Cost
0,86
0,36
-0,1
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8
0,9
Coefficient Value





6.4 Proposed Methodology Flow-Chart

The proposed in this Ph.D. thesis integrated project management whole-life methodology towards more effective project cost management in construction is further schematically described in the following *flow-chart* (Figure 6.4, page 379). The developed management processes (as extensively presented in Chapters 4, 5 and 6) cover both the early stage and physical construction time-discrete phases of the construction production process as well as the useful life of the constructed fixed asset.

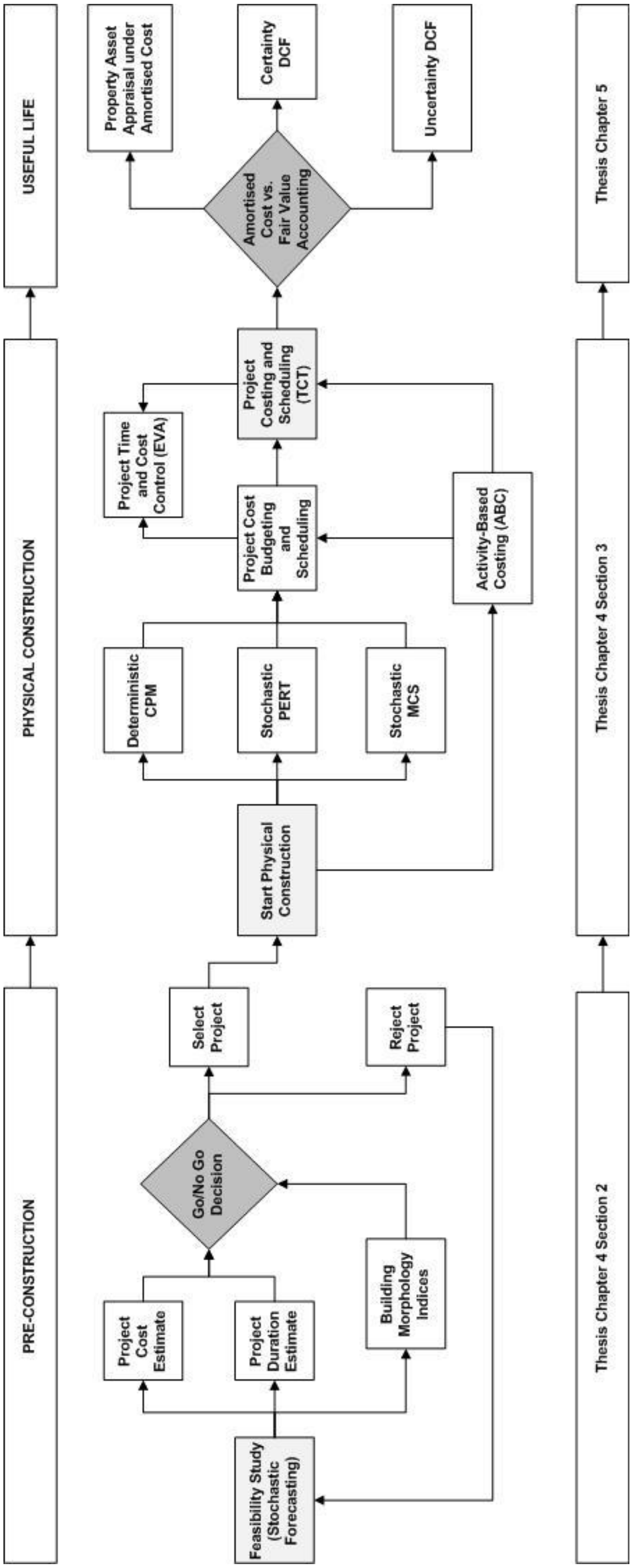


Fig. 6.4 Cost Management Integrated and Whole-Life Methodology *Flow-Chart*

CHAPTER 7

EPILOGUE

7.1 Discussion

Nowadays, the construction industry faces challenges on a scale it has not encountered before. This happens mainly due to the (sophisticated) clients' increasing demands for modern large and complex projects and the high speed with which they are expected to be delivered. Building clients have long been complaining for the discrepancies between tender prices and final accounts while the industry at large has come to accept that such variations are the norm. Future difficulties to the progress of projects cannot always be foreseen; nonetheless, uncertainty issues should be built into the project plan from the beginning, and kept under control as the project evolves. This can be facilitated through up to date and reliable information at project initiation and keeping close review over all critical aspects as the production work proceeds. Despite the considerable attention by both researchers and practitioners, the process of evaluating, planning and scheduling of construction projects still presents inefficiencies and potential for improvement. The importance of effective cost and time management in securing the completion of projects within the approved budgets and contract deadlines is paramount. The network-based CPM deterministic modelling of construction operations still dominates the industry by providing an easy to understand conceptual and computational estimating, budgeting and control useful framework. Nevertheless, a shift to the wider application of probabilistic approaches to construction management (beyond traditional PERT) should be strongly encouraged, considering today's availability of a number of Monte Carlo simulation/ optimisation software packages for stochastic solutions to time-cost trade-off problems.

The fact that traditional methods are simplistic is beyond doubt since they rest upon the static assumption that ‘everything else remains constant’ or *ceteris paribus*; this is an assumption that is virtually never true (Emblemsvåg, 2003). Therefore, instead of estimating one single input variable’s impact, one could vary all the critical variables, store the results, and perform a statistical analysis at the end. Thus, a virtual experiment is performed: the computer picks random numbers for the input (independent) variables and calculates the results of the corresponding output (forecast) variables. Monte Carlo simulation modelling enables construction managers to concentrate on tackling the *actual* problem and not just solving mathematical formulations of unrealistic possible scenarios. In order to assist managers in decision-making, cost forecasting should be reliable and covering all actual possible alternatives instead of deterministic ‘best-guess’ estimates. Conventional methods often attempt to ignore risk and uncertainty. On the other hand, quantitative risk analysis recognises the endemic uncertainty in construction management and allows all parties involved to better understand project risks and the probability of actual costs exceeding the baseline budget estimate. Project managers can use quantitative risk analysis to decide on the project budget and to estimate final budget at completion, by assigning *probability distributions* to the project costs. These estimates are normally produced by a project cost expert, and the final product is a probability distribution of the final total project cost. This distribution can assist in setting aside a project budget reserve, to be used when contingency plans are necessary to respond to risk events.

In years past, there were arguments between those who insisted that project management was primarily a *quantitative science* and those who believed it was a *social science*. Nowadays, it has become clear that projects cannot be adequately managed without depending heavily on *both* mathematics and human behaviour. To contend that mathematics is exact and that social science is *mushy* is to ignore the high level of subjectivity in the numeric estimates made about time, cost and uncertainty associated with projects. On the other hand, to assert that *'people don't really use that mathematical stuff'* is to substitute wishful thinking for reality (Meredith and Mantel, 2012). The goal therefore should not be to imitate the optimum solutions produced by mathematical programming but rather to produce schedules which are valuable to practising project managers as a reliable basis for decision-making.

However, management techniques are not a substitute for effective project management and should not be seen as the *panacea* for all the ills of construction management; they merely assist managers to operate more effectively. 'Techniques rely on solid analytical logic, but one will not get far in business if one relies solely on this. On the other hand, there is no place for flair inside these techniques. The position is probably this: many of these techniques are valuable as tools of analysis, they can be used to probe causes, identify relationships, to quantify and enumerate' (Argenti, 1969). Thus, techniques form the analytical part of management but this is only the first stage. One then needs to propose a solution and so construction managers must rely on *flair* and *expert judgment* to solve a problem once it has been analysed. The mixture of analysis and more personal skills is essential for effective management of construction.

Perhaps the most important knowledge concerning any cost modelling approach is an understanding of its limitations within the context of its use. The simplifications inherent in the creation of construction cost management models in particular should not be ignored. For any cost modelling exercise the achievable level of accuracy will depend on the level of understanding of the problem under study, the completeness and reliability of the information relating to the cost-driving critical variables, and the quality of the cost model itself. The desirable level of accuracy is that which is sufficient to ensure a correct decision-making process. Kirkham (2015) argued that in spite of the considerable amount of research work that has been carried out in the Universities in developing models during the past 30 years, few if any of them have had any impact on the practice of cost planning in the real world.

It is obviously essential that project management should realise the source and magnitude of *life-time costs* so that effective control actions can subsequently be taken. This holistic approach encourages a long-term view to the investment project decision-making process rather than attempting to save money in the short-term by delivering built products simply with lower initial construction cost. Building clients should then be concerned not only with the quality of the finished product but also with the cost of construction itself. Since operation and maintenance of a constructed facility is a part of the product life-cycle, the owners' expectation to satisfy investment project objectives during the useful life requires consideration of the operation and maintenance costs at the early stages of planning and programming.

7.2 Conclusions

Construction industry is a project-oriented industry. Capital projects are usually complex undertakings, requiring significant management skills, co-ordination of a wide range of human resources with different expertise and ensuring completion within the parameters of time, cost and value and contract specifications. Construction complexity, therefore, can no longer be ignored and both construction management *paradigms* and *practice* should be redefined and improved accordingly.

The construction process can be analysed in two time-discrete phases: a *construction project production* period which is further subdivided into *pre-construction* and *physical construction*; and a *product useful life* period whereas the constructed facility is occupied, operated and maintained by the owner.

The analysis of the *pre-construction* initial phase of building projects and specifically the calculations of the different building morphology complexity indices and their effect to building project economics, indicates that only 7 out of 252 coefficient calculations and 5 out of the total 36 Greek building projects of the sample meet the optimum criteria as these have long been suggested by the relevant literature. The above results reveal a strong need for an emphasis to be given by both clients and consultants operating within the Greek construction industry to develop more economical design proposals at early stage project decisions.

From the study of the relationship between project completion time, project total cost and the town planning restrictions and geometric characteristics of buildings, the following linear regression equations were produced:

$(\text{cost\_tot}) = -1069{,}529 + 3{,}616 * (\text{dur\_tot})$

$(\text{dur\_tot}) = 332{,}109 + 0{,}214 * (\text{cost\_tot})$

$(\text{cost\_tot}) = 20{,}778 + 0{,}746 * (\text{gross\_tot}) + 23{,}101 * (\text{st\_ag})$

$(\text{dur\_tot}) = 346{,}175 + 0{,}168 * (\text{gross\_tot})$

$(\text{cost\_m2}) = 1074{,}448 - 0{,}169 * (\text{env\_tot})$

$(\text{cost\_m3}) = 323{,}091 - 0{,}276 * (\text{cov\_area})$

$(\text{cost\_day}) = 299{,}317 + 0{,}656 * (\text{gross\_tot}) + 0{,}533 * (\text{env\_tot})$

Obviously, the usefulness of regression models depends on their accuracy and reliability. The derived mathematical formulas need to be tested on new ‘fresh’ data before they can be used for decision-making, in order to avoid misleading judgments.

From the Monte Carlo simulation analyses (using four different probability distribution functions) of the *physical construction* process for an actual commercial building, it is found that the most significant work packages/elements for project duration are the reinforced concrete structural frame, the colourings and the surrounding area works; in the case of the direct cost of the project, the most critical work packages/elements are (again) the reinforced concrete structural frame and the installation of boilers, panels and fan-coils. From the quantitative risk analysis performed on the aforementioned actual building project, in order to assess the effect of potential risks and opportunities to project duration and direct cost, it is concluded that for project duration the excavations work package/element is the most significant whilst for project direct cost it is the reinforced concrete structural frame. Finally, there is evidence that the choice of using the *Poisson* probability distribution function might be a reliable alternative to other distributions (*uniform*, *triangular* and *PERT*) typically used in stochastic construction scheduling. The use of probability distributions in cost/schedule risk analysis is a much more realistic way of incorporating variables' uncertainty in the models; variables then can have different probabilities of different outcomes occurring.

The *optimisation* of the construction project time-cost relationship (time-cost trade-off) can be of great significance to the clients in highlighting the effect of 'crashing' the work for early project completion on the maximisation of their capital investment (even though the initial direct cost is increased). Having accepted the above importance, it should be emphasised that the main difficulty with achieving an acceptable reliability level when applying time-cost trade-off techniques lies in the accuracy and reliability of data related to the additional (crash) costs for speeding-up the critical work activities. Hence, an immediate necessity arises for construction managers to collect accurate and relevant resource consumption data from historical projects, if time-cost trade-off results are to be used as a sound basis for decision-making.

The Greek construction industry is operating today in an unstable economic framework; as a result, the effect on project profitability and success of changes in critical variables which are used in *whole-life appraisal* of building projects (i.e. taxation rates, financing schemes, revenue/cost market prices) restrains any capital investments in construction.

Depreciation, as an accounting practice, follows the same point of view with life-cycle costing methodology. Thus, depreciation and *fair value* accounting methods following life-cycle costing are facing the same problem, the *time value* of built assets. The results from the empirical analyses presented in the thesis indicate that for building projects the most appropriate method of depreciation is the *sinking fund* method which is based on a financial approach to depreciated assets only when the fixed asset is profitable.

From the analysis of the effect of time-cost trade-off decisions during the construction process on the building project whole-life appraisal and valuation, it is found that extended useful life is more significant than increased direct cost when fully 'crashing' a project.

7.3 Contribution

'Better tools are needed to manage risk and uncertainty and to develop more rigorous system thinking approaches' (Flanagan, 2014:295).

This doctoral thesis develops a conceptual integrative project management whole-life methodology for construction projects. In spite of the appearance of a number of studies which combine building technology with economic concepts, most of them seem to be macro-oriented and directed towards theoretical analysis rather than suggesting solutions to real management problems. The research project attempts to fill this practice gap with the development of consistent and comprehensive management models derived from the basic theoretical approaches to the subject. Moreover, while there have been several previous attempts which deal with the time-discrete systems of construction project production and built asset useful life separately, to the writer's knowledge there is no other research work which has tried to *holistically* and *stochastically integrate* them in a logical and theoretical but still practical way.

Therefore, from both theoretical and practical perspectives, the main contribution of the thesis to the field of construction management is the development of an automated probabilistic mechanism for the *pre-construction*, *physical construction* and *useful life* periods in a project's whole-life cycle in order to assist in early stage project time and cost estimating and forecasting, investment project appraisal and selection, construction production scheduling, budgeting, control and project duration-direct cost optimisation, and constructed product's fair and amortised (depreciated) accounting valuation.

Cost management for construction projects should not be seen as a fragmentation of individual phases, systems and techniques, but rather as an integrated procedure over the built product's whole-life cycle. There is a strong need to shift from the traditional deterministic stance, where cost management is based upon 'single-figure' estimates, to a closer representation of reality in which variability issues are explicitly considered. The important point is that the early start of using Monte Carlo simulation provides an objective and scientific approach to deal with project uncertainty that allows for more accurate results in predicting a project's completion duration and associated final cost.

From the analysis of the capital requirements of the project, the owners (developers) can assess the net contribution of the investment to their equity and the effects of potential changes in the cost and value of main decision parameters and financing schemes.

It is therefore believed that the research will bring about an original contribution to the topic of cost management of construction projects and to assist construction clients, contractors and consultants in improving the effectiveness of managerial decision-making towards the delivery of more successful built products.

As project managers, planners and estimators are all involved in project planning, the content of this thesis is highly relevant to them as well as being relevant to senior management in construction organisations.

7.4 Future Directions

The thesis assumes a linear work package/element time-cost relationship for solving the time-cost trade-off problem. If time-cost profiles are linear, then finding the optimal duration of the project is a linear programming problem. In construction production, in most cases there is a *discrete* (no straight-linear) relationship between time and cost. This demands for a non-linear programming problem for which the definition of an algorithm based on heuristics is required. The discrete time-cost trade-off problem will be addressed by the writer in future research work.

In addition, there is a strong need in the construction industry for the development of ‘ideal’ time-cost equations to modelling the relationship between actual work duration and associated direct cost of work execution for different activities of the project work packages/elements and different types of projects. The writer is already in the process of collecting relevant historical construction project data together with *expert judgment* estimates from construction professionals, in order to deal with the above aspect at a reasonable level of accuracy. However, a useful basis for quick time-cost profile selection might be *Pareto’s Law of Distribution* which suggests that 20% of the constituents of a system account for 80% of its cost, as is the case in most *bills of quantities*.

Under conditions of uncertainty, there is a fundamental reason that the use of the *max*-NPV criterion for project selection should be questioned. NPV assumes that either an investment is reversible or, if the investment is irreversible, it is a ‘take it or leave it’ decision. However, a client with an *opportunity cost* to invest is holding an ‘option’. By making irreversible investment expenditures, clients lose their option to invest and give up the possibility of receiving new information in the future that might affect the timing or desirability of the expenditure. This lost option value represents an opportunity cost that must be included in the whole-life costing calculations as part of the investment cost.

Therefore, a future research direction might be the incorporation of *real options* theory to the integrated construction project management whole-life methodology proposed by the herein presented research work.

Finally, the research effort made so far to the construction project whole-life appraisal and selection problem has not taken into account any *externalities* i.e. positive, like public health and safety improvement and other social benefits or negative, like environmental pollution, traffic congestion or other social costs. The analysis and evaluation of these external costs and benefits is beyond the scope of this research project and will be addressed by the writer in future work.

This page intentionally left blank

REFERENCES

@RISK Guide (2009) *Guide to Using @RISK Version 5.5: Risk Analysis and Simulation Add-in for Microsoft Excel*, Palisade Corporation, New York.

AACEI (2006) *Total Cost Management Framework: An Integrated Approach to Portfolio, Program and Project Management*, International Association for the Advancement of Cost Engineering, AACEI, Holman, J.K. (ed.), Morgantown, WV.

AbouRizk, S.M., Knowles, P. and Hermann, U.A. (2001) 'Estimating labour production rates for industrial construction activities', *Journal of Construction Engineering and Management*, **127**(6), 502-511.

Ackoff, R.L. (1969) *A concept of corporate planning*, Wiley-Interscience, New York.

Adeli, H. and Karim, A. (1997) 'Scheduling/cost optimisation and neural dynamics model for construction', *Journal of Construction Engineering and Management*, ASCE, **123**(4), 450-458.

Adrian, J.J. (1979) *Construction Accounting*, Reston Publications, Reston, VA.

Ahuja, H.N. and Walsh, M.A. (1983) *Successful Cost Engineering*, Wiley, New York.

Ahuja, V. and Thiruvengadam, V. (2004) 'Project scheduling and monitoring: current research status', *Construction Innovation*, **4**(1), 19-31.

Aibinu, A.A. and Pasco, T. (2008) 'The accuracy of pre-tender building cost estimates in Australia', *Construction Management and Economics*, **26**(12), 1257-1269.

AIQS (2016) *What is a QS?*, The Australian Institute of Chartered Surveyors, AIQS Website, http://www.aiqs.com.au/ (accessed 20 June 2015).

Ajator, U.O., Ugochukwu, S. and Ogunsina, O. (2015) 'Modelling the Relationship of Architectural and Structural Design Variables for Estimating Substructure Cost of Duplexes', *Civil and Environmental Research*, **7**(2), 61-70.

Akintoye, A. (2000) Analysis of factors influencing project cost estimating practice, *Construction Management and Economics*, **18**(1), 77-89.

Al-Barak, A.A. (1993) *Causes of contractors' failures in Saudi Arabia*, M.Sc. thesis, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia.

Al-Hajj, A. (1991) *Simple cost-significant models for total life-cycle costing in buildings*, Ph.D. thesis, Department of Civil Engineering, University of Dundee, Dundee.

Al-Hajj, A. and Horner, M.W. (1998) 'Modelling the running costs of buildings', *Construction Management and Economics*, **16**, 459-470.

Al-Hammad, A. (1993) 'Factors affecting the relationship between contractors and their sub-contractors in Saudi Arabia', *Building Research and Information*, **21**(5), 269-273.

Al-Issa, A. and Zayed, T. (2007) 'Projects cash flow factors-contractor perspective', *Construction Research Congress (CRC) Conference*, ASCE, Bahamas, May 5-8.

Al-Jibouri, S.H. (2003) ‘Monitoring systems and their effectiveness for project cost control in construction’, *International Journal of Project Management*, **21**, 145-154.

Allmon, E., Haas, C.T., Borcherding, J.D. and Goodrum, P.M. (2000) ‘U.S. construction labour productivity trends 1970-1998’, *Journal of Construction Engineering and Management*, ASCE, **126**(2), 97-104.

Al-Sudairi, A.A. (2008) ‘Activity-Based Costing (ABC) Analysis in Design Processes’, *Proceedings of Design Management in the Architectural Engineering and Construction Sector*, 321-329.

Anand, M., Sahay, B.S. and Saha, S. (2005) ‘Cost Management Practices in India: An Empirical Study’, *ASCI Journal of Management*, **33**(1&2), 1-15.

Anderson, D.R., Sweeney, D.J., Williams, T.A., Camm, J.D., Cochran, J.J., Fry, M.J. and Ohlmann, J.W. (2013) *Quantitative Methods for Business*, 12th ed., Cengage Learning.

Arditi, D., Akan, G. and Gurdamar, S. (1985) ‘Reasons for delays in public projects in Turkey’, *Journal of Construction Management and Economics*, **3**(2), 171-181.

Aretoulis, G., Angelides, D., Kalfakakou, G., Fotiadis, G. and Anastasiadis, K. (2006) ‘A prototype system for the prediction of final cost in construction projects’, *Operational Research*, 08/2006, **6**(3), 323-332.

Argenti, J. (1969) *Management Techniques: A Practical Guide*, Allen & Unwin, London.

Artto, K.A., Lehtonen, J.-M. and Saranen, J. (2001) ‘Managing projects front-end: incorporating a strategic early view to project management with simulation’, *International Journal of Project Management*, **19**(5), 255-264.

Ashworth, A. (2004) *Cost Studies of Buildings*, 4th ed., Pearson Education Ltd., Harlow Essex.

Ashworth, A. and Skitmore, R.M. (1983) *Accuracy in Estimating*, Occasional Paper No.27, Englemere, Chartered Institute of Building, ISBN 0-906600-57-X.

Ashworth, A., Hogg, K and Higgs, C. (2013) *Willis’s Practice and Procedure for the Quantity Surveyor*, Wiley-Blackwell, Chichester.

Assaf, S.A. and Al-Hejji, S. (2006) ‘Causes of delay in large construction projects’, *International Journal of Project Management*, **21**(4), 349-357.

Assaf, S.A., Bubshait, A.A., Atiyah, S. and Al-Shahri, M. (2001) ‘The management of construction company overhead costs’, *International Journal of Project Management*, **19**, 295-303.

Assaf, S.A., Kalil, M. and Al-Hazmi, M. (1995) ‘Causes of delay in large building construction projects’, *Journal of Management in Engineering*, **11**(2), 45-50.

Atkinson, R. (1999) ‘Project management: cost, time and quality, two best guesses and a phenomenon, it’s time to accept other success criteria’, *International Journal of Project Management*, **17**(6), 337-342.

Baccarini, D. (1996) ‘The concept of project complexity – a review’, *International Journal of Project Management*, **14**(4), 201-204.

Back, E., Maxwell, D. and Isidore, L. (2000) 'Activity-Based Costing as a tool for process improvement evaluations', *Journal of Management in Engineering*, March/April, **16**(2), 43-58.

Baldwin, A. and Bordoli, D. (2014) *A Handbook for Construction Planning and Scheduling*, Wiley Blackwell, United Kingdom.

Baloi, D. and Price, A.D.F. (2003) 'Modelling global risk factors affecting construction cost performance', *International Journal of Project Management*, **21**, 261-269.

Banerjee, S. (2014) *Mathematical Modelling: Models, Analysis and Applications*, CRC Press, Taylor and Francis Group.

Banks, D.G. (1974) 'Uses of a length/breadth index and a plan shape ratio', *Building and Quantity Surveying Quarterly*, **2**(1).

Bashford, H.H. (1996) 'Small business in the construction industry', *Practice Periodical on Structural Design and Construction*, **1**(3), 71-73.

BCIS (2012) *Elemental Standard Form of Cost Analysis – Principles, Instructions, Elements and Definitions*, 4th (NRM) ed., RICS Building Cost Information Service (BCIS), London.

Belniak, S., Lesniak, A., Plebankiewicz, E. and Zima, K. (2013) 'The influence of the building shape on the costs of its construction', *Journal of Financial Management of Property and Construction*, Emerald, **18**(1), 90-102.

Bennett, F.L. (2003) *The Management of Construction: A Project Life Cycle Approach*, Butterworth-Heinemann, Oxford.

Bennett, J. (1991a) *International Construction Project Management: General Theory and Practice*, Butterworth-Heinemann, Oxford.

Bennett, J. and Ormerod, R.N. (1984) 'Simulation applied to construction projects', *Construction Management and Economics*, **2**, 225-263.

Bennett, R. (1991b) 'How is Research Carried out?' in Smith, N.C. and Dainty, P. (eds), *The Management Research Handbook*, Routledge, London.

Bertalanffy, L.V. (1951) 'General System Theory: A New Approach to Unity of Science', *Human Biology*, December, 303-361.

Bertelsen, S. (2003a): 'Complexity - Construction in a new Perspective', *Proceedings of IGLC-11*, Blacksburg, Virginia, 39-50.

Bertelsen, S. (2003b) 'Construction as a complex system', *Proceedings of IGLC-11*, Blacksburg, Virginia, 11-23.

Betts, M. (1992) 'Financial control of public- and private-sector construction projects in Singapore', *International Journal of Project Management*, **10**(1), 3-10.

Bon, R. (1989) *Building as an Economic Process*, Routledge, London.

Borison, A. (2003) 'Real Options Analysis: Where are the Emperor's Clothes?', *Real Options Conference*, Washington D.C., July.

Borland, J. (2001) ‘Cost, schedule and resource control’, available at: http://www.Calpoly.edu/jborland.

Boulding, K.E. (1956) ‘General systems theory: the skeleton of science’, *Management Science*, 2, 197-208.

Bowen, P.A. and Edwards, P.J. (1985) Cost modelling and price forecasting: practice and theory in perspective, *Construction Management and Economics*, **3**, 199-215.

Brandon, P. and Newton, S. (1986) Improving the forecast, *Chartered Quantity Surveyor*, May, 24-26.

Brandon, P.S. (1978) ‘A Framework for Cost Exploration and Strategic Cost Planning in Design’, *Chartered Surveyor Building and Quantity Surveying Quarterly*, **5**(4), 60-63.

BRE (2004), *Whole Life Costing Fact Sheet*, Building Research Establishment Ltd, Centre for Whole Life Construction and Conservation, Watford.

Brealey, R.A. and Myers, S.C. (2002) *Financing and Risk Management*, McGraw-Hill.

Brealey, R.A., Myers, S.C. and Allen, F. (2014) *Principles of Corporate Finance*, 11th ed., McGraw-Hill/Irwin.

Briscoe, J. (1988) *The Economics of the Construction Industry*, CIOB, Construction Technology and Management, B.T. Batsford Ltd., London.

Brock, H.R., Herrington, L.A. and Ramey, L.V.G. (2007) *Cost accounting: Principles and Applications*, 7th ed., McGraw-Hill.

Brook, M. (2008) *Estimating and Tendering for Construction Work*, 4th ed., Elsevier, Oxford.

Brown, L. (ed.) (2002) *Shorter Oxford English dictionary on historical principles*, Oxford University Press, New York.

Brucker, P., Drexl, A., Möhring, R., Neumann, K. and Pesch, E. (1999) ‘Resource-constrained project scheduling: notation, classification, models and methods’, *European Journal of Operational Research*, **112**(1), 3-41.

Bryman, A. and Bell, E. (2003) *Business Research Methods*, Oxford University Press.

BSI (2008) *BS ISO 15868-5:2008 Building and Constructed Assets – Service Life Planning; Part 5 – Life Cycle Costing*, British Standards Institution, London.

BSI (2010) *BS ISO 6079-2 Guide to Project Management*, British Standards Institution, London.

Bull, J.W. (1993) ‘The way ahead for life cycle costing in the construction industry’, in Bull, J.W. (ed.), *Life Cycle Costing for Construction*, Blackie Academic & Professional, Glasgow.

Burke, R. (2003) *Project management: planning & control techniques*, 4th ed., John Wiley & Sons, Chichester, UK.

Burns, S.A., Liu L. and Feng, C.W. (1996) ‘The LP/IP hybrid method for construction time-cost trade-off analysis’, *Construction Management and Economics*, **14**(3), 265-276.

Callahan, K.R., Stetz, G.S. and Brooks, L.M. (2007) *Project Management Accounting*, John Wiley & Sons, Hoboken, New Jersey.

Carr, R.I. (1989) ‘Cost-estimating principles’, *Journal of Construction Engineering and Management*, **115**(4), December, 545-551.

Cartlidge, D. (2012) *Quantity Surveyor*’*s Pocketbook,* 2nd ed., Routledge.

Cartlidge, D. (2015) *Construction Project Manager’s Pocket Book*, Routledge.

Centre for Strategic Studies in Construction (1988) *Building Britain 2000 Report*, University of Reading, United Kingdom.

CGMA (2015) *Global Management Accounting Principles – Effective management accounting: improving decisions and building successful organisations*, Chartered Global Management Accountant (CGMA), published by the Association of International Certified Professional Accountants (AICPA) and the Chartered Institute of Management Accountants (CIMA), December.

Chan, D.W.M. and Kumaraswamy, M.M. (1997) A comparative study of causes of time overruns in Hong Kong construction projects, *International Journal of Project Management*, **15**(1), 55-63.

Chan, S.L. and Park, M. (2005) Project Cost Estimation Using Principal Component, *Construction Management and Economics*, **23**(2), 295-304.

Charnes, J. (2007) *Financial Modelling with Crystal Ball and Excel*, Wiley Finance.

Chase, R.B., Jacobs, F.R. and Aquilano, N.J. (2003) *Operations Management for Competitive Advantage*, 10th ed., McGraw-Hill, Boston.

Chassiakos, A.P. and Sakellaropoulos, S.P. (2005) Time-cost optimization of construction projects with generalized activity constraints, *Journal of Construction Engineering and Management*, **131**(10), 1115-1124.

Chau, K.W. (1999) ‘On the Issue of Plan Shape Complexity: Plan Shape Indices Revisited’, *Construction Management and Economics*, **17**, 473-482.

Christensen, H.B. and Nikolaev, V.V. (2012) ‘Does fair value accounting for non-financial assets pass the market test?’, Working Paper No. 09-12, Booth School of Business, The University of Chicago, Chicago, IL.

Christian, J. and Kallouris, G. (1990) Predictive cost-time models for construction activities, *Proceedings of the CIB-90 International Symposium on Building Economics and Construction Management*, 14-21 March, **4**, 157-168.

Chua, D.K.H., Kog, Y.C., Loh, P.K. and Jaselskis, E.J. (1997) ‘Model for construction budget performance neural network approach’, *Journal of Construction Engineering and Management*, 123(33), 214-222.

Ciesielski, C.A. (2000) ‘ADCIC – automatic data collection in construction’, *presented in a Seminar given at the June 7th*, Haifa, Israel.

CIMA (2005) *Official Terminology*, 2005 ed., The Chartered Institute of Management Accountants, CIMA Publishing, Elsevier.

CIOB (2010) *Code of Practice for Project Management for Construction and Development*, 4th ed., Wiley Blackwell, Oxford, UK.

Cleland, D.I. and King, W.R. (1983) *Systems Analysis and Project Management*, 3rd ed., McGraw-Hill, Singapore.

CCF (2000) *A Client's Guide to Whole Life Costing*, Client's Construction Forum (CCF), London.

Clift, M. (2003) 'Life-cycle costing in the construction', UNEP Industry and Environment, September, 37-41.

Clough, H.R. (1986) *Construction Contracting*, 5th ed., John Wiley & Sons.

CMAA (2008) *Cost Management Procedures*, Construction Management Association of America, VA, USA.

Cokins, G. (1996) *Activity-based cost management – Making it work: a manager's guide to implementing and sustaining an effective ABC system*, McGraw-Hill.

Cokins, G. (1999) 'Using ABC to become ABM', *Journal of Cost Management*, **13**(1), 29-35.

Collis, J. and Hussey, R. (2009) *Business Research: A Practical Guide for Undergraduate and Postgraduate Students*, 3rd ed., Palgrave Macmillan.

Constructing Excellence (2003), *Fact Sheet: Whole Life Costing*, Constructing Excellence in the Built Environment, London.

Cooke, B. (2015) *Management of Construction Projects*, John Wiley & Sons, United Kingdom.

Cooke, B. and Jepson, W.B. (1979) *Cost and Financial Control for Construction Firms*, Macmillan.

Cooper, D., Grey, S., Raymond, G. and Walker, P. (2005) *Project Risk Management Guidelines: Managing Risk in Large Projects and Complex Procurements*, Wiley.

Cooper, R. (1990) 'Implementing an activity-based cost system', *Journal of Cost Management*, Spring, 33-42.

Copeland, T. and Weiner, J. (1990) 'Proactive management of uncertainty', *McKinsey Quarterly*, **4**, 133-152.

Creswell, J.W. (2003) *Research Design: qualitative, quantitative, and mixed methods approaches*, 2nd ed., SAGE Publications.

Cunningham, T. (2013) *Factors Affecting the Cost of Building Work – An Overview*, Dublin Institute of Technology.

Cunningham, T. (2014) *The Work and Skills Base of the Quantity Surveyor in Ireland – An Introduction*, Dublin Institute of Technology.

Cusack, M.M. (1984) 'The use and limitations of mathematical models in the planning and control of construction projects', *Construction Management and Economics*, **2**(3), 219-224.

Cusack, M.M. (1985) ‘Optimization of time and cost’, *International Journal of Project Management*, **3**(1), 50-54.

Dainty, A.R.J. (2007) ‘A review and critique of construction management research methods’, in Hughes, W. (ed.) *Proceedings of Construction Management and Economics 25th Anniversary Conference*, University of Reading, 16-18 July.

Dantzig, G. (1963) *Linear Programming and Extensions*, Princeton University Press, NJ.

Davidson, I.N. and Skibniewski, M.J. (1995) ‘Simulation of automated data collection in buildings’, ASCE, *Journal of Computing in Civil Engineering*, **9**(1), 9-20.

Davis Langdon (2007) ‘Life Cycle Costing as a contribution to sustainable design: a common methodology – Final report’, available online from: http://ec.europa.eu/enterprise/construction/compet/life_cycle_costing/index_life_cycle_en.htm (accessed 10 January 2013).

Davis, E.W. and Pointon, J. (1984) *Finance and the Firm*, Oxford University Press.

Davis, R. (1991) *Construction Insolvency*, Chancery Law Publishing, London.

De Marco, A. (2011) *Project Management for Facility Constructions: A Guide for Engineers and Architects*, Springer.

De Ridder, H.A.J. and Vrijhoef, R. (2004) ‘Process and system innovation in the building and construction industry: developing a model for integrated value chain and life cycle management of built objects’, in *Proceedings CIB World Building Congress*, Toronto, Canada, May, 1-11.

De, P., Dunne, E.J., Ghosh, J.B. and Wells, C.E. (1995) ‘The discrete time-cost trade off problem revisited’, *European Journal of Operational Research*, **81**, 225-238.

Deckro, R.F., Hebert, J.E. and Verdini, W.A. (1995) ‘Nonlinear time/cost tradeoff models in project management’, *Computers & Industrial Engineering*, **28**(2), 219-229.

Dell’Isola, M.D. (2002) *Architect’s Essentials of Cost Management*, John Wiley & Sons, New York.

Demeulemeester, E.L. and Herroelen, W.S. (2002) *Project Scheduling: A Research Handbook*, Kluwer Academic Publishers.

Department of Industry (1977) *Life Cycle Costing in the Management of Assets – A Practical Guide*, Department of Industry, HMSO: London.

Dhillon, B.S. (1989) *Life Cycle Costing: Techniques, models, and applications*, Gordon and Breach Science Publishers, New York.

Dhillon, B.S. (2010) *Life Cycle Costing for Engineers*, CRC Press, Taylor and Francis Group.

Dixit, A.K. and Pindyck, R.S. (1995) ‘The Options Approach to Capital Investment’, *Harvard Business Review*, May-June.

Doloi, H.K. (2011) ‘Understanding stakeholders’ perspective of cost estimation in project management’, *International Journal of Project Management*, **29**, 622-636.

Draper, N. and Smith, H. (1998) *Applied Regression Analysis*, 3rd ed., John Wiley & Sons, New York.

Drury, C. (2006) *Cost and Management Accounting: An Introduction*, 6th ed., Thomson.

Edum-Fotwe, F., Price, A. and Thorpe, A. (1996) ‘A review of financial ratio tools for predicting contractor insolvency’, *Construction Management and Economics*, **14**, 189-198.

Egan, J. (1998) *Rethinking Construction: The Report of the Construction Task Force to the Deputy Prime Minister, John Prescott, on the Scope for Improving the Quality and Efficiency of UK Construction*, HMSO, London.

Elbeltagi, E., Hegazy, T. and Grierson, D. (2005) ‘Comparison among five evolutionary-based optimisation algorithms’, *Advanced Engineering Informatics*, **19**(1), 43-53.

Elmaghraby, S.E. (1977) *Activity Networks: Project Planning and Control by Network Models*, John Wiley & Sons, New York.

El-Rayes, K. and Kandil, A. (2005) ‘Time–cost-quality trade-off analysis for highway construction’, *Journal of Construction Engineering and Management*, **131**(4), 477-486.

ELSTAT (2016) *Greece in Figures*, January-March 2016, Hellenic Statistical Authority, Statistical Information and Publications Division, 80-84.

Emblemsvåg, J. (2003) *Life-Cycle Costing: Using Activity-Based Costing and Monte Carlo Methods to Manage Future Costs and Risks*, John Wiley & Sons, NJ.

Emmitt, S. and Gorse, C.A. (2014) *Barry’s Introduction to Construction of Buildings*, 3rd ed., Wiley Blackwell, United Kingdom.

Enshassi, A., Abdul Aziz, A.R. and El Karriri, A. (2008) ‘Investigating the overhead costs in construction projects in Palestine’, *Journal of Financial Management of Property and Construction*, **13**(1), 35-47.

Eshtehardian, E., Afshar, A. and Abbasnia, R. (2009) ‘Fuzzy-based MOGA approach to stochastic time-cost trade-off problem’, *Automation in Construction*, **18**(5), 692-701.

Evans, J.R. and Olson, D.L. (1998) *Introduction to simulation and risk analysis*, Prentice Hall, NJ.

Evans, R., Haryott, R., Haste, N. and Jones, A. (1998) *The Long Term Costs of Owning and Using Buildings*, The Royal Academy of Engineering, London.

Falk, J.E. and Horowitz, J.L. (1972) ‘Critical Path Problems with Concave Cost-Time Curves’, *Management Science*, **19**(4), 446-455.

FAS (2010) *Financial Accounting Standards No. 157: Fair Value Measurements*, Financial Accounting Standards Board, Financial Accounting Foundation (FAF).

Fayek, A.R. (2000) ‘An Activity-Based Data Acquisition and Job Costing Modelling’, *Proceedings of the Construction Congress IV: building together for a better tomorrow in an increasingly complex world*, Walsh, K.D. (ed.), ASCE, Orlando, FL, 30-35.

Fayek, A.R. (2001) ‘Activity-based job costing for integrating estimating, scheduling and cost control’, *Cost Engineering*, **43**(8), 23-32.

Feiler, A.M. (1972) Project risk management, *Proceedings of the 3rd International Congress on Project Planning by Network Techniques*, Stockholm, Sweden, INTERNET, **1**, 439-461.

Fellows, R. and Liu, A. (2008) *Research Methods for Construction*, 3rd ed., Blackwell, Oxford.

Fellows, R.F. (2010) 'New research paradigms in the built environment', *Construction Innovation: Information, Process, Management*, **10**(1), 5-13.

Fellows, R.F. and Langford, D.A. (1980) Decision theory and tendering, *Building Technology and Management*, Oct.

Fellows, R.F., Langford, D.A., Newcombe, R. and Urry, S.A. (2002) *Construction Management in Practice*, 2nd ed., Blackwell Science, Oxford.

Feng, C.W, Liu, L. and Burns, S.A. (1997) 'Using genetic algorithms to solve construction time-cost trade-off problems', *Journal of Computing in Civil Engineering*, ASCE, **11**(3), 184-189.

Feng, C.W, Liu, L. and Burns, S.A. (2000) 'Stochastic construction time-cost trade-off analysis', *Journal of Computing in Civil Engineering*, ASCE, **14**(2), 117-126.

Ferry, D.J. and Flanagan, R. (1991) 'Life cycle costing – a radical approach', CIRIA Report No. 122, London.

Ferry, D.J., Brandon, P.S. and Ferry, J.D. (1999) *Cost planning of buildings*, 7th ed., Wiley-Blackwell.

Flanagan, R. (2014) 'Whole life thinking and engineering the future', *Frontiers of Engineering Management*, **1**(3), 290-296.

Flanagan, R. and Norman, G. (1987) *Life Cycle Costing: Theory and Practice*, RICS, Surveyors Publications, London.

Flanagan, R., Norman, G. and Furbur, J.D. (1983) *Life Cycle Costing for Construction*, Quantity Surveyors Division of the Royal Institution of Chartered Surveyors, London.

Fleming, Q. and Koppelman, J. (2010) *Earned Value Project Management*, 4th ed., Project Management Institute, Newtown Square, Pa, USA.

Flyvbjerg, B., Holm, M.S. and Bulh, S. (2002) 'Costs in Public Works Projects: Error or Lie?', *Journal of the American Planning Association*, **68**(3), 279-295.

Foldes, S. and Sourmis, F. (1993) 'PERT and crashing revisited: Mathematical generalizations', *European Journal of Operational Research*, **64**, 286-294.

Fondahl, J.W. (1961) 'A non-computer approach to the critical path method for the construction industry', Technical Report No. 9, Department of Civil Engineering, Stanford University, CA.

Frimpong, Y., Oluwoye, J. and Crawford, L. (2003) 'Causes of delay and cost overruns in construction of groundwater projects in developing countries; Ghana as a case study', *International Journal of Project Management*, **21**, 321-326.

Froese, T. (1999) Industry foundation classes for project management – a trial implementation, available at: http://itcon.org/1999/2.

Fryer, B. (1990) *The Practice of Construction Management*, 2nd ed., BSP Professional Books, Oxford.

Fulkerson, R.D. (1961) 'A network flow computation for project cost curves', *Management Science*, **7**(2), 167-168.

Garcia-Fornieles, J.M., Fan, I.-S., Perez, A., Wainwright, C. and Sehdev, K. (2003) 'A Work Breakdown Structure that Integrates Different Views in Aircraft Modification Projects', *Concurrent Engineering*, **11**(1), 47-54.

Garrison, R.H. and Noreen, P.E. (1999) *Managerial Accounting*, Irwin McGraw-Hill.

Gatti, S. (2008) *Project Finance in Theory and Practice: Designing, Structuring, and Financing Private and Public Projects*, Academic Press.

Gidado, K.I. (1996) 'Project complexity: The focal point of construction production planning', *Construction Management and Economics*, **14**(3), 213-225.

Goyal, S.K. (1975) 'A Note on A Simple CPM Time-Cost Algorithm', *Management Science*, **21**(6), 718-722.

Gray, C.F. and Larson, E.W. (2008) *Project Management: The Managerial Process*, 4th ed., McGraw-Hill, New York.

Greves, D. and Joumier, H. (2003) 'Cost Engineering for Cost-Effective Space Programmes', *ESA Bulletin No. 115*, August 2003, 71-75.

Gruneberg, S.L. and Weight, D.H. (1990) *Feasibility Studies in Construction*, Mitchell, London.

Guerrero, H. (2010) *Excel Data Analysis: Modelling and Simulation*, Springer.

Haidar, A.D. (2016) *Construction Program Management – Decision Making and Optimisation Techniques*, Springer International Publishing.

Hajdu, M. (2013a) *Network Scheduling Techniques for Construction Project Management*, Springer-Science + Business Media B.V.

Hajdu, M. (2013b) 'Two Scheduling Models, One Project: Are Models Applicable in Case of Real Projects?', 26th IPMA World Congress, *Procedia – Social and Behavioral Sciences*, **74**, 165-174.

Hajdu, M. and Bokor, O. (2014) 'The Effects of Different Activity Distributions on Project Duration in PERT Networks', 27th IPMA World Congress, *Procedia – Social and Behavioral Sciences*, **119**, 766-775.

Hanna, A.S. and Gunduz, M. (2005) 'Early warning signs for distressed projects', *Canadian Journal of Civil Engineering*, **32**(5), 796-802.

Hardy, J.V. (1970) *Cash Flow Forecasting in the Construction Industry*, M.Sc. Report, Department of Civil Engineering, Loughborough University of Technology.

Harris, F. and McCaffer, R. (2001) *Modern Construction Management*, 5th ed., Blackwell.

Harrison, F. and Lock, D. (2004) *Advanced Project Management: A Structured Approach*, 4th ed., Gower Publishing, England.

Harvey, J. (1987) *Urban Land Economics – The Economics of Real Property*, 2nd ed., Macmillan.

Hegazy, T. (1999) ‘Optimisation of Resource Allocation and Levelling Using Genetic Algorithms’, *Journal of Construction Engineering and Management*, **125**(3), May-June.

Hendrickson, C. (2008) *Project Management for Construction: Fundamental Concepts for Owners, Engineers, Architects and Builders*, World Wide Web Publication, Ver. 2.2, Summer.

Hertz D. B. (1964) ‘Risk Analysis in Capital Investment’, *Harvard Business Review*, **42**, 95-106.

Hester, W.T., Kuprenas, J.A. and Chang, T.C. (1991) Construction changes and change orders: Their magnitude and impacts, University of California, Berkeley.

Hillebrandt, P.M. (1977) ‘Going bust: what are the facts?’, *Building*, 11 February, 52-53.

Hillebrandt, P.M. (2000) *Economic Theory and the Construction Industry*, 3rd ed., Palgrave-Macmillan.

Hillebrandt, P.M. and Cannon, J. (1990) *The Modern Construction Firm*, Macmillan.

Hillebrandt, P.M. and Cannon, J. (eds.) (1989) *The Management of Construction Firms: Aspects of Theory*, Macmillan.

Hillier, F.S. and Lieberman, G.J. (2009) *Introduction to Operations Research*, 9th ed., McGraw-Hill Higher Education, New York.

Hillson, D. (2002) ‘Extending the risk process to manage opportunities’, *International Journal of Project Management*, **20**(3), 235-240.

Hlaing, N.N., Singh, D., Tiong, R.L.K. and Ehrlich, M. (2008) ‘Perceptions of Singapore construction contractors on construction risk identification’, *Journal of Financial Management of Property and Construction*, Emerald Group Publishing Ltd., **13**(2), 85-95.

Hoar, D.W. (1993) ‘An overview of life-cycle costing techniques’, *Property Management*, **6**(2), 92-98.

Holland, N. and Hobson, D. (1999) ‘Indirect cost categorization and allocation by construction contractors’, *Journal of Architectural Engineering*, ASCE, **5**(2) 49-56.

Holmes, P. (1998) *Investment Appraisal*, International Thompson Business Press, London.

Horngren, C.T. (1965) *Accounting for Management Control: An Introduction*, Prentice-Hall.

Horngren, C.T., Datar, S.M. and Rajan, M.V. (2012) *Cost Accounting: A Managerial Emphasis*, 14th ed., Pearson/Prentice-Hall.

Hudson, K.W. (1978) ‘DHSS expenditure forecasting model’, *Quantity Surveying Quarterly*, **5**(2), Spring, 42-45.

Hughes, W.P. (1989) *Organisational Analysis of Building Projects*, PhD thesis, Liverpool Polytechnic (now Liverpool John Moores University), Liverpool, United Kingdom.

Hulett, D.T. (2009) *Practical Schedule Risk Analysis*, Routledge, Gower Publishing.

IASB (2009) International Accounting Standard 40 (IAS 40) – *Investment Property*, International Accounting Standards Board.

IASB (2013) International Financial Reporting Standard 13 (IFRS 13) – *Fair Value Measurement*, International Accounting Standards Board.

Ibbs, C.W., Ashley, D.B., Neil, J.M. and Feiler, F.W. (1987) 'An implementation strategy for improving project control systems', in *Project controls: needs and solutions (Proc. of Specialty Conf.)*, Ibbs C.W. and Ashley, D.B. (eds.), ASCE, New York, June, 101-112.

Ibrahim, A.D. (2007) Effect of Changes in Layout Shape on Unit Construction Cost of Residential Buildings, *Samaru Journal of Information Studies*, **7**(1), 24-31.

Iman, R.L., Davenport, J.M. and Zeigler, D.K. (1980) 'Latin hypercube sampling (a program user's guide)': Technical Report SAND79-1473, Sandia Laboratories, Albuquerque, NM.

Ireland, V. (1985) 'The role of managerial actions in the cost, time and quality performance of high rise commercial building projects', *Construction Management and Economics*, **3**, 59-87.

Isidore, L.J., Back, W.E. and Fry, G.T. (2001) 'Integrated probabilistic schedules and estimates from project simulated data', *Construction Management and Economics*, **19**(4), 417-426.

Ive, G.J. and Gruneberg, S.L. (2000) *The Economics of the Modern Construction Firm*, Palgrave Macmillan, United Kingdom.

IVSC (2007) *International Valuation Standards*, 8th ed., International Valuation Standards Committee.

Jaselskis E.J. and Ashley D.B. (1991) 'Optimal allocation of project management resources for achieving success', *Journal of Construction Engineering and Management*, **117**(2), 321-340.

Jaskowski, P. and Biruk, S. (2011) 'The conceptual framework for construction project risk assessment', *Reliability, Theory & Applications*, RT & A, **22**(2).

Johnson, H.T. and Kaplan, R.S. (1987) *Relevance Lost: The Rise and Fall of Management Accounting*, Harvard Business School Press.

Johnson, R.A. and Wichern, D.W. (1997) *Business statistics: decision making with data*, John Wiley & Sons, New York.

Johnson, R.A. and Wichern, D.W. (2013) *Applied Multivariate Statistical Analysis*, 6th ed., Pearson Education.

Johnson, R.A., Kast, F.E. and Rosenzweig, J.E. (1963) *The Theory and Management of Systems*, McGraw-Hill.

Johnson, R.A., Kast, F.E. and Rosenzweig, J.E. (1964) 'Systems Theory and Management', *Management Science*, **10**(2), 367-384.

Kaka, A.P. (1996) 'Towards more flexible and accurate cash flow forecasting', *Construction Management and Economics*, **14**, 35-44.

Kaka, A.P. and Price, A.D.F. (1991) 'Net cash-flow models: are they reliable?', *Construction Management and Economics*, **9**(3), 291-308.

Kalhor, E., Khanzadi, M., Eshtehardian, E. and Afshar, A. (2011) ‘Stochastic time-cost optimisation using non-dominated archiving ant colony approach’, *Automation in Construction*, **20**(8), 1193-1203.

Kaliba, C., Muya, M. and Mumba, K. (2009) ‘Cost escalation and schedule delays in road construction projects in Zambia’, *International Journal of Project Management*, **27**, 522-531.

Kaming, P.F., Olomolaiye, P.O., Holt, G.D. and Harris, F.C. (1997) ‘Factors influencing construction time and cost overruns on high-rise projects in Indonesia’, *Construction Management and Economics*, **15**(1), 83-94.

Kang, L.S. (1998) ‘Information management to integrate cost and schedule for civil engineering projects’, *Journal of Construction Engineering and Management*, ASCE, **124**(5), 381-389.

Kehily, D. and Hore, A. (2012) *‘Life Cycle Cost Analysis Under Ireland's Capital Works Management Framework’,* Proceedings of the Joint CIB W070, W092 & TG72 International Conference on Facilities Management, Procurement Systems and Public Private Partnership – Delivering Value to the Community, Department of Construction Economics and Management, Cape Town, South Africa, 23-25 January.

Kelley, J.E. (1961) ‘Critical-path planning and scheduling: Mathematical basis’, *Operations Research*, **9**(3), 167-179.

Kelley, J.E. and Walker, M.R. (1959) *Critical-Path Planning and Scheduling*, Proceedings of the Eastern Joint Computer Conference, New York, USA, December, 160-173.

Kennett, S. (2009) ‘RICS tool to aim to cut time overruns’, http://www.building.co.uk/rics-tool-to-cut-time-overruns/3136910.article.

Kernohan, D., Gray, J. and Daish, J. (1996) *User Participation in Building Design and Management*, 2nd ed., Butterworth Architecture, London.

Kerzner, H. (2009) *Project Management: A Systems Approach for Planning, Scheduling, and Controlling*, 10th ed., John Wiley & Sons, New York.

Khodakarami, V. and Abdi, A. (2014) ‘Project cost risk analysis: A Bayesian networks approach for modelling dependencies between cost items’, *International Journal of Project Management*, **32**, 1233-1245.

Khosrowshahi, F. (1993) ‘TASC as a forecasting tool for deterministic management decision implementation’, *Proceedings of the First International Conference on Management of IT for Construction*, 17-20 August, Singapore.

Kim, H.-J., Seo, Y.-C. and Hyun, C.-T. (2012) ‘A hybrid conceptual cost estimating model for large building projects’, *Automation in Construction*, **25**, 72-81.

Kim, K., Kim, J.J. and Ahn, B.J. (1999) ‘Collaborative construction planning data model for cost estimation, scheduling and cost control systems’, *International Journal of Computer Integrated Design and Construction* (CIDAC), **1**(1), 49–60.

Kim, Y.-W. and Ballard, G. (2001) 'Activity-Based Costing and its Application to Lean Construction', *Proceedings of the 9th Annual Conference of the International Group for Lean Construction,* Singapore.

Kim, Y.-W. and Ballard, G. (2002) 'Case Study – Overhead Costs Analysis', *Proceedings of the 10th Annual Conference of the International Group for Lean Construction*, Gramado, Brazil.

Kim, Y-W., Han, S., Shin, S. and Choi, K. (2011) 'A case study of activity-based costing in allocating rebar fabrication costs to projects', *Construction Management and Economics*, **29**(5), 449-461.

Kirk, S.J. and Dell'Isola, A.J. (1995) *Life cycle costing for design professionals*, McGraw-Hill, New York.

Kirkham, R. (2015) *Ferry and Brandon's Cost Planning of Buildings*, 9th ed., Wiley Blackwell, United Kingdom.

Kirkham, R.J., Alisa, M., Da Silva, A.P., Grindley, T. and Brøndsted, J. (2004) 'Rethinking life cycle cost based design decision-making', *In:* Khosrowshahi, F. (ed.), *Proceedings of the 20th Annual ARCOM Conference*, Association of Researchers in Construction Management, Heriot-Watt University, Edinburgh, UK, 1-3 September 2004.

Kishk, M., Al-Hajj, A., Pollock, R., Aouad, G., Bakis, N. and Sun, M. (2003) 'Whole life costing in construction: a state of the art review', *The RICS Foundation Research Paper Series*, April, **4**(18), 1-39.

Kodikara, G.W. and McCaffer, R. (1993) 'Flow of estimating data in Sri Lankan building contractor organizations', *Construction Management and Economics*, **11**, 341-346.

Kog, Y.C., Chua, D.K.H., Loh, P.K. and Jaselskis, E.J. (1999) 'Key determinants for construction schedule performance', *International Journal of Project Management*, **17**(6), 351-359.

Kogut, B. and Kulatilaka, N. (1994) 'Options Thinking and Platform Investments: Investing in Opportunity', *California Management Rev.*, **36**, 52-71.

Kohler, N. and Moffatt, S. (2003) 'Life-cycle analysis of the built environment', *UNEP Industry and Environment*, September, 17-21.

Koskela, L. (1999) 'Management of Production in Construction: A Theoretical View'. *In: 7th Annual Conference of the International Group for Lean Construction*, 26-28 July, Berkeley, California, USA.

Kothari, C.R. (2004) *Research Methodology: Methods and Techniques*, 2nd ed., New Age International Ltd., New Delhi.

Koushki, P.A., Al-Rashid, K. and Kartam, N. (2005) 'Delays and Cost Increase in the Construction of Private Residential Projects in Kuwait', *Journal of Construction Management and Economics*, **23**(3), 285-294.

Kouskoulas, V. and Koehn, E. (1974) Predesign cost estimation function for buildings, *Journal of the Construction Division*, Proceedings of the American Society of Civil Engineers (ASCE), December, 589-604.

Krieger, J. (1997) ‘Establishing activity-based costing: Lessons & Pitfalls’, *Newspaper Financial Executives Quarterly*, **3**(4), 14-17.

Kuhn, T.S. (1970) *The Structure of Scientific Revolutions*, 2nd ed., University of Chicago Press, Chicago.

Kwak, Y.H. and Ingall, L. (2007) ‘Exploring Monte Carlo simulation applications for project management’, *Risk Management*, **9**, 44-57.

Landau, S. and Everitt, B.S. (2004) *A Handbook of Statistical Analyses using SPSS*, Chapman & Hall/CRC, London.

Lander, D.M. and Pinches, G.E. (1998) ‘Challenges to the practical implementation of modelling and valuing real options’, *The Quarterly Review of Economics and Finance*, No. 38, Special Issue, 537-567.

Lave, C.A. and March, J.G. (1975) *An Introduction to Models in the Social Sciences*, Harper and Row, New York.

Law, A.M. and Kelton, W.D. (1991) *Simulation Modelling and Analysis*, 2nd ed., McGraw-Hill, New York.

Lawther, P.M. and Edwards, P.J. (2001) ‘Design Cost Modelling – A Way Forward’, *The Australian Journal of Construction Economics and Building*, **1**(1), 32-42.

Lee, S. and Halpin, D.W. (2003) ‘Predictive tool for estimating accident risk’, *Journal of Construction Engineering and Management*, **129**(4), 431-436.

Leslie, K.J. and Michaels, M.P. (1997) ‘The real power of real options’, *The McKinsey Quarterly*, No. 3, 4-22.

Lester, A. (2014) *Project Management, Planning, and Control: Managing Engineering, Construction and Manufacturing Projects to PMI, APM and BSI Standards*, 6th ed., Butterworth-Heinemann, Elsevier.

Leung, M.-Y., Ng, S.T. and Cheung, S.O. (2004) ‘Measuring construction project participant satisfaction’, *Construction Management and Economics*, **22**(3), 319-331.

Leung, M.Y., Ng, T.S., Skitmore, M. and Cheung, S.O. (2005) ‘Critical stressors influencing construction estimators in Hong Kong’, *Construction Management and Economics*, **23**(1), 33-43.

Levin, R.I. and Rubin, D.S. (1994) *Statistics for Management*, 6th ed., Prentice-Hall, Englewood Cliffs, NJ.

Li, H. and Love, P. (1997) ‘Using improved genetic algorithms to facilitate time-cost optimization’, *Journal of Construction Engineering and Management*, **123**(3), 233-237.

Liapis, K.J. and Christodoulopoulou, E.P. (2011) ‘How GAAP and accounting treatments influence property management’, *Journal of Property Investment & Finance*, **29**(3), 251-279.

Liapis, K.J., Christofakis, M.S. and Papacharalampous, H.G. (2011) ‘A new evaluation procedure in real estate projects’, *Journal of Property Investment & Finance*, **29**(3), 280-296.

Lind, D.A., Marchal, W.G. and Wathen, S.A. (2008) *Basic Statistics for Business & Economics*, 6th ed., McGraw-Hill.

Liu, L., Burns, S.A. and Feng, C.W. (1995) ‘Construction time-cost trade-off analysis using LP/IP hybrid method’, *Journal of Construction Engineering and Management*, **121**(4), 446-454.

Lockyer, K.G. (1974) *An Introduction to Critical Path Analysis*, 3rd ed., Pitman, London.

Loizou, P. and French, N. (2012) ‘Risk and uncertainty in development: A critical evaluation of using the Monte Carlo simulation method as a decision tool in real estate development projects’, *Journal of Property Investment & Finance*, **30**(2), 198-210

Lorance, R.B. and Robert, V.W. (1999) ‘Basic techniques for analysing and presentation of cost risk analysis’, *AACE International Transactions*, Association for the Advancement of Cost Engineering.

Love, P.E.D., Sing, C.-P., Wang, X., Edwards, D.J. and Odeyinka, H. (2013) ‘Probability distribution fitting of schedule overruns in construction projects’, *Journal of the Operational Research Society*, **64**(8), 1231-1247.

Lowe, D.J., Emsley, M.W. and Harding, A. (2006) ‘Predicting construction cost using multiple regression techniques’, *Journal of Construction Engineering and Management*, ASCE, **132**(7), 750-758.

Mackay, S. (1999) ‘Building for life’, *the Building Economist*, 4-9.

Maghrebi, M., Afshar, A. and Maghrebi, M.J. (2013) ‘A Novel Mathematical Model for Deterministic Time-Cost Trade-off Based on Path Constraint’, *International Journal of Construction Engineering and Management*, **2**(5), 137-142.

Malcolm, D.G., Roseboom, C.E., Clark, C.E. and Fazar, W. (1959) ‘Applications of a Technique for R and D Program Evaluation’, *Operations Research*, Vol. VII, No. 5, September-October, 646-669.

Manseau, A. and Seaden, G. (eds.) (2001) *Innovation in Construction: An International Review of Public Policies*, Spon Press: London and New York. A paper presenting the framework and conclusions preceded the comprehensive detailed report in *Building Research and Information*, **29**, 182-196.

Mansfield, N.R., Ugwu, O.O. and Doran, T. (1994) ‘Causes of delay and cost overruns in Nigerian construction projects’, *International Journal of Project Management*, **12**(4), 254-260.

Marchesan, P.R.C. and Formoso, C.T. (2001) ‘Cost Management and Production Control for Construction Companies’, *Proceedings of the 9th International Group for Lean Construction Conference*, Singapore, 6-8 August, Chua, D. and Ballard, G. (eds.), National University of Singapore.

Maxwell, D., Back, W. and Toon, J. (1998) ‘Optimization of crew configurations using activity-based costing’, *Journal of Construction Engineering and Management*, **124**(2), 162-168.

Mbachu, J.I.C. and Nkado, R.N. (2004) ‘Reducing Building Construction Costs; the Views of Consultants and Contractors’, COBRA, available from: http://www.rics.org.

McCaffer, R. (1975) ‘Some examples of the use of regression analysis as an estimating tool’, *The Quantity Surveyor*, December, 81-86.

McCaffer, R., McCaffrey, M.J. and Thorpe, A. (1984) ‘Predicting the tender price of buildings in the early design stage: method and validation’, *Journal of Operational Research Society*, **35**(5), 415-424.

McCuen, R.H. (ed.) (1996) *The Elements of Academic Research*, ASCE Publications, New York.

McCullouch, B. (1997) ‘Automating field data collection in construction organisations’, *Proceedings of Construction Congress V*, ASCE, Reston, VA, 957-963.

Mendenhall, W. and Sincich, T. (2007) *Statistics for Engineering and the Sciences*, 5th ed., Prentice Hall, NJ.

Meredith, J.R. and Mantel, S.J. (2012) *Project Management: A Managerial Approach*, 8th ed., John Wiley & Sons.

Meunier, K. (2012) ‘Historical cost and fair value accounting’, retrieved from http://business-accountingguides.com/historical-cost.

Meyer, W.L. and Shaffer, L.R. (1963) *Extensions of the critical path through the application of integer programming*, Report issued by the Department of Civil Engineering, University of Illinois.

Miles, M.B. and Huberman, M. (1994) *Qualitative data analysis: an expanded sourcebook*, 2nd ed., SAGE Publications.

Miller, E. and Rice, A.K. (1967) *Systems of Organisation*, Tavistock Publications, London.

Miller, J.A. (1996) *Implementing activity-based management in daily operations*, John Wiley & Sons, New York, NY.

Mirham, G.A. (1972) *Simulation: Statistical Foundations and Methodology*, Academic Press, New York.

Mislick, G.K. and Nussbaum, D.A. (2015) *Cost Estimation: Methods and Tools*, John Wiley & Sons, New Jersey.

Moder, J., Phillips, C. and Davis, E. (1983) Project Management with CPM, PERT and Precedence Diagramming, 3rd ed., Van Nostrand Reinhold Company.

Mole, R.H. (1985) *Basic Investment Appraisal*, Butterworths Basic Series, Butterworth-Heinemann.

Morris, P.W.G. (1988) ‘Managing project interfaces – key points for project success’, in *Project Management Handbook*, Cleland, D.I. and King, W.R. (eds.), Van Nostrand Reinhold, 16-55.

Morris, P.W.G. (1997) *The management of projects*, Thomas Telford, London.

Morris, P.W.G. and Hough, G.H. (1987) *The anatomy of major projects: A study of the reality of project management*, John Wiley & Sons, New York.

Morris, P.W.G., Crawford, L., Hodgson, D., Shepherd, M.M. and Thomas, J. (2006) ‘Exploring the role of formal bodies of knowledge in defining a profession: the case of project management’, *International Journal of Project Management*, **24**(8), 710-721.

Morrison, N. (1984) ‘The accuracy of quantity surveyors cost estimating’, *Construction Management and Economics*, **2**, 57-75.

Moselhi, O. (1993) ‘Schedule compression using the direct stiffness method’, *Canadian Journal of Civil Engineering*, **20**, 65-72.

Moselhi, O. and Roofigari-Esfahan, N. (2013) ‘Project schedule compression: a multi-objective methodology’, *Construction Innovation*, **13**(4), 374-393.

Moussourakis, J. and Haksever, C. (2004) ‘Flexible model for time/cost trade-off problem’, *Journal of Construction Engineering and Management*, **130**(3), 307-314.

Mubarak, S. (2015) *Construction Project Scheduling and Control*, 3rd ed., John Wiley & Sons, New Jersey.

Mulligan, G. (1993) ‘Building Economics: The use of Economics in the Built Environment’, *Student Economic Review*, **7**, 67-72.

Myers, D. (2008) *Construction economics: a new approach*, 2nd ed., Taylor and Francis, London.

NAO (2005), *Report on ‘Improving Public Services Through Better Construction’*, National Audit Office, available at: www.nao.org.uk.

Naoum, S.G. (2007) *Dissertation Research & Writing for Construction Students*, 2nd ed., Elsevier, Oxford.

Navon, R. (1995) ‘Resource-based model for automatic cash flow forecasting’, *Construction Management and Economics*, **13**, 501-510.

Navon, R. (2005) ‘Automated Project Performance Control (APPC) of Construction Projects’, *Automation in Construction*, **14**(4), 467-476.

*n*CRISP (2003) *From the Construction Industry’s Contribution to Sustainable Development*, By Professor David Pearce OBE, *n*CRISP, Construction Industry Research and Innovation Strategy Panel, London.

Newcombe, R., Langford, D.A. and Fellows, R.F. (1990) *Construction Management 2: Management Systems*, Mitchell, London.

Ng, S.T. and Zhang, Y. (2008) ‘Optimizing construction time and cost using ant colony optimization approach’, *Journal of Construction Engineering and Management*, **134**(9), 721-728.

Nicholas, J.M. and Steyn, H. (2008) *Project Management for Business, Engineering and Technology – Principles and Practice*, Butterworth-Heinemann, Elsevier.

Nobes, C.W. (1997) *Introduction to Financial Accounting*, 4th ed., International Thompson Business Press, London, UK.

Norman, G. (1993) ‘Life cycle costing’, *Property Management*, **8**(4), 344-356.

NS 3454 (2000) *Life Cycle Costs for Building and Civil Engineering Work – Principles and Classification*, Norwegian Standard, Oslo.

Olawale, Y. and Sun, M. (2010) ‘Cost and time control of construction projects: Inhibiting factors and mitigating measures in practice’, *Construction Management and Economics*, **28**(5), 509-526.

Olubodun, F., Kangwa, J., Oladapo, A. and Thompson, J. (2010) ‘An appraisal of the level of application of life cycle costing within the construction industry in the UK’, *Structural Survey*, **28**(4), 254-265.

Oxley, R. and Poskitt, J. (1996) *Management Techniques Applied to the Construction Industry*, 5th ed., Blackwell Science, Oxford.

Pellicer, E., Yepes, V., Teixeira, J.C., Moura, H.P. and Catalá, J. (2014) *Construction Management*, John Wiley & Sons Ltd., United Kingdom.

Pelzeter, A. (2007) ‘Building optimisation with life cycle costs – the influence of calculation methods’, *Journal of Facilities Management*, **5**(2), 115-128.

Perera, A.A.D.A.J. and Imriyas, K. (2004) ‘An integrated construction project cost information system using MS Access and MS Project’, *Construction Management and Economics*, **22**(2), 203-211.

Peterson, R.H. (2009) *Accounting for Fixed Assets*, 2nd ed., John Wiley & Sons, New York.

PMI (2013) *A Guide to the Project Management Body of Knowledge (PMBOK® Guide)*, 5th ed., Project Management Institute, Upper Darby, PA.

Potts, K.F. and Ankrah, N.A. (2013) *Construction Cost Management: Learning from case studies*, Routledge, UK.

Prager, W. (1963) ‘A structured method of computing project cost-polygons’, *Management Science*, **9**(3), 394-404.

Proverbs, D. and Gameson, R. (2008) ‘Case Study Research’, in *Advanced Research Methods in the Built Environment*, Wiley-Blackwell, Chichester, UK.

Purnus, A. and Bodea, C.-N. (2015) ‘Financial Management of the Construction Projects: A Proposed Cash Flow Analysis Model at Project Portfolio Level’, *Organisation, Technology and Management in Construction: An International Journal*, **7**(1), 1217-1227.

Qian, L. and Ben-Arieh, D. (2008) ‘Parametric Cost Estimation Based on Activity-Based Costing: A Case Study for Design and Development of Rotational Parts’, *International Journal of Production Economics*, **113**(2), 805-818.

Rad, P. (1979) ‘Delays in construction of nuclear power plants’, *Journal of Energy Division*, ASCE, **105**(1), 33-46.

Rader, D.J. (2010) *Deterministic Operations Research: Models and Methods in Linear Optimisation*, John Wiley & Sons.

Raffish, N. and Turney, P. (1991) ‘Glossary of Activity-Based Management’, *Cost Management Journal*, Fall, 53-63.

Raftery, J. (1994) *Risk Analysis in Project Management*, E and FN Spon, London.

Raftery, J.J. (1984) 'Models in Building Economics: A Conceptual Framework for the Assessment of Performance', 3rd International Symposium on building Economics, CIB Conference (Proceedings), Ottawa, July, **3**, 103-111.

Raftery, J.J. (1984) *An investigation of the suitability of cost models for use in building design*, Ph.D. thesis, CNAA, Liverpool Polytechnic.

Raftery, J.J. (1991) *Principles of building economics*, Blackwell Publications, London.

Rasdorf, W.J. and Abudayyah, O.Y. (1991) 'Cost and schedule – control integration: issues and needs', *Journal of Construction Engineering and Management*, ASCE, **117**(3), 486-501.

Raz, T. and Elnathan, D. (1999) 'Activity based costing for projects', *International Journal of Project Management*, **17**(1), 61-67.

Reda, R.M. and Carr, R.I. (1989) 'Time-cost trade-off among related activities', *Journal of Construction Engineering and Management*, ASCE, **115**(3), 475-486.

Reugg, R.T. and Marshall, H.E. (1990) *Building Economics: Theory and Practice*, Van Nostrand Reinhold, New York.

RICS (1986) *A Guide to Life Cycle Costing for Construction*, Royal Institution of Chartered Surveyors, Surveyors Publications, London.

RICS (1991) *The Research and Development Strengths of the Chartered Surveying Profession: The Academic Base*, Royal Institution of Chartered Surveyors.

RICS (2015) *Quantity Surveying and Construction*, Associate Assessment Pathway Guide, Royal Institution of Chartered Surveyors, March 2015, www.rics.org.

Riggs, J.L. (1968) *Economic decision models for engineers and managers*, McGraw-Hill Book Company, New York.

Ritz, G.J. and Levy, S.M. (2013) *Total Construction Project Management*, 2nd ed., McGraw-Hill Education, New York.

Robinson, D.R. (1975) 'A dynamic programming solution to cost-time trade-off for CPM', *Management Science*, **22**(2), 158-166.

Ross, A. and Williams, P. (2013) *Financial Management in Construction Contracting*, John Wiley & Sons, United Kingdom.

Rowlinson, S.M. (1988) *An Analysis of Factors Affecting Project Performance in Industrial Building*, PhD thesis, Brunel University, Uxbridge, United Kingdom.

Roy, B. (1959) 'Theorie des graphes: Contribution de la theorie desigraphes a l'etude de certains problemes linearies', *Comptes rendus des Seances de l'Acedemiedes Sciences*, Avril, 2437-2449.

Ruan, L., Xiong, Y. and Wang, Y. (2001) 'Construction cost integrated control based on computer simulation', *Journal of Zhejiang University (Science)*, **2**(1), 28-33, Jan-Mar 2001.

Ruddock, L. (1992) *Economics for Construction and Property*, Edward Arnold, London.

Saidi, K.S., Lytle, A.M. and Stone, W.C. (2003) ‘Report of the NIST workshop on data exchange standards at the construction job site’, *Proceedings of ISARC 2003 The Future Site*, Eindhoven, The Netherlands, September 21-25, 617-622.

Schwindt, C. (2005) *Resource Allocation in Project Management*, GOR Publications, Springer.

Sears, S.K., Sears, G.A., Clough, R.H., Rounds, J.L. and Segner, R.O. (2015) *Construction Project Management: A Practical Guide to Field Construction*, 6th ed., Wiley, United States.

Seeley, I.H. (1996) *Building Economics*, 4rd ed., Macmillan, London.

Sherwood, D. (2002) *Seeing the forest for the trees: a manager’s guide to applying systems thinking*, Nicholas Brealey Publishing, London.

Shi, J.J. (1999) ‘A neural network based system for predicting earthmoving production’, *Construction Management and Economics*, **17**, 463-471.

Shtub, A., Bard, J.F. and Globerson, S. (2005) *Project Management: Processes, Methodologies, and Economics*, 2nd ed., Pearson Education Inc.

Siemens, N. (1971) ‘A Simple CPM Time-Cost Trade-off Algorithm’, *Management Science*, **17**(6), 354-363.

Simon, H.A. (1960) *The New Science of Management Decision*, Harper & Brothers, New York.

Sizer, J. (1989) *An Insight into Management Accounting*, 3rd ed., Penguin.

Skitmore, M. (1991) ‘Early stage construction price forecasting – a review of performance’, *Occasional Paper*, Royal Institution of Chartered Surveyors.

Skitmore, M. and Marston, V. (eds.) (1999) *Cost Modelling*, E & FN Spon, Taylor and Francis.

Skutella, M. (1998) ‘Approximation Algorithms for the Discrete Time-Cost Tradeoff Problem’, *Mathematics of Operations Research*, **23**(4), 909-929.

Smith, M. (2011) *Research Methods in Accounting*, 2nd ed., SAGE Publications, London.

Smith, N.J. (ed.) (1995) *Project Cost Estimating*, Thomas Telford, London, United Kingdom.

Smith, P. (2014) ‘Project Cost Management – Global Issues and Challenges’, 27th IPMA World Congress, *Procedia – Social and Behavioral Sciences*, **119**, 485-494.

Smyth, H.J. and Morris, P.W.G. (2007) ‘An epistemological evaluation of research into projects and their management: Methodological issues’, *International Journal of Project Management*, **25**, 423-436.

Sommer, B. (2001) *Personal Communication*, DPR Construction Inc., Redwood City, CA.

Sonmez, R. (2004) ‘Selection of a probability distribution function for construction cost estimation’, *In:* Khosrowshahi, F. (ed.), *Proceedings of the 20th Annual ARCOM Conference*, Association of Researchers in Construction Management, Heriot-Watt University, Edinburgh, UK, 1-3 September 2004, 125-128.

Sonmez, R. and Bettemir, Ö. H. (2012) ‘A hybrid genetic algorithm for the discrete time-cost trade-off problem’, *Expert Systems with Applications*, **39**(13), Elsevier, October, 11428-11434.

Sonmez, R. and Rowings, J.E. (1998) ‘Construction labor productivity modelling with neural networks’, *Journal of Construction Engineering and Management*, **124**(6), 498-504.

Staub, S. and Fischer, M. (1999) ‘The practical needs of integrating scope, cost and time’, in *Durability of Building Materials & Components 8*, Vancouver, May 30-June 3, **4**, Information Technology in Construction, CIB W78 Workshop, NRC Research Press, Ottawa, 2888-2898.

Steiner, G.A. (1969) *Top management planning*, Macmillan, New York.

Stevenson, W.J. (2012) *Operations Management*, 11th ed., McGraw-Hill, New York.

Sun, M. and Aouad, G. (1999) ‘Control mechanism for information sharing in an integrated construction environment’, available at: http://itcon.org.

Swaffield, L.M. and Pasquire, C.L. (1996) ‘A critique of Mechanical and Electrical Services cost planning: existing methods and published information’, *Journal of Financial Management of Property and Construction*, Emerald, **1**(3), 23-41.

Swaffield, L.M. and Pasquire, C.L. (1999) ‘Examination of relationships between building form and function, and the cost of Mechanical and Electrical Services’, *Construction Management and Economics*, **17**, 483-492.

Syal, M. and Kakakhel, A. (1999) ‘Integration of project cost estimate and project time schedule: a project breakdown structure approach’, PhD Thesis, Construction Management, Michigan State University, USA.

Tah, J., Thorpe, A. and McCaffer, R. (1993) ‘Contractor project risks contingency allocation using linguistic approximation’, *Computing Systems in Engineering*, **2**(4), 281-293.

Tam, C.M. and Tong, T.K.L. (2005) ‘Multiple GMDH models for estimating resource requirements’, *Construction Innovation*, **5**(2), p. 115.

Tan, W. (1999) ‘Construction Cost and Building Height’, *Construction Management and Economics*, **17**, 129-132.

Tavistock Institute (1966) *Interdependence and Uncertainty: A Study of the Building Industry*, Tavistock Publications, London.

Teicholz, P.M. (1987) ‘Current needs for cost control systems’, Project controls: Needs and solutions (Proc. Special Conf.), Ibbs, C.W. and Ashley, D.B. (eds.), *ASCE*, 47-57.

Tempelmans Plat, H. (2001) *The Economics of Property Management: The Building as a Means of Production*, Butterworth-Heinemann, Elsevier.

The Concise Oxford Dictionary of Current English (1995) (ed. D. Thompson), 9th ed., Clarendon Press, Oxford.

The Penguin Dictionary of Economics (1992) (eds. G. Bannock, R.E. Baxter and E. Davis), 5th ed., Penguin, London.

The Royal Academy of Engineering (2007) *Creating systems that work: Principles of engineering systems for the 21st century*, London.

Thompson, J.D. (1967) *Organisations in Action: Social Science Bases of Administrative Theory*, McGraw-Hill, New York.

Tietz, S.B. (1987) 'Lifecycle costing and whole-life design', *The Structural Engineer*, **65A**(1), 10-11.

Turner, J.R. (2009) *The Handbook of Project-Based Management*, 3rd ed., McGraw-Hill.

Upson, A. (1987) *Financial Management for Contractors*, BSP Professional Books, Oxford.

Urry, S.A. (1991) *An Introduction to Operational Research*, Longman Scientific and Technical.

Van de Ven, A.H. (1992) 'Suggestions for studying strategic process: a research note', *Strategic Management Journal*, **13**(S1), 169-188.

Van Slyke, R.M. (1963) 'Monte Carlo Methods and the PERT Problem', *Operations Research*, Vol.11, No.5, September-October, 839-860.

Vanderbeck, E.J. (2013) *Principles of Cost Accounting*, 16th ed., Cengage Learning.

Vanhoucke, M. (2013) *Project Management with Dynamic Scheduling: Baseline Scheduling, Risk Analysis and Project Control*, 2nd ed., Springer.

Vanhoucke, M. and Debels, D. (2007) The discrete time/cost trade-off problem under various assumptions exact and heuristic procedures, *Journal of Scheduling*, **10**, 301-326.

Venkataraman, R.R. and Pinto, J.K. (2008) *Cost and Value Management in Projects*, Wiley.

Verma, H.L. and Gross, C.W. (1978) Introduction to quantitative methods: a managerial emphasis, Wiley/Hamilton, Santa Barbara.

Vose, D. (1996) *Quantitative Risk Analysis: A Guide to Monte Carlo Simulation Modelling*, John Wiley & Sons, England.

Walker, A. (2002) *Project Management in Construction*, 4th ed., Blackwell Science, Oxford.

Weaver, W. (1948) 'Science and complexity', *American Scientist*, **36**, 536-544.

Westney, R.E. (ed.) (1997) *The Engineer's Cost Handbook: Tools for Managing Project Costs*, Marcel Decker Inc., New York.

Williams, T. (1999) 'The need for new paradigms for complex projects', *International Journal of Project Management*, **17**(5), 269-273.

Williams, T. (2003) 'The contribution of mathematical modelling to the practice of project management', *IMA Journal of Management Mathematics*, **14**(1), 3-30.

Winch, G.M. and Kelsey, J. (2005) 'What do construction project planners do?', *International Journal of Project Management*, **23**(2), 141-149.

Winston, W.L. (2004) *Operations Research: Applications and Algorithms*, 4th ed., Cengage Learning Higher Education.

Wong, A. (1993) ‘Integrated construction project management for Hong Kong contractors’, available at: http://home.bre.poly.edu.hk/bskdwong.

Woodward, D.G. (1997), ‘Life cycle costing – theory, information acquisition and application’, *International Journal of Project Management*, **15**(6), 335-344.

Woodward, S., Purbrick, A. and Ayres, N. (1994) ‘Cost Management – The Software Solution’, In Harlow, P. (ed.) *Construction Papers*, Chartered Institute of Building, No.31.

Woollett, J.M. (1978) *A Methodology for Financial Forecasting in the Building Industry*, PhD Thesis, University of Michigan, Ann Arbor, University Microfilms International, *Order no. 79-00659*.

World Bank (1996) *World Development Report 1996: Infrastructure for Development*, Oxford University Press, Oxford, UK.

Wright, D. (1996) *Management Accounting*, Addison Wesley Longman Ltd., England.

Yang, I.-T. (2005) ‘Impact of Budget Uncertainty on Project Time-Cost Tradeoff’, *IEEE Transactions of Engineering Management*, **52**(2), May, 167-174.

Yang, X., Yuan, J. and Mao, H. (2007) ‘A modified particle swarm optimizer with dynamic adaptation’, *Applied Mathematics and Computation*, **189**, 1205-1213.

Yao, M-J. and Chu, W-M. (2007) ‘A new approximation algorithm for obtaining the probability distribution function for project completion time’, *Computers and Mathematics with Applications*, **54**(2), 282–295.

Yeo, K.T. (1993) ‘Systems thinking and project management – time to reunite’, *International Journal of Project Management*, **11**(2), 111-117.

Zayed, T. and Liu, Y. (2014) ‘Cash flow modelling for construction projects’, *Engineering, Construction and Architectural Management*, Emerald, **21**(2), 170-189.

Zayed, T.M. and Halpin, D.W. (2005) ‘Productivity and Cost Regression Models for Pile Construction’, *Journal of Construction Engineering and Management*, ASCE, **131**(7), 779-789.

Zima, K. and Plebankiewicz, E. (2012) ‘Analysis of the building shape erected in Krakow and its impact on construction costs’, *International Journal of Organisation, Technology and Management in Construction*, **4**(1), 411-419.

Zimmermann, J. and Schwindt, C. (2002) ‘Parametric optimization for the evaluation of investment projects’, *Eighth International Workshop on Project Management and Scheduling* (PMS 2002), Valencia, Spain, 378-382.

Zwikael, O. (2009) ‘Critical planning processes in construction projects’, *Construction Innovation: Information, Process, Management*, **9**(4), 372-387.

This page intentionally left blank

APPENDICES

APPENDIX (A)

A.1 Indirect Taxes

The most common taxation in the building industry is *indirect taxation*. The following tax rates and fees are levied:

A.1.1 Taxes and fees on land purchase

- Property transfer tax levies in the contract value; the tax rate is 8% on property with a value up to €20.000,00 and the percentage increases to 10% for property values greater than €20.000,00;
- City tax 3% levies on the total payment on property transfer tax when the property is transferred;
- Fee 0,65% for legal fund on contract authorship;
- Fee 0,45% - 0,75% for legal fund on contract registry;
- Additional fee 0,45% - 0,75% on contract registry; and
- Notary fee 1% on purchase value.

A.1.2 Taxes on property construction

- Value added tax (VAT) 24% on construction materials;
- VAT 24% on net value of contracting work; and
- Social Security Contribution or Social Security Charges (SSC): employer's social security contribution 65% on wages calculated on net value of contracting work.

A.1.3 Taxes on property maintenance cost

- VAT 24% on maintenance materials;
- VAT 24% on net value of work required for property maintenance; and
- SSC: employer's social security contribution 19,95% on wages calculated on net value of maintenance work.

A.1.4 Taxes on property operating cost

- VAT 24% on net value of work required for property operation; and
- SSC: employer's social security contribution 28,56% on wages calculated on net value of operating work.

A.1.5 Taxes on property completion cost

SSC: employer's social security contribution 28,56% on wages calculated on net value of labour rates.

A.1.6 Taxes on property end-of-life cost

VAT 24% on net value of work required for built asset end-of-life.

A.2 Direct Taxes (Taxes on Income)

- 26% corporate tax on income; plus dividend tax 9%; total average tax rate on income 33%;
- Additional tax on rental income 3%.

A.3 Property Taxes

- Annual property taxation: the tax rate ranges from 0,25% to 0,35% and is imposed on the objective value of the property;
- Special end properties: a special estate fee of €3,00 to €16,00 per square meter with an average property tax of €4,00 per square meter;
- Municipal lighting and cleaning fees in accordance with the decisions of the municipal council of the city-owned property;
- Fees for drainage properties according to the decisions of the municipal council of the city-owned property; and
- Primary end occupation of sidewalks according to the decisions of the municipal council of the city-owned property.

APPENDIX (B)

The complete data set for the sample of building projects and required calculations for the pre-construction period analysis (Chapter 4, pages 215-242) are presented as follows:

B.1 Definition of Input/Output Variables

(cost_tot)	project total completion cost (final account) (in €*1000)
(dur_tot)	project total duration (in days)
(cost_m2)	project cost per m^2 of total gross floor area (in €/m^2)
(cost_m3)	project cost per m^3 of total building volume (in €/m^3)
(cost_day)	project cost per day of total project duration (in €/day)
(plot_area)	plot area (land) (m^2)
(cov_area)	coverage ratio area (m^2)
(cov_ratio)	coverage ratio = (cov_area) : (plot_area)
(gross_ag)	gross floor area above ground level, including walls (m^2)
(build_coef)	building coefficient = (gross_ag) : (plot_area)
(gross_bg)	gross floor area below ground level, including walls (m^2)
(gross_tot)	total gross floor area (m^2) = (gross_ag) + (gross_bg)
(misc_ag)	miscellaneous gross floor area above ground level (m^2)
(ht_ag)	building height above ground level, including roof (m)
(vol_ag)	building volume above ground level, including roof (m^3)
(vol_bg)	building volume below ground level (m^3)
(vol_tot)	total building volume (m^3) = (vol_ag) + (vol_bg)
(st_ag)	number of storeys above ground level (no.)
(st_bg)	number of storeys below ground level (no.)
(st_tot)	total number of storeys (no.) = (st_ag) + (st_bg)
(env_tot)	total external envelope wall area (m^2)

B.2 Definition of Building Geometry Parameters

F	ground floor plan area (m^2) = coverage ratio area (cov_area)
P	perimeter (m) of ground floor plan area (F)
V	total volume (m^3) of building (vol_tot)
G	sum of perimeters (m) of floor plans divided by total no. of storeys: G = (per_tot) : (st_tot)
R	total gross floor area (m^2) divided by total no. of storeys: R = (gross_tot) : (st_tot)
W	external envelope (wall) area (m^2) for perimeter (P), including doors, windows etc. and assuming an equal ground floor height of h = 3,50m for all projects: W = (P * h)
H	total height of building (m)

B.3 Historical Data for the Sample of Building Projects ($n = 36$)

project	year	cost_tot	dur_tot	cost*1000	cost/m^2	cost/m^3	cost/day
1	2006	314000	398	314,00	879,26	220,45	788,94
2	2008	167000	275	167,00	824,41	244,33	607,27
3	2008	278000	400	278,00	1288,29	324,16	695,00
4	2006	415000	517	415,00	842,38	281,04	802,71
5	2010	237000	325	237,00	818,37	222,12	729,23
6	2007	224000	350	224,00	988,18	307,45	640,00
7	2010	328000	406	328,00	874,85	248,49	807,88
8	2005	223000	338	223,00	837,53	295,37	659,76
9	2009	985000	661	985,00	859,41	303,70	1490,17
10	2011	395000	512	395,00	1235,03	371,28	771,48
11	2010	279000	390	279,00	864,37	225,69	715,38
12	2005	541000	505	541,00	815,13	235,86	1071,29
13	2005	346000	410	346,00	1024,67	354,85	843,90
14	2005	398000	435	398,00	861,53	239,03	914,94
15	2008	364000	366	364,00	1021,64	330,75	994,54
16	2009	195000	313	195,00	1221,35	421,16	623,00
17	2012	365000	479	365,00	1338,37	374,29	762,00
18	2010	276000	385	276,00	1201,20	320,32	716,88
19	2013	1570000	670	1570,00	955,86	309,59	2343,28
20	2011	294000	374	294,00	787,59	211,39	786,10
21	2007	422000	483	422,00	1051,87	344,70	873,71
22	2007	367000	397	367,00	1265,43	401,62	924,43
23	2008	1378000	591	1378,00	892,97	297,66	2331,64
24	2014	248000	306	248,00	803,08	241,97	810,46
25	2015	528000	520	528,00	856,66	237,37	1015,38
26	2015	369000	355	369,00	1031,01	251,58	1039,44
27	2009	2286000	732	2286,00	789,40	240,58	3122,95
28	2009	1228000	582	1228,00	986,65	257,97	2109,97
29	2014	933000	542	933,00	1032,51	273,18	1721,40
30	2013	1180000	589	1180,00	740,73	181,90	2003,40
31	2005	417000	360	417,00	758,13	220,28	1158,33
32	2011	384000	374	384,00	815,91	325,67	1026,74
33	2001	832000	560	832,00	747,31	213,01	1485,71
34	2004	660000	505	660,00	854,36	260,24	1306,93
35	2004	640000	498	640,00	891,50	276,10	1285,14
36	2005	795000	513	795,00	772,44	248,31	1549,71

B.3 Historical Data for the Sample of Building Projects ($n = 36$) – *cont’d.*

project	plot_area	cov_area	cov_ratio	gross_ag	build_coef	gross_bg	gross_tot
1	4351,44	158,06	0,04	199,06	0,05	158,06	357,12
2	117,86	67,47	0,57	135,10	1,15	67,47	202,57
3	785,83	100,71	0,13	115,08	0,15	100,71	215,79
4	321,35	123,20	0,38	369,45	1,15	123,20	492,65
5	320,00	144,80	0,45	144,80	0,45	144,80	289,60
6	268,00	89,93	0,34	136,75	0,51	89,93	226,68
7	322,26	123,39	0,38	231,78	0,72	143,14	374,92
8	267,07	74,02	0,28	148,04	0,55	118,22	266,26
9	793,00	237,83	0,30	721,39	0,91	424,75	1146,14
10	610,00	91,45	0,15	173,00	0,28	146,83	319,83
11	4568,00	199,86	0,04	199,86	0,04	122,92	322,78
12	758,67	187,87	0,25	374,92	0,49	288,78	663,70
13	126,18	84,18	0,67	222,17	1,76	115,50	337,67
14	517,25	131,27	0,25	205,31	0,40	256,66	461,97
15	503,35	130,16	0,26	226,13	0,45	130,16	356,29
16	102,84	53,22	0,52	106,44	1,04	53,22	159,66
17	610,00	102,65	0,17	170,07	0,28	102,65	272,72
18	253,55	76,59	0,30	153,18	0,60	76,59	229,77
19	345,17	157,57	0,46	1382,66	4,01	259,84	1642,50
20	320,33	127,40	0,40	198,88	0,62	174,41	373,29
21	471,77	133,73	0,28	267,46	0,57	133,73	401,19
22	329,37	100,20	0,30	195,11	0,59	94,91	290,02
23	432,06	217,51	0,50	1305,06	3,02	238,10	1543,16
24	424,65	101,76	0,24	207,05	0,49	101,76	308,81
25	400,00	156,60	0,39	459,75	1,15	156,60	616,35
26	4536,30	147,55	0,03	210,35	0,05	147,55	357,90
27	456,00	310,49	0,68	1543,20	3,38	1352,67	2895,87
28	198,00	138,15	0,70	837,81	4,23	406,80	1244,61
29	922,57	338,87	0,37	538,40	0,58	365,22	903,62
30	1737,60	589,11	0,34	989,59	0,57	603,43	1593,02
31	151,64	103,78	0,68	446,26	2,94	103,78	550,04
32	154,35	94,52	0,61	376,12	2,44	94,52	470,64
33	499,14	204,37	0,41	816,04	1,63	297,29	1113,33
34	322,48	134,43	0,42	602,98	1,87	169,53	772,51
35	418,32	133,36	0,32	584,53	1,40	133,36	717,89
36	457,00	139,77	0,31	676,16	1,48	353,05	1029,21

B.3 Historical Data for the Sample of Building Projects (*n* = 36) – *cont'd.*

project	misc_ag	height_ag	vol_ag	vol_bg	vol_tot	st_ag	st_bg	st_tot	env_tot
1	41,00	9,50	1013,37	410,96	1424,33	2	1	3	628,84
2	37,94	10,10	494,36	189,14	683,50	2	1	3	467,88
3	36,60	6,90	585,67	271,92	857,59	2	1	3	436,03
4	51,42	10,75	1156,46	320,19	1476,65	3	1	4	636,66
5	41,48	4,00	627,64	439,35	1066,99	1	1	2	477,75
6	21,89	7,30	458,79	269,79	728,58	2	1	3	391,40
7	27,80	9,60	976,44	343,54	1319,98	2	1	3	580,44
8	10,96	8,00	518,13	236,86	754,99	2	1	3	426,92
9	100,68	12,70	2139,02	1104,35	3243,37	3	1	4	1192,02
10	30,50	8,30	608,71	455,17	1063,88	2	1	3	505,82
11	38,30	5,20	892,01	344,18	1236,19	1	1	2	487,20
12	57,40	9,50	1488,5	805,25	2293,75	2	1	3	830,00
13	14,90	10,50	570,10	404,95	975,05	3	1	4	542,50
14	18,72	9,00	895,11	769,98	1665,09	2	1	3	671,64
15	35,20	8,00	710,04	390,48	1100,52	2	1	3	600,60
16	20,40	6,70	303,35	159,66	463,01	2	1	3	284,99
17	24,40	7,50	667,23	307,95	975,18	2	1	3	484,79
18	18,17	9,00	631,86	229,77	861,63	2	1	3	447,60
19	248,52	27,00	4187,77	883,46	5071,23	9	1	10	1729,76
20	38,68	9,10	937,31	453,47	1390,78	2	1	3	937,87
21	33,04	7,70	849,80	374,44	1224,24	2	1	3	640,19
22	44,80	7,70	648,06	265,75	913,81	2	1	3	481,22
23	198,00	18,00	3915,18	714,30	4629,48	6	1	7	1652,70
24	29,20	9,00	740,01	284,93	1024,94	2	1	3	500,32
25	71,23	12,00	1785,85	438,48	2224,33	2	1	3	786,32
26	39,53	7,50	1053,6	413,14	1466,74	2	1	3	620,06
27	160,89	22,00	5714,47	3787,48	9501,95	6	3	9	1815,61
28	180,60	27,00	3610,96	1149,21	4760,17	8	2	10	1478,08
29	139,26	8,10	2210,09	1205,23	3415,32	2	1	3	1009,13
30	201,06	7,80	4474,99	2012,18	6487,17	2	1	3	1339,77
31	108,70	15,30	1623,18	269,83	1893,01	5	1	6	855,08
32	70,79	12,00	942,81	236,30	1179,11	4	1	5	630,32
33	260,31	16,00	2954,59	951,33	3905,92	5	1	6	1255,10
34	114,19	16,00	1993,65	542,50	2536,15	5	1	6	1027,78
35	183,93	16,00	1944,57	373,41	2317,98	5	1	6	906,16
36	154,71	15,80	2071,89	1129,76	3201,65	5	1	6	1014,60

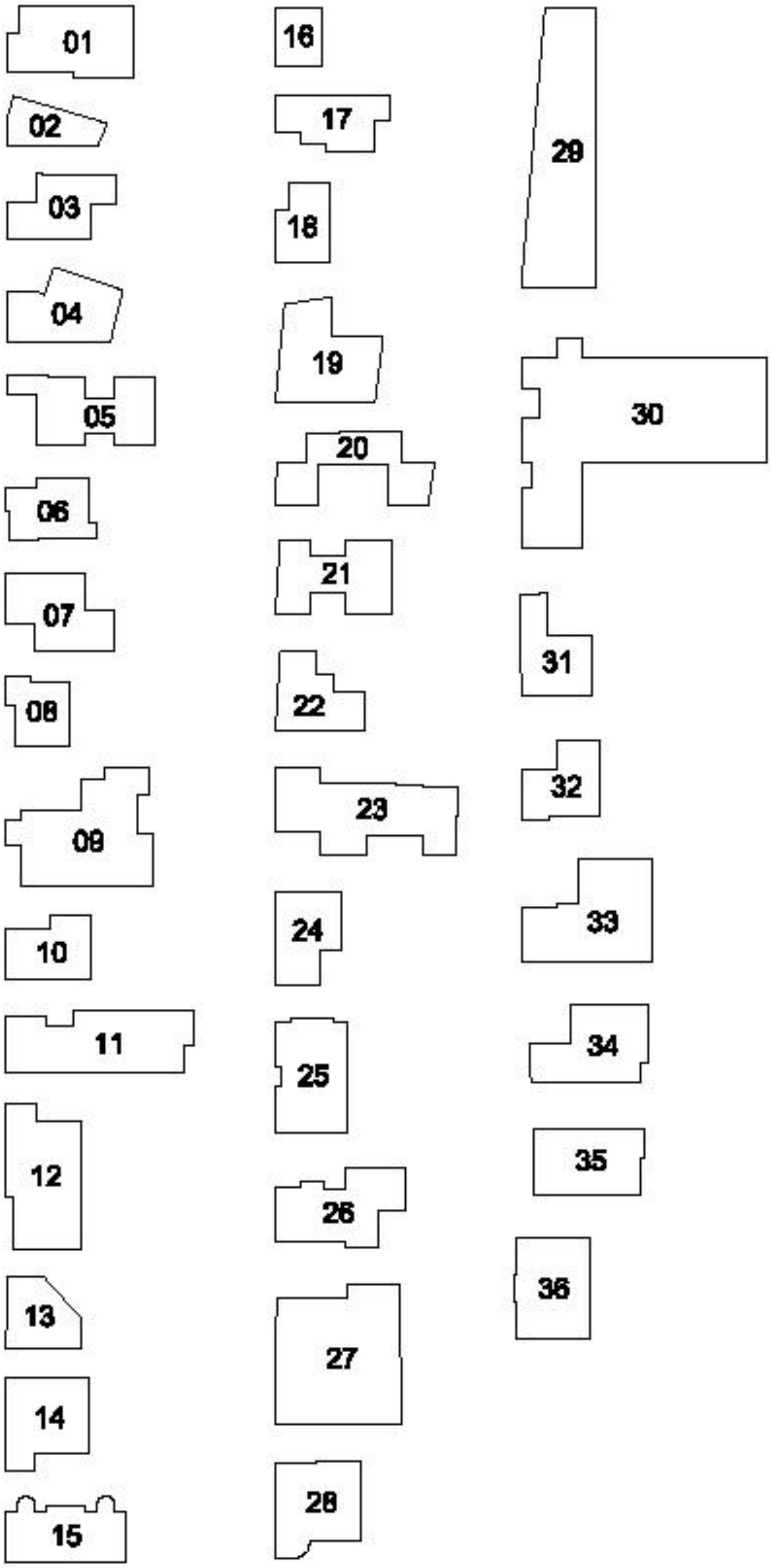
B.4 Calculated *Building Geometry Parameters* for the Sample of Building Projects

project	F	P	V	G	R	W	H
1	158,06	54,70	1424,33	51,97	144,39	191,45	12,10
2	67,47	36,27	683,28	36,27	67,47	126,95	12,90
3	100,71	47,75	857,59	45,42	95,86	167,13	9,60
4	123,20	47,69	1476,78	47,69	123,20	166,92	13,35
5	144,80	68,25	1062,04	68,25	144,80	238,88	7,00
6	89,93	41,80	728,58	38,00	75,56	146,30	10,30
7	123,39	51,00	1319,98	48,37	120,15	178,50	12,00
8	74,02	37,00	849,15	39,53	88,75	129,50	10,80
9	237,83	76,20	3243,37	77,91	261,44	266,70	15,30
10	91,45	40,90	1063,88	44,37	109,91	143,15	11,40
11	199,86	71,60	1236,19	60,90	161,39	250,60	8,00
12	187,87	61,25	2297,08	67,48	221,51	214,38	12,30
13	84,18	36,70	974,35	38,75	94,62	128,45	14,00
14	131,27	49,10	1665,09	55,97	166,43	171,85	12,00
15	130,16	55,05	1100,52	54,60	123,16	192,68	11,00
16	53,22	29,38	463,01	29,38	53,22	102,83	9,70
17	102,65	47,50	975,18	46,17	100,32	166,25	10,50
18	76,59	37,30	861,63	37,30	76,59	130,55	12,00
19	157,57	55,33	5071,23	56,90	164,25	193,66	30,40
20	127,40	74,78	1390,78	80,16	143,07	261,73	11,70
21	133,73	60,97	1224,24	60,97	133,73	213,40	10,50
22	100,20	45,83	913,81	45,83	96,67	160,41	10,50
23	217,51	79,47	4629,48	78,70	220,45	278,15	21,00
24	101,76	43,60	1024,94	42,40	96,79	152,60	11,80
25	151,87	53,70	2224,33	53,13	148,88	187,95	14,80
26	147,55	60,20	1466,74	60,20	136,76	210,70	10,30
27	310,49	72,57	9501,95	73,21	321,76	254,00	24,80
28	138,15	49,52	4750,00	49,60	146,13	173,32	29,80
29	338,87	94,84	3415,32	88,52	301,21	331,94	11,40
30	589,11	133,73	6466,31	120,70	531,01	468,06	11,10
31	103,78	47,77	1893,01	47,77	103,78	167,20	17,90
32	94,52	43,47	1179,11	43,47	94,52	152,15	14,50
33	204,37	64,30	3905,92	65,37	219,86	225,05	19,20
34	134,43	53,50	2536,15	53,53	140,28	187,25	19,20
35	133,36	48,20	2317,98	48,20	133,36	168,70	18,80
36	139,77	48,50	3201,65	53,40	175,32	169,75	19,00

B.5 Calculated *Building Morphology Coefficients* for the Sample of Building Projects

project	W/F	JC SE	POP	VOLM	LBI	PSI	m
1	1,21	0,09	0,81	0,98	2,30	2,23	4,35
2	1,88	0,10	0,80	1,40	2,47	2,47	4,42
3	1,66	0,19	0,75	1,10	3,36	3,05	4,76
4	1,35	0,07	0,83	1,29	2,15	2,15	4,30
5	1,65	0,42	0,63	0,88	5,87	5,87	5,67
6	1,63	0,10	0,80	1,10	2,45	2,35	4,41
7	1,45	0,15	0,77	1,19	2,93	2,46	4,59
8	1,75	0,08	0,82	1,48	2,16	1,87	4,30
9	1,12	0,24	0,72	1,13	3,84	3,52	4,94
10	1,57	0,07	0,83	1,39	2,10	1,97	4,28
11	1,25	0,27	0,70	0,70	4,17	3,46	5,06
12	1,14	0,12	0,79	1,13	2,61	2,78	4,47
13	1,53	0,00	0,89	1,43	1,01	N/A	4,00
14	1,31	0,07	0,83	1,31	2,12	2,26	4,29
15	1,48	0,21	0,73	1,00	3,54	3,79	4,83
16	1,93	0,01	0,88	1,37	1,26	1,26	4,03
17	1,62	0,17	0,76	1,17	3,18	2,98	4,69
18	1,70	0,07	0,83	1,44	2,05	2,05	4,26
19	1,23	0,10	0,80	2,29	2,45	2,53	4,41
20	2,05	0,66	0,54	1,19	8,86	9,12	6,63
21	1,60	0,32	0,67	1,05	4,74	4,74	5,27
22	1,60	0,14	0,77	1,15	2,90	3,11	4,58
23	1,28	0,35	0,66	1,56	5,06	4,82	5,39
24	1,50	0,08	0,82	1,22	2,22	2,19	4,32
25	1,24	0,09	0,81	1,37	2,32	2,31	4,36
26	1,43	0,24	0,72	1,07	3,88	4,40	4,96
27	0,82	0,03	0,86	1,77	1,63	1,50	4,12
28	1,25	0,05	0,84	2,50	1,92	1,57	4,21
29	0,98	0,29	0,69	0,82	4,41	4,27	5,15
30	0,79	0,38	0,64	0,72	5,40	4,64	5,51
31	1,61	0,17	0,76	1,80	3,18	3,18	4,69
32	1,61	0,12	0,79	1,44	2,62	2,62	4,47
33	1,10	0,12	0,79	1,48	2,69	2,45	4,50
34	1,39	0,15	0,77	1,69	2,99	2,74	4,61
35	1,26	0,04	0,85	1,60	1,80	1,80	4,17
36	1,21	0,03	0,86	1,90	1,57	1,29	4,10

B.6 Floor Plan Shapes of the Sample of Building Projects



This page intentionally left blank