Development of a risk based decision analysis system for project management in construction projects

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La vida es una aventura llena de riesgos, quien no se aventura a tomar esos riesgos, no la vive.

Live is an adventure full of risks, one who doesn't dare to take these risks doesn't live it.

Jesús Alfredo Sandoval Wong

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“*Padres: gracias por apoyarme a lograr este objetivo, el cual es totalmente dedicado a ustedes*”.

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Contents

List of Abbreviations

AHP	Analytic Hierarchical Process
AI	Artificial Intelligence
ALARP	As low as reasonably practicable
ANNs	Artificial Neuronal Networks
AS/NZS	Standards Australia and New Zealand
Att	Attibute
BREEAM	BRE Environmental Assessment Method
Caltrans	California Department of Transportation
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
CD	Concordance
COSO	Committee of Sponsoring Organizations of the Treadway Commission
Cp	Comprimising
DAR	Direct Access Ramp
DAM	Decision Analysis Methods
DAP	Decision Analysis Process
DBMS	Database Management Systems
DGMS	Dialog Generation and Management System
DIN	German Industrial Standard (Deutsche Industrie Norm)
DM	Decision Maker
DS	Descriptive Sampling
DSS	Decision Support Systems
DVP	German Association of Project Managers (Deutsche Verband der Projektsteuerer)
e.g.	Exempli gratia (for example)
ELECTRE	Elimination et Choix Traduisant la Réalité
ERM	Enterprise Risk Management
HOAI	German Fee Scales for Architects and Engineers (Honorarordnung für Architekten und Ingenieure)
hr	Hour
ICT	Information and communication Technology
KonTraG	Gesetz zur Kontrolle und Transparenz im Unternehmensbereich
KPI	Key Performance Indicator
KRi	Key Risk Indicator
KT	Kepner Trigoe Decision Analysis
kW	Kilo Watt
LAM	Linear Assignment Method
LEED	Leadership in Energy & Environmental Design

LHS	Latin Hyper-Cube Sampling
Macbeth	Measuring Attractiveness by a Categorical Based Evaluation Technique
MADA	Multi Attribute Decision Analysis
MAHP	Modified Analytic Hierarchy Process
MANIAC	Mathematical Analyzer Numerical Integrator And Computer Model I
MAPPAC	Multicriterion Analysis of Preferences by Means of Pairwise Actions and Criterion Comparisons
MAUT	Multi Attribute Utility Theory
MAVT	Multi Attribute Value Theory
MBMS	Model Based Management Systems
MCDA	Multi Criteria Decision Analysis
MCMC	Markov Chain Monte Carlo
MIVES	Modelo integrado de valor para estructuras sostenibles
MODA	Multi Objective Decision Analysis
MS	Microsoft
NC	Nominal Classification
NRAS	Neuronal-Risk Assessment System
NSW	New South Wales
OGC	Office of Government Commerce
PACMAN	Passive and Active Compensability Multicriteria Analysis
PERT	Program Evaluation and Review Technique
PMI	Project Management Institute
PM	Project Management
PMs	Project Managers
PRAGMA	Preference Ranking Global Frequencies in Multicriterion Analysis
PROMETHE	Preference Ranking Organization Method for Enrichment Evaluations
QRA	Quantitative Risk Analysis
RAROC	Risk Adjusted Return on Capital
RM	Risk Management
RMP	Risk Management Process
RPA	Risk Potential Assessment
SAW	Additive Weighting Method
Sc	Screening
[sic]	Intentionally so written, according to the source
SMART	Simple Multi Attribute Rating Technique
Sr	Sorting
SVM	Support Vector Machines
TODIM	Tomada de Decisão Interativa Multicriterio
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
UK	United Kingdom
USA	United States of America

VaR	Value at Risk
VMIA	Victorian Managed Insurance Authority

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1 Introduction

In every construction project there are a high number of criteria and factors, the combination of them should always be performed aimed to fulfil the desired requirements; which criteria and how to evaluate them, that's the main core of the project development. However the criteria selection and evaluation process is a result of a decision analysis problem, therefore every decision taken requires systematic and defined evaluation methods.

Human being take decisions all the time, though it is difficult for us to explain how our intern decision analysis procedure works, this mainly because it is so efficient besides fast that we don't even realize how we evaluate and weight criteria. However when we are confronted with decisions using a high number of criteria, our intern decision analysis procedure is deficient; according to Miller we cannot achieve a reliable decision when more than 7 +/- 2 criteria are involved[1]. Thus it is imperative to implement a systematic aimed to secure a liable decision in every construction project.

The decision analysis methods are mathematical procedures that make it possible to analyse and evaluate alternatives, based in a high number of requirements and goals in a quantitative form; they also permit it to introduce a systematic to de decision process and make possible to review the decision in a quantitative way at any moment. Besides they also permit the elaboration of global assessment procedures, in which all required criteria are simultaneously evaluated regardless of their units.

Another topic is the use of risk management in construction projects. This field is concentrated in the analysis of fluctuations in all variables and finally the way they influence a desired goal and the corresponding probabilities of success together with the procedure of how to abet them. Nevertheless risk management is no new field in the construction industry, however the recent events of global crisis in 2008 have shown, that the way in which risk analysis has been performed, is not reliable and requires new conceptions. In the project development, risk management and especially its sub process "risk analysis" is gaining in importance in order to provide more certainty to the construction projects.

The main Target of this work is the utilization of decision analysis to make possible the inclusion of risk analysis as a criterion in project management.

1.1 Current situation and scenario definition and motivation

Decisions analysis is the main occupation of the human being, nevertheless we never take time to analyse how we really evaluate our decisions. After contact with a state agency in Germany, it was clear that this problematic is the same in the development of every construction project. Project development has a strong need of sys-

[1] (Miller, 1956) and according to interviews by (Kaiser, 2011)

tematic, transparency and risk management aimed at performing an alternatives evaluation under quantitative considerations.

Nowadays there are several decision analysis methods that support the selection of alternatives, and in this form they provide more certainty to the decision analysis process. Nevertheless they are still not quite common in the construction industry and consequently, their benefits are not exploited. These methodologies are gaining in relevance due to their application as computer programs, and in this form they can be easily applied in the construction industry.

Risk analysis is performed mostly as a subjective evaluation (check lists) in the construction industry and in very rare occasions as a quantitative procedure (stochastic evaluation). Currently there are many risk analysis methods that can be applied as computer programs and they are mostly used in the financial sectors, science and research but rarely in the construction industry and still many of these methods are not even known for many constructors. Thus the benefits offered by risk analysis are also not exploited. In the last days new methodologies from the artificial intelligence are emerging and they have shown high potentials for its application in the risk analysis.

Another problematic is even the definition of “risk”; risk can be understood in many different forms, from the multiplication of probabilities with their effects, until uncertainty. Consequently this provokes strong misunderstandings and problems among the many participants in a project. Therefore it is vital for any project, to clarify this criterion before the project development takes place. This dissertation present a differentiation between risk and uncertainty, nevertheless in practice and in research there is not a unique definition.

1.2 Aim and objectives

The main goal of this research is the combination of project management together with decision analysis and risk management; for developing a decision risk analysis system that allows evaluating all necessary criteria required in a construction project in a single assessment method. This system aids the project development in the assessment (project alternatives), for the fulfilment of expectations in any construction project, through the introduction of clear goals, systematic and transparency into the process.

The proposed system is composed of a “System” and a “Decision analysis model”. The system is developed to assure the correct functionality of the decision analysis model. Its practical application is presented at the end of this work.

1.3 Structure of the dissertation

The state of the art, foundations and definitions of decision analysis are presented in chapter 2. Several decision analysis methodologies their advantages and drawbacks are analysed and discussed in this section. The selected decision analysis method applied in the system is presented at the end of this chapter.

In chapter 3 the state of the art, foundations, history and a brief introduction to risk management is explained. A definition of risk and uncertainty is also presented in this section, together with the risk management process and the different methods for the risk analysis. The new methodologies from the artificial intelligence field are also here analysed and discussed.

Chapter 4 presents framing and requirements for an appropriate functionality of the system, thus the state of the art, foundations, history and a brief introduction of project management and project development are presented. Other fields that gained high relevance recently are the sustainability and life cycle analysis in construction projects. Therefore this analysis or in other words requirements, are briefly presented due to the fact they conform and define the proposed system. This chapter presents how the criteria can be collected for the decision analysis model performed in the system and delimitate the functional requirements given by the project management.

Chapter 5 introduces and explains the new decision risk analysis system and presents its functionality. This section also introduces a methodology for the risk analysis by combining artificial neuronal networks (ANNs) and Monte Carlo simulation (MCS). This methodology permits to increase levels of certainty in the risk analysis. The decision risk analysis system is described in detail together with all important requirements for its implementation.

Chapter 6 presents the application of the new decision risk analysis system; therefore the testing and analysis process of the decision risk analysis system is included in this chapter. For this objective data provided from a real life project were employed. The tests were divided into three stages; first to evaluate the applicability of the system on real projects, therefore a performed project developed was modelled with the analytic hierarchical process (AHP). Second to evaluate functionality and flexibility of the proposed decision analysis model, the same test was performed with the proposed decision risk analysis model. A third test was prepared using an empirical example, conducted to high light the new possibilities offered by the proposed system and the use of risk analysis, specially the ANNs + MCS developed in this work. This chapter explains how to apply risk analysis in the project development for a construction project.

Conclusions are presented in chapter 7. The opportunities offered by the implementation of the system in the construction field are included with further enhancement recommendations.

2 Decision Analysis State of the Art

2.1 Introduction

The most important characteristic of the human being is his capacity to think and to analyse factors with the ultimate goal of making a decision. These decisions are permanently influenced by several factors, attributes and characteristics; their combination conforms and defines the desired result of the decision process.

In the construction industry but also in many others fields, decision analysis is often a ly complicated process mostly because of the high amount of factors, the criteria evaluation, sort of the data and information, etc., for all these reasons, methodical procedure in its approaches proves itself as an important and meaningful support for the decision analysis process. Therefore “Decision Analysis” is one of the most important achievements of an engineer within the project management.

There are different concepts with corresponding methodologies which support decision analysis, they are known as the “Decision Analysis Methods (DAM)”. Currently the DAM are widely used in many and diverse fields, according to their specific considerations, different methods were developed with different points of view and principles. The adequate selection of the most appropriate method according the problem’s characteristics is one of the most important tasks on its own solution through DAM.

The terms Multi Criteria Decision Making (used in North America) and Multi Criteria Decision Aid (Introduced by Roy, 1985 and Vincke, 1992 and commonly used in Europe) are two analogue notations used for the Decision Analysis[2]. These notations are currently known by researchers (the today’s state of arts surveys) as the “Multi Criteria Decision Analysis” (MCDA).

There are terms and concepts in the decision analysis field that are commonly used by decision researchers, the most important concepts are defined in the glossary[3] for a better comprehension of the methods and their basic characteristics treated in this chapter.

2.2 Decision Analysis

Decision analysis is a process in which alternatives are compared and conducted to meet an adequate acceptance according to the desired expectations. This process has been analysed and classified in two large disciplines, the “Descriptive Decisions Theory” and the “Prescriptive Decision Theory”.

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[2] For the present research the terms “Decision Making” and “Decision Aid” are integrated into the “Decision Analysis” to uniformity and adequacy with the newest state of arts surveys.

[3] These concepts have several definitions according to several authors; the definitions presented by this research are made by the means of this work.

- Descriptive Decision Theory - attempts to describe how the decisions are made based on the functionality of the human brain (better known as "entity").
- Prescriptive Decision Theory - deals with making the best decision possible, hence this discipline develops techniques and methods to assure that the selection of the best choice will be achieved.

In general, decision analysis encompasses examinations from cognitive research (descriptive decision analysis as the process of how the decisions in the brain are made), to the development of mathematical procedures to evaluate and select solutions from suitable alternatives (prescriptive decision analysis).

The main target of this work is based on prescriptive theory, which means the conception of decision models that make it possible to evaluate the alternatives and to confer aid selecting the best choice.

Thinking and action psychology defines Decision Analysis Process (DAP) as behaviour's chain which follows actions and effects[4]. It's known that the brain works with the same pattern regardless of the size or importance of the decision; this means that the brain always has the same behaviour, independent of the kind and importance of the decision to be made.

The beginning of the process (when we refer to the DAP as mental process), takes place with an analysis of the inputs that the decision maker (DM) collects or has available. The inputs will be compared and assigned into a pattern; in this form the Input-pattern will be created (Figure 2-1).

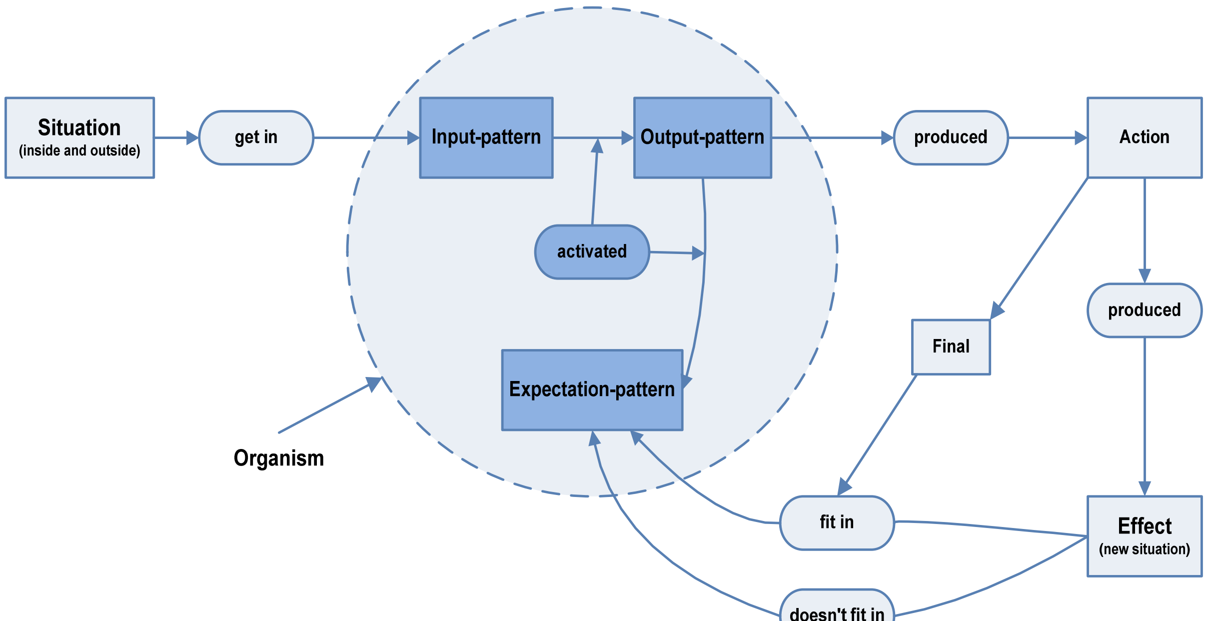

Figure 2-1: Action-reaction, expectation and result translated from (Dietrich, 1985)

[4] (Dietrich, 1985)

The Figure 2-1 illustrates the Decision Analysis Process from the thinking and action psychology view. The Input-pattern is processed by the brain and it will activate an Output-pattern (action-reaction), the Output-pattern will be compared and analysed in opposition to the expectation; these expectations (a set of goals) are normally determined by the DM or a group of them, these expectations will be defined as the Expectations-pattern.

This Expectation-pattern will be the base of the expected ideal Output-pattern and in the case that the Output-pattern doesn't fit the expectation-patterns, the Output-pattern will become a new Input-pattern after it is adjusted (or reworked) by the DM, based on the expectations-pattern (the newly-arranged situation is also known as "effect"). This process will be repeated until an acceptable Output-pattern (normally the ideal or best solution) is found.

Dittfach classified the decisions from the cognitive psychology view in four different types according their information, time for the decision, mental representation, cognitive process and consciousness[5]:

- **Routine decisions:**
  Normally fixed not flexible decisions with lower mental display, these decisions are normally met through a matching process in accustoming hierarchies, low time and no consciousness needed.
- **Stereotype decisions:**
  Normally fixed low flexible decisions with lower mental display, these decisions are normally met through a learned schema with no need of verification but by a situation's check, low time and low consciousness needed.
- **Reflective decisions:**
  Normally high varying and flexible decisions with higher mental display, these decisions are normally met through a preferences analysis of data from different options gained by research and experience. The option's information will be compared with the goals and the desired adequacy, high time and high consciousness needed.
- **Constructive decisions:**
  Normally high varying and flexible decisions with higher mental display, these decisions are targeted to the goals and normally met through a preferences analysis of data gained by research and experience, in contrast to reflective decisions the options are not given, they have to be results-oriented, high time and high consciousness needed.

The decision analysis problems are normally important and complex challenges to solve and to structure, they normally require a great number of information and criteria. The effective compiling and processing of all these factors means an effective support to the task. Accordingly to this work the concept of decision analysis will be

[5] (Dittfach, 2006)

used exclusively, around the alternative selection process concerning the construction projects.

The construction projects require an enormous number of data and goals as well as high consciousness from the DM; hence the kind of decisions to be treated in this work lies within the Reflective and Constructive decisions. The main topic of this research is to accomplish the selection of the best alternative possible; therefore the Prescriptive Decision Theory will be the foundation to scrutinize.

2.3 Multiple Criteria Decision Analysis (MCDA)

The first references to decision analysis date back from the Catalonian theologian, philosopher and logician "Ramon Llull" (1232-1316) and his analysis of logical functions (conjunctive and disjunctive). However the decision analysis was treated first in a better way by the Italian engineer, sociologist and economist Vilfredo Federico Damaso Pareto (1848-1923) from an axiomatic view and with special consideration of the criteria inconsistency and evaluation index[6].

Because of those first considerations the procedures of the multiple criteria decision analysis were created. The current MCDA is based on the researches of Simon (1982), Keeney and Raiffa (1976) who proposed the utility functions and Roy (1968, 1985) who established the outranking methodology and Kahneman and Tversky (1979) of the psychological investigations[7].

The field of decision analysis has been very active in the last 30 years and especially in the last years great improvements have been developed, this is reflected by a high number of applications on computer programs (see section 2.8), which opened new and important possibilities for Decision Analysis.

2.4 The General Decision Analysis Problem

When a decision has to be made, it's important to develop a strategy (a disciplined methodology) with the intention of securing and facilitating the accomplishment of the task (meeting a decision); the strategy shall help to make the best or appropriate decision in an adequate time, with optimal use of resources besides minimal costs and, as a result, high reliability.

Decision analysis methodologies are a very large concept field, they are normally utilized to provide structure and reliability to the analysis process, DAM have been applied to very different knowledge fields like engineering, operations research, psychology, management, sciences, business, etc. and were examined from several different approaches.

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[6] (Doumpos, 2006)

[7] (Eiselt, 2004) and (Belton, 2002)

Many authors have proposed many approximations regarding how to address a decision analysis problem. Most of them proposed methods that in general require similar information, structures and have similar needs, these are:

- Goals
- Expectations
- Criteria
- Structure (regarding to the DM and the criteria)
- Alternatives
- Definition of the decision maker(s)
- Decision analysis methods

The systematization of the DAP is based (regardless of the order) on the factors mentioned before. The *"Guidebook to Decision-Making Methods"*[8] presents an approximation to this matter; in which the DAP is described in eight steps; all these eight steps have the goal of solving all kinds of decision making problems through a "General Decision Analysis Problem".

The General Decision Analysis Problem (Figure 2-2) is a simple representation of different sub processes contained in the DAP; this representation allows the DM to contemplate the DAP in eight different steps, through them the DM can reach a better organization concerning to the collection and processing of all the necessary data to accomplish each of the eight steps and finally achieve the best decision possible.

By making the decision, many factors can be overlooked, loosened, not registered, forgotten or just not adequately prepare in its analysis. The systemization of the DAP ensures that the decision to achieve, reach the best accuracy possible and that the possible hazards that by the planning come into being, to be reduced to its minimal or properly treated. The use of a system to structure the DAP can be translated as a support in order to the increase of effectiveness and quality in the process plus a better accuracy within the DAP.

Nevertheless the ability to reduce the hazards created on the DAP itself, is based in the preparation and skills of the decision analysis team besides the knowledge of the specialists on the different fields to be solved.

The different steps of the General Decision Analysis Problem (see Figure 2-2), are defined as follows:

"Step 1, Define the Problem:

The goal is to express the issue in a clear, one-sentence problem statement that describes both the initial conditions and the desired conditions.

Step 2, Determine Requirements:

[8] (Baker, 2002)

Requirements are conditions that any acceptable solution to the problem must meet. Requirements spell out what the solution to the problem must do.

<u>*Step 3, Establish Goals:*</u>

Goals are broad statements of intent and desirable programmatic values. Goals are useful in identifying superior alternatives; they are developed prior to alternative identification.

<u>*Step 4, Identify Alternatives:*</u>

Alternatives offer different approaches for changing the initial condition into the desired condition.

<u>*Step 5, Define Criteria:*</u>

Each criterion should measure something important, and not depend on another criterion. Criteria must discriminate among alternatives in a meaningful way.

<u>*Step 6, Select a Decision-Analysis Tool:*</u>

The method selection needs to be based on the complexity of the problem and the experience of the team. Generally, the simpler the method, the better.

<u>*Step 7, Evaluate Alternatives against Criteria:*</u>

Alternatives can be evaluated with quantitative methods, qualitative methods, or any combination. Criteria can be weighted and used to rank the alternatives.

<u>*Step 8, Validate Solution(s) against Problem Statement:*</u>

After the evaluation process has selected a preferred alternative, the solution should be checked to ensure that it truly solves the problem identified"[9].

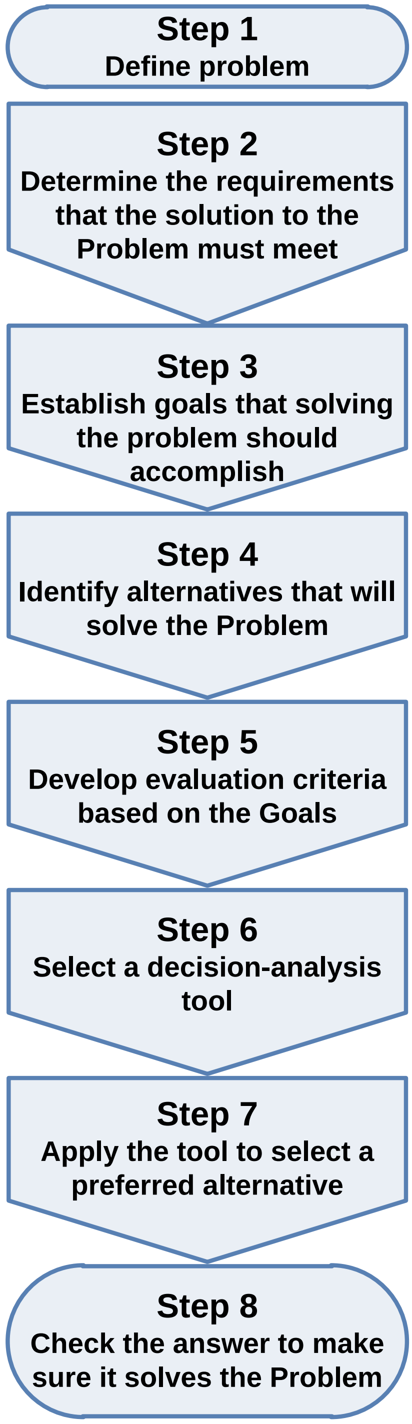

Figure 2-2: General decision analysis problem (according to (Baker, 2002)).

The General Decision Analysis Problem presents an adequate basic structure for the solution of decision analysis problems (it's important to mention that this is only for the preparation of the decision analysis process). Step 6 Select a Decision-Analysis Tool is a very important process, for which the different Decision Analysis Methods need to be defined, listed and classified.

[9] (Baker, 2002)

2.5 Decision Analysis Methods (DAMs)

In 1956 a professor of psychology at Princeton University "George A. Miller" published *"The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information"*[10]. On this paper Miller proved that the human being can make without problems a decision, when no more than 7 +/- 2 criteria or data are involved; beyond this limit (7 +/- 2) the DM will have accuracy problems and consequently, the own efficiency will be reduced. The DAMs are Instruments to compensate this human deficiency.

DAMs are rational techniques in which the logic and systematic processes are abstracted and synthesized in different steps (these steps are built in compliance with the method). The DAM in general (according to its complexity), use the same information and have similar requirements or entities which normally are:

- Decision Maker
- Criteria
- Goals
- Alternatives
- Scores and Weights

Depending on the method the different factors are conformed to and used in virtue of the method's principles, there are different basic comparison principles on which the DAM are established; based on those principles and other concepts, some classifications are here presented.

Two of the simplest methods within the decision analysis are methods like the decisions trees and the Pros- and Cons analysis, these methods present not enough certainty on its procedure and may be considered like a preliminary evaluation, besides these methods are normally contained in other methods, hence they don't need to be considered in the present analysis because of its simplicity, but they are important enough to be mentioned; they can be classified as linguistic aggregation methods.

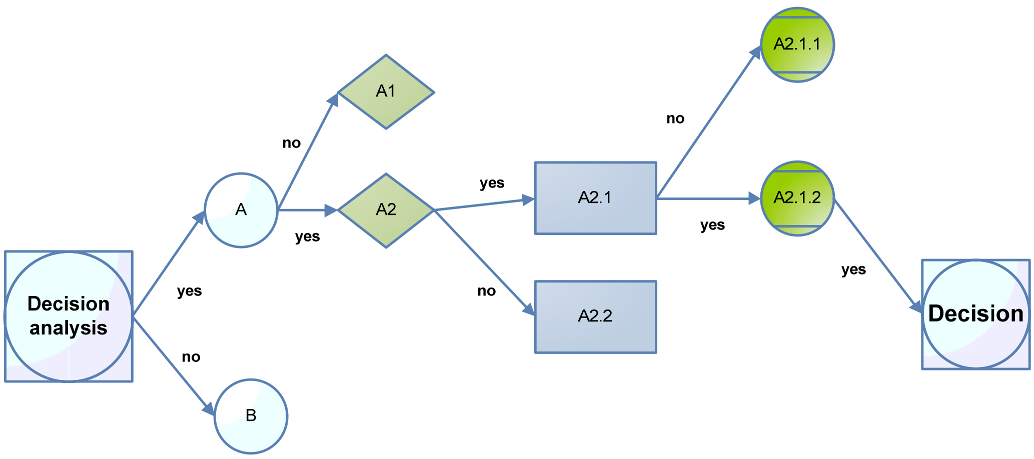

Figure 2-3: Example of a decision tree

[10] (Miller, 1956)

Figure 2-3 presents a diagram of a decision tree, it is clear to see how this method works based on a linguistic rule like the "if …, then…". This method is helpful when the DM needs a rule to follow when the justification is clear.

The Pros- and Cons analysis is a list with the advantages and disadvantages of each alternative or criteria, this procedure is very subjective and presents complications to maintain the overview when the number of criteria is high (remember the seven criteria by Miller).

2.6 Decision Analysis Methods Classification

The classification of the multi criteria decision analysis methods (MCDAM) is a problematic that represents a gigantic challenge, many authors have attempted this problematic, but because of the enormous amount of data, considerations, mathematical procedures, goals and logic it remains only partially solved. Anyhow the classification of the MCDAM makes sense when is elaborated based in the problem's needs.

The classification of the MCDAMs enclosure on this section is based in the problematic and needs of this work, which is from a civil engineering point of view. Several authors have classified the DAM under their terms and different criteria, by the implementation of the present research, the classification of the MCDAM is not the main target of this work but it represents an important effort to simplify the task of choosing the appropriate method.

Hwang[11] as well as Zimmerman[12] defined two different appreciations of the DAM; the Multi Attribute Decision Analysis (MADA) and the Multi Objective Decision Analysis (MODA). The MADA attend to a problem in which the numbers of alternatives are set (discrete problems) and the MODA are problems on which its variables have a tendency to be constant. This means that the MADA take care of the prioritizations and Ranks between the alternatives, with the goal of choosing the best of them, while the MODA concerns to the design of the most promising alternative from endless alternatives.

The general framework of this work is focused on the MADA, which implies the solution of a discrete problem; because of this reason the methods created for the MADA will be the gist of this work.

Bernard Roy (1996) identified four different categories for the MCDA, the *"Choice Problematic"* (simple choice of an alternative), the *"Sorting problematic"* (distribute action in categories), the *"Ranking problematic"* (place actions in preference orders) and the "Description problematic" (action reaction evaluation). Belton, V. and Stewart, T. included two more categories the *"Design problematic"* (creation / identification

[11] (Hwang, 1981)
[12] (Eiselt, 2004)

of goal targeted alternatives) and the Portfolio problematic" (to confine the number of alternatives not only by the criteria, but by their collective interactions)[13].

Ye[14] classifies the DAM by their simple functionality related to how the Methods solve the problems; he divides them in three main groups; the *"Screening problems in MCDA", "Sorting problems in MCDA"* and the *"Multi Criteria Nominal Classification"*. These three methodologies comprehend several methods; from the simplest methodologies like interviews to the most complicated multi attribute problems applied in mathematical procedures.

Screening (choice) problems in MCDA:

The principle idea is to reduce a large amount of alternatives to a manoeuvrable group that contains the best (feasible) choice. A typical example of this method is a job interview; many candidates are interviewed to define the best alternative[15]. This methodology applies when not much information is available and the best choice can be directly identified.

Sorting problems in MCDA:

In this category the decisive principle is to classify a high amount of alternatives into a small number of groups in a preference order; with the main intention of simplifying and supporting the DM to make his decision in a more effective way. Within this category are two kinds of sorting methods, the "*Direct judgement methods"* and the "*Case-based reasoning methods*"[16].

The direct judgement methods exercise a decision model in which the DM collects information to evaluate the desired alternative's parameters. On the case-based reasoning methods the DM perform simulations on selected cases in order to distinguish the parameter's behaviour and with this to regulate the procedure.

Multi Criteria Nominal Classification (MCNC):

Under this category, the alternatives will be placed in structured groups; these groups are previously defined by the considerations of the DM, as well as the number of groups and their characteristics. An example of this category is the selection process by human resources department, when a group of co-workers have to be distributed on different departments, therefore their capabilities will be analysed and the distribution will be according to each particular result of their capacities[17].

This classification proposed by Ye Chen is just one of the several attempts to deliver a definitive classification of the MCDA, he achieves an important analysis and defini-

[13] (Belton, 2002)
[14] (Ye, 2006)
[15] Likewise
[16] Likewise
[17] Likewise

tion of these three categories plus an investigation of how should a researcher approach to the MCDA, his work is oriented to mathematicians and operation researchers, either way the problem of classifying the MCDAM is a large endeavour. The following classification developed in this work, has been made based on the method's principles and their mathematical data processing or in other words, the mathematical data comparison procedure.

Decision Analysis Methods		
Classification		
Simple Comparison	- Dominance Method - Maximax - Maximin - Conjunction Method - Disjunction Method - Lexicographic - Lexicographic Semi order Method	- Elimination by Aspects - Permutation - Distance from TargetNon-Dominated Set (NDS Computation) - Argus
Aggregation	- Linear Assigment Method - Simple Additive Weighting Method (SAW) - Analytic Hierarchy Process (AHP) - Modified AHP - Measuring Attractiveness by a Categorical Based Evaluation Technique (Macbeth) - Ariadne Method - Kepner Tregoe (K-T) Decision Analysis	- Cost/Benefit Analysis - Multi Attribute Utility / Value Theory (MAUT / MAVT) - Simple Multi Attribute Rating Technique (SMART) - Goal Programming - UTA
Outranking comparison	- Elimination et Choix Traduisant la Réalité (ELECTREE) - Preference Ranking Organization Method for Enrichment Evaluations (PROMETHE) - Tomada de Decisão Interativa Multicriterio (TODIM) - Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) - ORESTE	- Qualiflex - MAPPAC - Regime - MELCHIOR - IDRA - PACMAN - PRAGMA - TACTIC

Table 2-1: Classification of the decision analysis methods

The classification (Table 2-1) is based on the method's principles; it shows an arrangement to differentiate the DAM in three main categories or principles related to their mathematical comparing procedure, which represents the main mathematical discernment. These methods are widely used DAM applied on many fields, it's important to remark that the functionality of these methods is not the only difference between them, they have diverse particularities according to the kind of problem they solve as well as their information's requirements.

- **Simple Comparison Methods:**

These methods realise a "systematic direct comparison" of all the available data (criteria) of each alternative compared to others. Through these comparisons the best alternative is chosen.

- **Aggregation Methods**:

These methods can be defined as the arrangement of an unique "criterion synthesis", the fundamental procedure in the aggregation methods is the determination of scores and weights, through the multiplication of the criteria weights with their scores and its addition the result are determined, the results will be a global score and its presented in partial or complete ranking lists, from which the highest score normally means the best choice. These sorts of methods have a compensatory nature.

- **Outranking Methods:**

The most imperative principle by the Outranking methods is the "binary scrutiny" (pair wise comparison also known like binary comparison) of the whole decision's criteria. "*The outranking relations approach was developed in Europe with the presentation of the ELECTRE methods*"[18]. Most of the methods perform a comparison of the alternative's criteria to each other based on the Concordance and Discordance principles in this way elaborate a structure (Outranking-relationship) on which the preferred alternative is presented. These sorts of methods have a non-compensatory nature or in other words, they are based on the most dominant characteristics of the assessed alternative's criteria.

Most of the DAM make use of weighting techniques, that allows the attribution of values to the criteria and in this form to reflect the preferences of the DM, finally the DAMs assess the comparison of alternatives in a single representative function; in other words they use the "trade off based weights", which means that the methods are compensatory like for example the analytic hierarchical process (AHP) method, besides the outranking methods are an example of the "non-trade off based weights" or non-compensatory.

Many other methods like UTA (Jacquet-Lagreze, E. & Siskos, J. 1982), MAUT (Keeny & Raiffa 1976) and SMART (Kamenetzky 1982) make use of the "Utility functions", these functions are based on the Utility Theory developed by Neumann and Morgenstern in 1944[19]. These methods are aggregation models based on preferences with regard to every criterion; in these models the DM is able to shape the global preferences through a mathematical function for its evaluation.

Utility functions transform the inputs (alternative's values) under predetermined considerations in desired dimensionless values and through them; the DAM performs its evaluations to produce better accuracy on the selection process.

Within the MCDAM exist three different logical principles for their functionality relating to the ideal alternative (solution); these principles enable the MCDAM to perform its discernment and assessment of the alternatives:

1) **Scoring principle:**
   The alternative with the highest score will be selected

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[18] (Zopounidis, 2006)

[19] "The "Utility Theory" is the application of axioms (Benefit functions) (De Montis) that transpose different alternative values (quantitative and qualitative) into a homogeneous scale (normally from 0 until 1). This scale is used for the evaluation of the criteria. The axioms must be arranged from the characters of the criteria.
Aragonés ascertain that the valuable function is supposed to reflect the DM's preferences in to a value, which is a scale into real numbers. They have to satisfy two properties: transitivity and comparability.

2) **Compromising Principle:**
   The alternative nearest to the ideal solution will be selected
3) **Concordance and Discordance Principle:**
   A set of preferences will be arranged along with a concordance (pairwise index about the positive arguments that alternative "A" is better than "B") and discordance (pairwise index about the negative arguments that alternative "A" is better than "B") quantification, the alternative that fits better this measuring, will be selected.

Chen presented also a classification in a simple table (see Table 2-2)[20], it is a classification based on the type of information required to the development of the evaluations. This classification illustrates clearly which methods need information from the DM and which methods are able to use cardinal and ordinal Information as well as the way this information is presented.

The mentioned "complementary methods" have been added to the table during the completion of the present research, many of them were developed after the publication of the work of Chen; however this classification presents an appropriate applicability to the discernment of choosing a DAM.

S. Moffett and S. Sarkar presented in 2006 in their work *"Incorporating multiple criteria into the design of conservation area networks: a minireview with recommendations"*[21], the *"Taxonomy of MCDM methods"*. The taxonomy of the MCDA methods represents an important contribution to the classification of the decision analysis methods, it is easy to see there how the methods can be easily classified through their simple discernment, their rankings functionality and the type of criteria.

[20] (Chen, 1992)
[21] (Moffett, 2006)

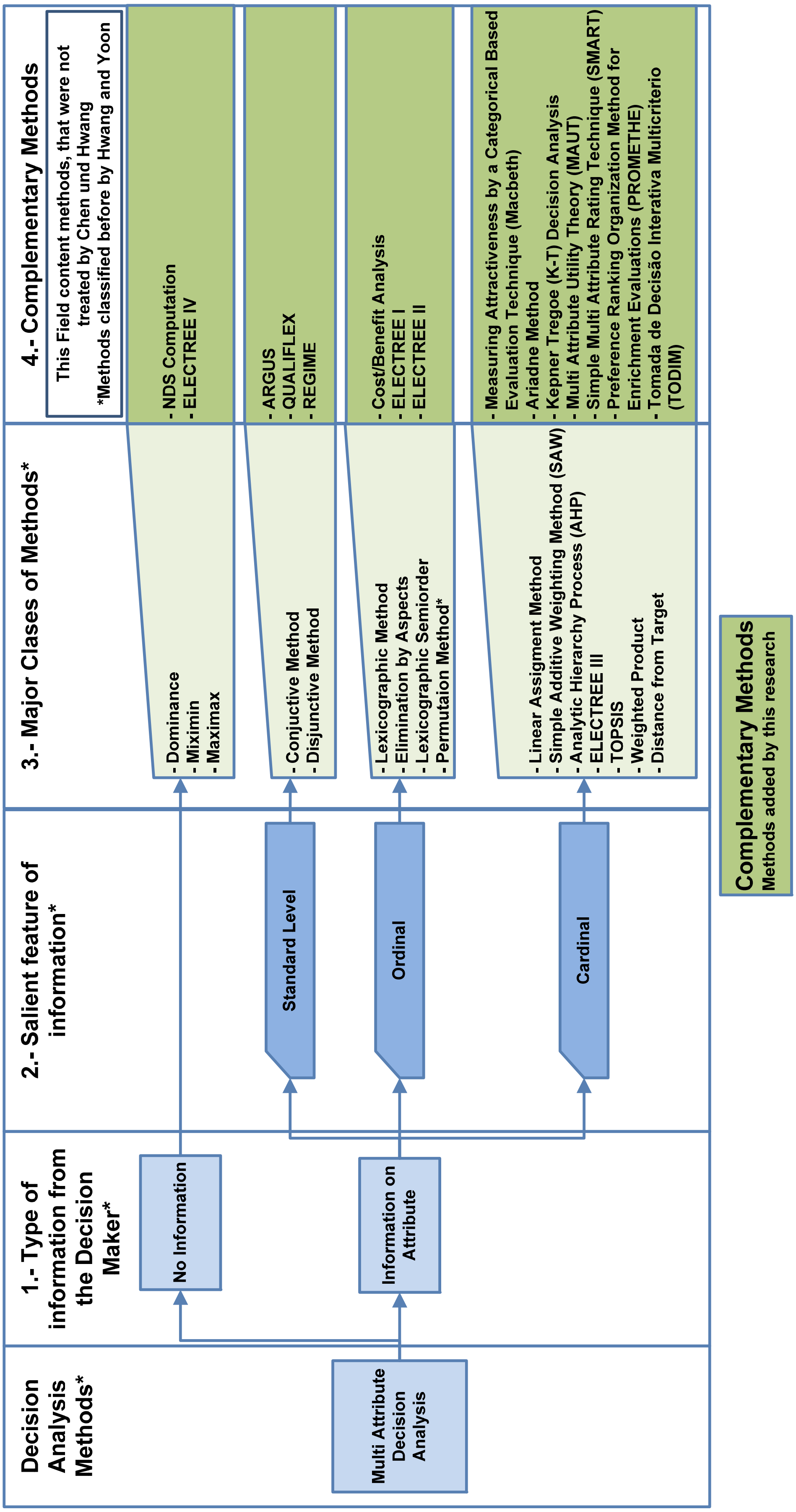

Table 2-2: MADA classification by the required sources of Information, according to (Chen, 1992) with complementary methods.

This taxonomy was presented under the consideration of solving a design of conservation area networks problem, hence the methods were filtered for their own problematic; for this reason the taxonomy here presented (see Figure 2-4), was completed with some other methods (complementary methods) not mentioned by S. Moffett and S. Sarkar but important for this work.

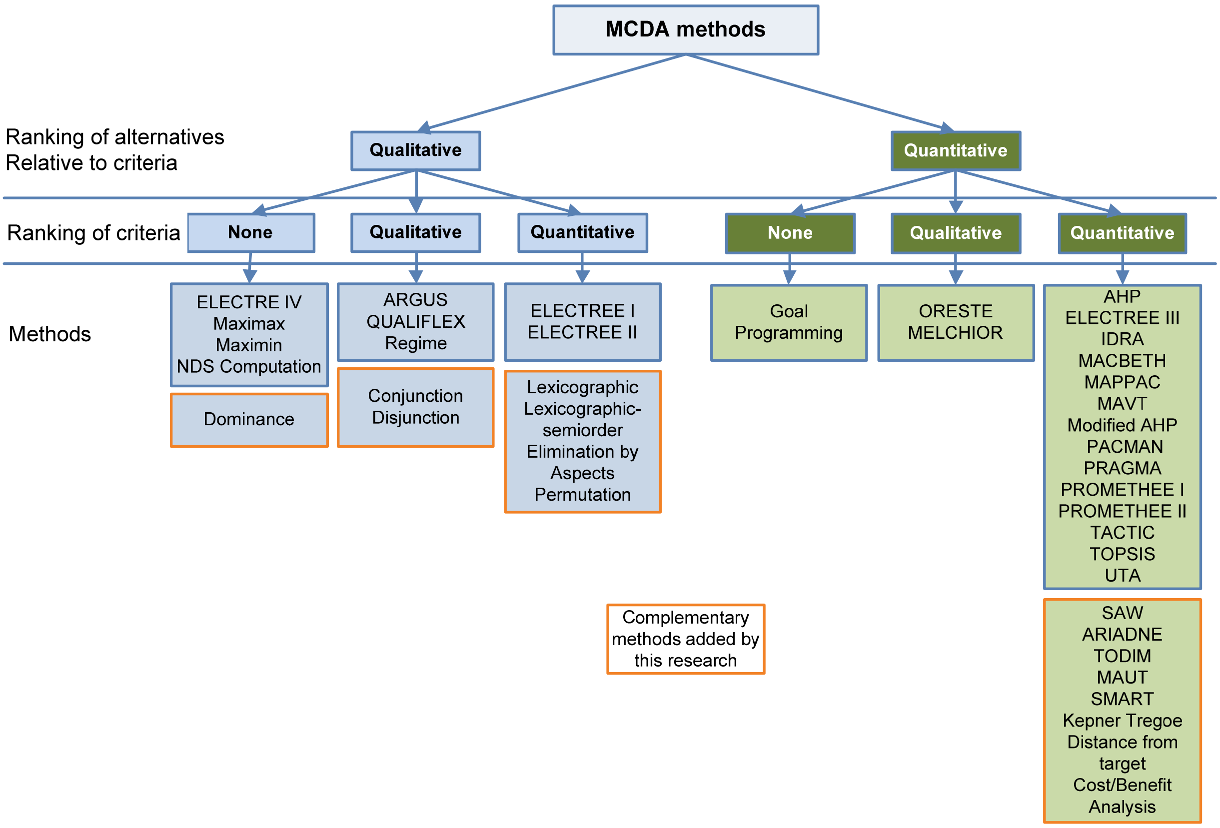

Figure 2-4: “Taxonomy of MCDA methods” based on requirements placed on criteria and alternatives (Moffett, 2006) with complementary methods.

2.7 *Description of Decision Analysis Methods*

The above mentioned methods on the Table 2-1, Table 2-2 and Figure 2-4 are mainly the most relevant methods within the framework of this research. The “complementary methods” mentioned on the Table 2-1, Table 2-2 and Figure 2-4 includes methods developed until the development of this work (state of the art surveys).

In the mentioned tables and figure it can be easily seen that the development of the DAM has an important growth within the multi criteria aggregation and outranking methods (using cardinal and ordinal criteria types). For the reason that in the actuality the regular problems are a combination of several conflicting factors (ordinal and cardinal) with each other, and only sometimes big decisions are made under one single not multi criteria factor or based action.

The methods that are able to perform a decision analysis with a simultaneous implementation of this two different types of criteria are more suitable methods, for the reason that they are the closest representation of reality and consequently more appropriated and versatile.

Nevertheless it's important to get an overview of the different DAM and describe their discernment, pros and contras; with this intention is a brief description of them and their most important characteristics.

1) Dominance Method

Discernment: It works with a basic comparison principle, an alternative is the best until another alternative exceeds it in one or more attributes and equal on the others; method based on the scoring principle.
Pros: Easy to use and to understand.
Contras: Some of the discarded alternatives can be better than some other (none dominating) alternatives; non compensatory.

2) Maximax Method

Discernment: The selection of the best alternative is determinate on the selection of the best value of one attribute; method based on the scoring principle.
Pros: Easy to use and to understand.
Contras: An alternative is represented with just one attribute, the rest are ignored; non compensatory.

3) Maximin Method

Discernment: The general evaluation of an alternative depends on its weakest attribute; method based on the scoring principle, the weakest attribute rules the selection; method based on the scoring principle.
Pros: Easy to use and to understand.
Contras: An alternative is represented with just one attribute, the rest are ignored; non compensatory.

4) Conjunction Method (Satisfying Method)

Discernment: Through the definition of minimal values for the attributes, the alternatives which don't fulfil them will be rejected or delegated; method based on the compromising principle.
Pros: Easy to use and to understand.
Contras: Alternatives with just one bad valued attribute will be rejected, no matter how good the other attributes are; non compensatory.

5) Disjunction Method

Discernment: Through the definition of expected values for the attributes, the basic principle is to select the alternatives with extremely good performance in one criterion; the alternatives that exceed at most the expectations based on the criterion will be selected; method based on the compromising principle.
Pros: Easy to use and to understand.
Contras: Alternatives which are good in all the attributes and with just one very bad valued attribute will be rejected; non compensatory.

6) Lexicographic Method (Debreu, 1954)

Discernment: An important list of attributes (dominant attributes) is defined and through this a list of preferences of alternatives based on the attributes is elaborate, hence the alternatives will be valued on ranks; method based on the scoring principle.
Pros: Easy to use and to understand.
Contras: High dependence of the preference rankings; non compensatory.

7) Lexicographic Semi order Method (Luce, R.D. 1964, Tversky, A. 1969 & Fishburn 197)

Discernment: Alternatives are evaluated not only because it's most dominating attribute, all the not dominating criteria will be evaluated and ordered in score lists; method based on the scoring principle.

Pros: Easy to use and to understand.
Contras: High dependence of the preference rankings, non-compensatory.

8) Elimination by Aspects (Tversky, A. 1971)

Discernment: Each attribute of the alternatives will be evaluated against a minimal acceptable value, if they don't exceed the valued will be rejected; method based on the scoring principle.
Pros: Method with probabilistic nature, easy to use and to understand.
Contras: Alternatives with just one bad valued attribute will be rejected, no matter how good the other attributes are; non compensatory.

9) Permutation

Discernment: All possible ranks of the alternatives will be compared to each other to find the dominating alternative[22]; method based on the concordance principle.
Pros: Easy to use and to understand. Ordinal but especially cardinal data can be used.
Contras: Without a dominating alternative, the results can be difficult to understand, the calculations increases rapidly when the alternatives increase; non compensatory

10) Distance from Target (Easton 1965)

Discernment: The alternative which has the minimal distance from the ideal alternative will be selected; method based in the compromising principle.
Pros: Easy to use and to understand, is compensatory.
Contras: Target must be specified.

11) NDS Computation (Sarkar, S., & Garson, J. 2004)

Discernment: For two alternatives the one that outperforms the other will be chosen (similar to the dominance relations); method based on the scoring principle.
Pros: Easy to use and to understand.
Contras: The DM is not able to indicate the cardinality of the alternatives; non compensatory.

12) ARGUS (De Keyser, W. & Peters, P. 1994)

Discernment: Classifies the best criteria by means of scores on each alternative and synthesize them in rankings (preference rankings) and finally creates a final overall ranking; method based on the concordance and discordance principle.
Pros: Easy to use and to understand, not qualitative or quantitative evaluation needed.
Contras: Problems by the comparison of some alternatives as well as vagueness on the scales; non compensatory.

13) Linear Assignment Method (LAM) (Bernardo, John J. & Blin, J. M. 1977)

Discernment: The alternative with many high ranked attributes will be high ranked, through the cumulative sum of the ranks the best is chosen; method based on the scoring principle.
Pros: Easy to use and to understand; ordinal and cardinal data can be used, is compensatory.
Contras: Problems to discriminate between criteria or attributes with small differences.

14) Simple Additive Weighting Method (SAW) (MacCrimon, K.R. 1968)

Discernment: The rank of an alternative is the result of the weighted sum of its attributes; method based on the scoring principle.
Pros: Easy to use and to understand, designed for ordinal and cardinal data, is compensatory.

[22] (Chen, 1992)

Contras: The method can go against the principle of separable utility of the attributes[23].

15) Analytic Hierarchy Process (AHP) (Saaty, T. 1980)

Discernment: Values for criteria and alternatives are set for each criterion, hence a rank will be prepared as the weighted sum of pair wise comparisons between attributes and criteria, those comparisons are checked for internal consistency; method based on the scoring principle.

Pros: Ordinal and cardinal data can be used, is compensatory, easy to program.

Contras: When new alternatives are added it can produce "rank reversal" outcomes. The scale for 1 – 9 in AHP might be not enough sometimes.

16) Modified Analytic Hierarchy Process (MAHP) (Donegan, Dodd & McMaster. 1992)

Discernment: Values for criteria and alternatives are set through the use of a function for each criterion, hence a rank will be prepared as the weighted sum of pair wise comparisons between attributes and criteria, those comparisons are checked for internal consistency; method based on the scoring principle. It introduces a new set of scales for mapping Saaty´s scales.

Pros: Ordinal and cardinal data can be used, is compensatory, easy to program.

Contras: The Scale for 1 – 9 in AHP might be not enough sometimes; occasionally value functions have to be elaborate, it also presents "rank reversal".

17) Measuring Attractiveness by a Categorical Based Evaluation Technique (Macbeth) (Bana e Costa, C. & Vansnick, J. 1994)

Discernment: Through pair wise comparisons based on the performance of the alternatives to each criterion, the respective utility function will be developed from a basic point of view, together with the parameters related to the information between the criteria (weights); all this on the aggregation phase. The method determinates weights based on the preferences of the DM; method based on the compromising principle.

Pros: Ordinal and cardinal data can be used, is compensatory.

Contras: It can present numerical representation problems by multiple semi-orders in constant thresholds[24].

18) Cost benefit Analysis

Discernment: A decision analysis tool based on monetary costs vs. monetary benefits. The rank of an alternative is result of the weighted sum of its attributes; method based on the scoring principle.

Pros: Easy to use and to understand; elaborate scoring scales is compensatory.

Contras: Reliability has a high dependency on the accuracy of the data; utility functions have to be detailed. Method designed especially for monetary problems.

19) Kepner Trigoe (KT) Decision Analysis (Kepner, C. & Tregoe, B. 1958)

Discernment: A set of weights and scores for each attribute are defined for every alternative; in this way by multiplication of scores and weights the best ranked alternative will be chosen; method based on the scoring principle.

Pros: Ordinal and cardinal data can be used, easy to use and to understand.

Contras: The scale for 1 – 10 might be not enough sometimes; can have difficulties to discriminate between criteria or attributes with small differences.

20) Multi Attribute Utility Theory (MAUT) (Churchman, Ackoff & Arnoff 1957)**; Multi Attribute Value Theory (MAVT)** (Dyer, J. & Sarin, R. 1979)

Discernment: Through the use of utility / value functions (Utility Theory), the data will be transforming in dimensionless scales for weights and attributes, by its multipli-

[23] (Chen, 1992)

[24] (Bana e Costa, 1995)

cation the best ranked alternative will be chosen; method based on the scoring principle.

Pros: Ordinal and cardinal data can be used, easy to use and to understand, is compensatory.

Contras: Utility / Value functions have to be elaborate; with the high number of alternatives with a high number of attributes the overview can be complicated.

21) Simple Multi Attribute Rating Technique (SMART) (Kamenetzky 1982)

Discernment: Variation of the MAUT with simple utility relationships, the data will be transform in dimensionless scales for weights and attributes, by its multiplication the best ranked alternative will be chosen; method based on the scoring principle.

Pros: Ordinal and cardinal data can be used, easy to use and to understand; have shown a better robustness than MAUT[25], is compensatory.

Contras: Utility functions have to be elaborate; with the high number of alternatives with a high number of attributes the overview can be complicated.

22) ARIADNE Method (Goicochea, A. 1991)

Discernment: Is a method in which the maximal and minimal values of each alternative are found through a proposed lineal model, in character the weights of the lineal programming and the preferences of the DM the best alternative is chosen; method based on the compromising principle.

Pros: Ordinal and cardinal data can be used, is compensatory.

Contras: Based on SMART method[26]. Utility functions have to be elaborate; with the high number of alternatives with a high number of attributes the overview can be complicated.

23) UTA Method (Jacquet-Lagreze, E. & Siskos, J. 1982)

Discernment: Through the use of a value functions (Utility Theory) for the criteria, the data will be transformed and the alternatives will be ranked, by its multiplication the best ranked alternative will be chosen; method based on the scoring principle; method based on the scoring principle.

Pros: Small differences between alternatives can be quantify, easy to use and to understand, is compensatory.

Contras: Value functions have to be elaborate; in some cases the scenario performed by this method, will be not adequate.

24) Goal programming (Hwang, C. a& Masud, A. (1979))

Discernment: The method determines for the alternatives a quantitative value for each criterion, the minimal performance value for the criteria is defined, the alternative with the best overall performance will be chosen; method based on the compromising principle.

Pros: Easy to use and to understand, is compensatory.

Contras: Target values must be specified, problems by its accuracy, doesn't provide a rank.

25) Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Hwang, C. Yoon, K. 1975)

Discernment: The distance of the best alternative should be small to the ideal solution and large to the negative-ideal solution; method based on the compromising principle.

Pros: Ordinal and cardinal data can be used, easy to use and to understand, is compensatory.

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25 (Multicriterio, Red Iberoamericana de Evaluación y Decisión, 1999)

26 (Georgilakis, 2005)

Contras: For the reason that the supposed optimal solution is not a realistic alternative, the distances from it might be insignificant.

26) Elimination et Choix Traduisant la Réalité (ELECTRE) (Roy, B. & Benayoun, R. 1966)

Discernment: Based on the outranking relationship and distance to the ideal solution; it takes utilities and scores from criteria and weights to, compare attributes to each other using concordance and discordance principles, the best ranked alternative is the preferred one. This method has been developed on different variations with different points of view;

ELECTRE I: For partial rankings based on the concordance index, discordance index and threshold values[27].

ELECTRE II: (Roy & Bertier, 1973) for ranking of the alternatives, includes in the concordance and discordance index two opposite outranking comparisons, the weak relationship and the strong relationship.

ELECTRE III:With an outranking index to perform an outranking credibility between alternatives (Fülöp), the method has more reliability, but it's also complicated[28].

ELECTRE IV: (Roy & Hugonnard, 1982) is based in pseudo criteria, through the weak and the strong comparisons as well as the a common sense, de comparison take place in two outranking levels, the weights between criteria are treated in the same category among each other.

ELECTRE IS: Through a consistent discrete group of pseudo criteria targeted to obtain a final alternative or a group of them[29].

ELECTRE TRI: Designed for classification or segmentation problems, according a group of criteria (qualitative or/and quantitative) and predetermined categories, offers two different procedures to affect the alternatives, the pessimistic and the optimistic.

Pros: Ordinal and cardinal data can be used.

Contras: Partial prioritization of alternatives; do more alternatives; do more the number of calculations rises, non-compensatory.

27) Preference Ranking Organization Method for Enrichment Evaluations (PROMETHE) (Brans, J. & Vincke, P. 1985)

Discernment: Based on an outranking relationship, it demands utilities and scores from criteria and weights to compare attributes to each other based on a preferences matrix and arranges them in an overall preference index. Through the use of two functions (the Φ^+ outgoing flow and the Φ^- incoming flow) an overall outranking level is defined. This method (like with ELECTREE) has been developed on different variations with different points of view; method based on the concordance principle.

PROMETHE I: To obtain a partial pre order.

PROMETHE II: To obtain a total pre order, based on the criteria flows between alternatives

PROMETHE III: Applies a concept of indifference based in probabilistic flows[30].

PROMETHE IV: Establishes a complete or partial pre order, using a selection and ranking problematic in which the solutions are feasible and discrete[31].

PROMETHE V: Establishes a complete order like PROMETHE II, includes a philosophy of integral optimisation, also for investment problems with determinate budged[32].

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[27] (Huang, 2005)

[28] (Multicriterio, Red Iberoamericana de Evaluación y Decisión, 1999)

[29] (Multicriterio, Red Iberoamericana de Evaluación y Decisión, 1999)

[30] (FüLüp, 2006)

[31] (Costa Morais, 2006)

[32] (Costa Morais, 2006), (Multicriterio, Red Iberoamericana de Evaluación y Decisión, 1999)

PROMETHE VI: Establishes a complete or partial pre order, using a selection and ranking problematic in which the DM don't get fixed values for the weights[33].

PROMETHE GAIA: Extends the results of PROMETHE through visual interactive procedure "GAIA"[34].

Pros: Ordinal and cardinal data can be used.

Contras: Partial prioritization of alternatives; do more alternatives, do more the number of calculations rises; non compensatory.

28) Tomada de Decisão Interativa Multicriterio (TODIM) (Gomes, L.F. & Lima, M. 1992)

Discernment: It constructs a preference model for risky decisions, in agreement with Prospect Theory base (Kahneman and Tversky, 1979). This method uses the additive difference model to determine the ranking of an alternative compared to another[35]; method based on the concordance principle.

Pros: Ordinal and cardinal data can be used, minimizes the rank reversal problem.

Contras: Does not allow for fuzziness with scoring[36], non-compensatory.

29) ORESTE (Roubens, 1982; Pastijn and Leysen, 1989)

Discernment: Values are set to each alternative based to its performance on each criterion. In character to qualitative rankings of criteria, concordance index and preference relation ranks, the overall rank is defined; this method is based on the concordance and discordance principle.

Pros: Ordinal and cardinal data can be used.

Contras: Target values must be specified, problems by its accuracy, non-compensatory.

30) Qualiflex (Paelink, J. 1976)

Discernment: Values for the criteria are defined and with this the alternatives are classified on rankings, and through pair wise comparisons between alternatives for each ranking a concordance index is associated based on the criteria, the alternative with the best overall concordance score will be chosen; method based on the concordance and discordance principle.

Pros: Ordinal and cardinal data can be used.

Contras: High dependence in the consistency of the consistency between rankings and alternatives. In some cases the scenario performed by this method, will be not adequate; non compensatory

31) Multicriterion Analysis of Preferences by Means of Pairwise Actions and Criterion Comparisons (MAPPAC) (Matarazzo, B. 1990)

Discernment: A set of weights and scores for each criterion are defined through value functions, the basic preference index are set for the pair comparisons and with these final overall values are fixed to the alternatives; this method is based on the concordance and discordance principle.

Pros: Ordinal and cardinal data can be used.

Contras: The method needs the calculation of values to each criterion and for the pairs to be compared, non-compensatory.

32) Regime (Hinloopen, E., Nijkamp, P. & Rietvekd, P. 1983)

Discernment: Pair wise comparisons between alternatives for each criterion are made based on a mapping of criteria up to the most important criterion, the alternative that outperforms the other will be chosen; method based on the concordance and discordance principle.

Pros: Ordinal and cardinal data can be used.

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[33] (Costa Morais, 2006)

[34] (Costa Morais, 2006)

[35] (Seixas Costa, 2002)

[36] (Craven, 2007)

Contras: High dependence in the consistency of the rankings; non compensatory.

33) MELCHIOR (Leclercq, J. 1984)

Discernment: The performance of the alternatives is evaluate for each criterion, preference and indifference thresholds are delineate to elaborate a qualitative ranking of the criteria, through a complicated algorithm the overall ranking is elaborate; this method is based on the concordance and discordance principle.

Pros: produces a linear ordering of alternatives.

Contras: Target values and indifference thresholds must be specified, non-compensatory.

34) IDRA (Greco, S. 1997)

Discernment: To each criterion a value function is developed and with it the maximal and minimal values to each criterion are defined, according to other normalized quantitative values to each of the comparison pairs, a ranking is set, using a combination of random weights mixed with the value function; this method is based on the concordance and discordance principle.

Pros: Ordinal and cardinal data can be used.

Contras: The method needs the calculation of values to each criterion and for the pairs to be compared, non-compensatory.

35) Passive and Active Compensability Multicriteria Analysis (PACMAN) (Giarlotta, A. 1998)

Discernment: Values are determinate to each alternative based to its performance on each criterion, through a pair comparison, a compensatory function is built to define the compensate preferences; this method is based on the concordance and discordance principle.

Pros: produces a linear ordering of alternatives.

Contras: Value Functions have to be elaborate, high complexity and requires a high number of information from the DM, non-compensatory.

36) Preference Ranking Global Frequencies in Multicriterion Analysis (PRAGMA) (Matarazzo, B. 1988)

Discernment: Values are determinate to each alternative based on its performance on each criterion. Quantitative weights are defined to each criterion as well as a value function, through a linear representation a matrix is set with values assigned to the alternatives, finally a rank is developed; this method is based on the concordance and discordance principle.

Pros: Produces a linear ordering of alternatives.

Contras: Values have to be assigned, high complexity and requires a high number of information from the DM, non-compensatory.

37) TACTIC (Vansnick, J. 1986)

Discernment: Values are determinate to each alternative based to its performance on each criterion, differences on the values are calculated and through a concordance threshold selected by the DM, the ranking is set; this method is based on the concordance and discordance principle.

Pros: Produces a linear ordering of alternatives, criteria don't need to be independent.

Contras: The difference thresholds to each pair of alternatives have to be assigned, non-compensatory.

The current decision analysis makes use of the different decision analysis methods combined with the different computer sciences aimed to create computer applications that permit to perform decision analysis in faster and easiest form.

2.8 Decision Support Systems (DSS)

Decision support systems are the applications of the decision analysis methods into the computer science. DSS has its origins in the early 40's and 50's when electronic data processing first became possible. The combination and development of decision analysis and the possibilities offered by computers ensures better functionality, through the enforcement via the computer's velocity and processing; in this form decisions can be made utilizing a high amount of data and factors. The decision analysis methods (DAMs) set the structures and enable the collection and methodology for its compilation.

DSS can be defined as "*computer-based systems that assist business and complex decision-making environment*"[sic][37]. From the definition it is easy to perceive, that these kinds of methods are nowadays oriented for management applications or in other words, DSS are the application of the DAM in the form of electronic tools (software) into the practice.

Eom presents a definition based on a collection of arguments from different authors, DSS is described as "*a computer-based interactive human–computer decision-making system that:*

- *supports decision makers rather than replaces them;*
- *utilizes data and models;*
- *solves problems with varying degrees of structure: (a) non-structured (unstructured or ill-structured)* (Bonczek, 1981)*; (b) semi-structured* (Keen, 1978)*; (c) semi-structured and unstructured* (Sprague, 1982)*;*
- *focuses on effectiveness rather than efficiency in decision processes (facilitating decision processes)"[38].*

The definition presented above together with the Figure 2-5 shows that DSS are just one arm of the DAM, DSS requires source information (inputs) controlled by a "Data-Base Management Systems" (DBMS), these inputs are applied to a model "Model Based Management Systems" (MBMS) (mathematical problem's representation) for its assessment in a computer application (interface) "Dialogue Generation and Management System" (DGMS). Therefore DSS together with DAM are complementary sciences. The database is always required and a decision's model, database and the model are based on computer applications, but the functionality and calculation process is based totally on DAM.

All this to support the decision maker, which means to achieve the best decision possible with a better comprehension of the problem and with more criteria than just 7 +/- 2 (see 2.5).

[37] (Marakas, 2003), for DSS there are several definitions (Sprague, 1980), by the means of this work the definition according Marakas is used.

[38] (Eom, 2001)

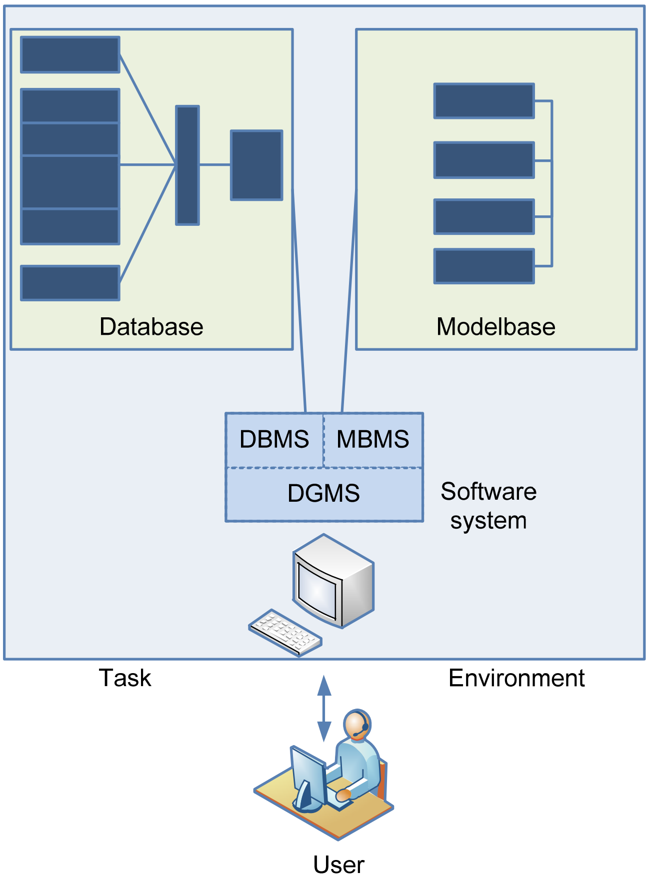

Figure 2-5: Components of decision support system (Sprague, 1982)

2.9 Hazards and Opportunities in the Decision Analysis Methods

The decision analysis as well as many other methods from different fields, offers great potentiality and is also connected with their own particular risks. As already shown, the multi criteria decision analysis methods (MCDAM) are an important aid in the process of decision analysis, they create structure for the main problem, according to the several different methodologies (organised disciplines), they are a very important assistance at the moment of making a decision. Nevertheless the roll of the decision maker is the decisive factor with high relevance.

One of the principal virtues of the multi criteria approaches is that these kinds of approaches are created to avoid the possibility of making decisions that do not really reflect the demanded expectation. Another improvement is a strong gain of transparency on the selection/valuation procedure, which represents a ruling characteristic by multi criteria nature problems in contrast to solutions based on just one single criterion.

The strongest consideration within the multi criteria decision analysis (MCDA) is that it is assumed that there is no perfect solution. The principal hypothesis is that there is no perfect acquaintance no matter the method and the field, the most significant achievement is to find the most feasible solution that fits the most expectations. Bernard Roy argued *"Decision aiding cannot and must not be envisaged jointly with a hypothesis of perfect knowledge"*[39].

MCDA succeeds by introducing a better determination through increasing objectivity on the determination and analysis of the criteria. Perhaps the most important is that the objectivity must be justified when the criteria is evaluated. In other words, objectivity in judgement is doubtlessly improved by the use of these methods.

The MCDA is a process that supposes that the decision maker (DM) can prepare the analysis of a decision with a simple structure at the moment of approaching the analysis, therefore the methods to approach a decision problem like the mentioned "General Decision Analysis Problem" (see section 2.4), bring a background and an initial strategy to define the most critical factors and procedures in the decision analysis problem. In general it is known that the MCDA is an interactive process based on at least three basic steps, a problem identification, problem resolution and finally strategy development, the strategies shall assure that the attained effectiveness can be verified and with this to improve the methodology and evaluate it deficiencies.

The following Figure 2-6 presents a procedure of the different steps of the MCDA process, the figure presents four steps plus one: "Problem Identification", "Problem definition", "Model development" and "Model Application" as well as their most relevant sub process to its procedure in each step. It is important to remark that the method is interactive and the evaluation of every step has to be focussed and goal targeted to meet the decision followed by a strategy and to secure its functionality (Final step).

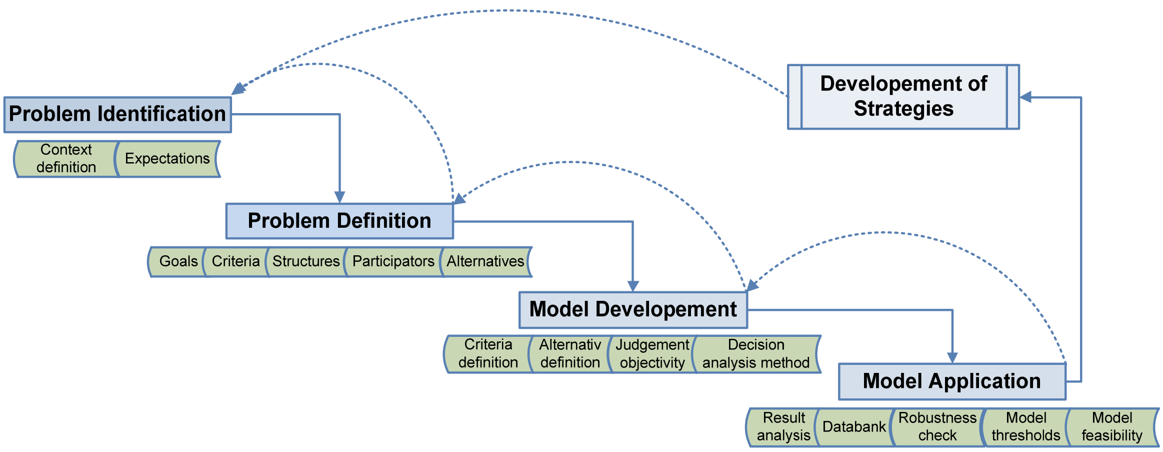

Figure 2-6: MCDA process

Hazards can be located in many places during the performance of MCDA, many of the principal problems take place on the settlement of the criteria and its own classification, the kind of data to be treated has to be defined, based on their gaps and on the threshold values and by these means, identify in which category the data belongs (when ordinal, cardinal, interval, probabilistic or fuzzy criteria is needed).

[39] (Figueroa, 2004)

One of the principal hazards in the implementation of MCDA is the definition of scales on the selected criteria. Nowadays there are many of methodologies that can provide aid to the quantification of data. MCDA procedures bring better functionality with an appropriate scale determination, in this way the objectivity of the procedure will be assured, nevertheless on this step of the procedure (Scale determination) can lead to inaccurate or false results, when these scales are not correctly abstracted or understood.

2.10 Selection of a Decision Analysis Method (DAM)

All the methods described on section 2.7 are methods that have shown an appropriate functionality and are widely used in many fields; they have particularities that make them adequate for different kind of problems because of their discernment, thus the selection of a DAM can be done by answering simple questions in terms of the available criteria (see Figure 2-4 and Figure 2-8).

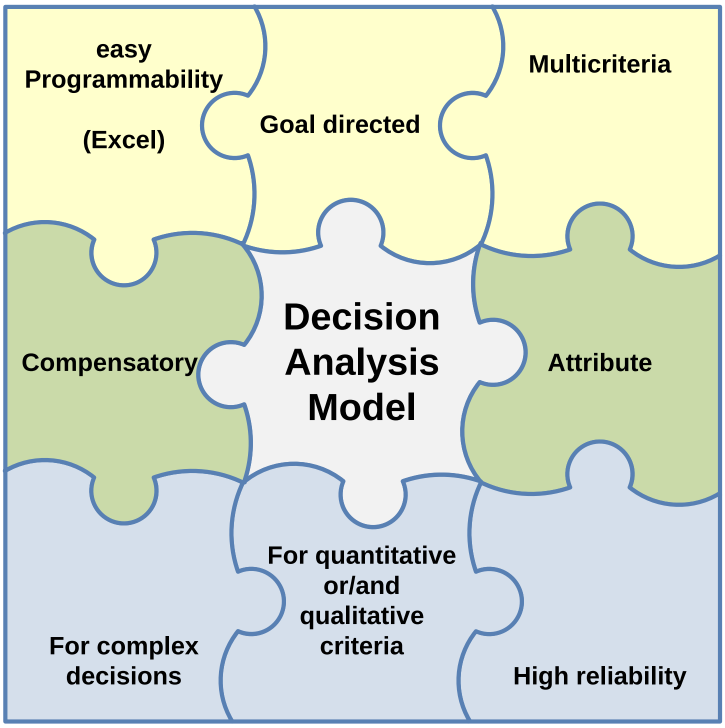

Figure 2-7: Model requirements

For the development of the decision analysis model proposed in this work, it is known that the model shall be easy to use, confer high reliability on complex problems, it shall perform an analysis based on attributes (split the main problem in different small problems), these attributes might be in ordinal and cardinal form and it shall allow a compensatory analysis of all data. For the elaboration of the decision analysis model the factors content on the Figure 2-7 are the most important foundation pieces by the selection of the DAM.

In section 2.7 the various DAM were summed up and explained according their discernment and possibilities, however the amount of Information is high, for this reason thirty-seven methods were classified and analysed; aimed to become a better overview of the DAM. A very important help is to present the DAM in a table that allows selecting the appropriate method according to the problems requirements and demands.

In the work *"Incorporating multiple criteria into the design of conservation area networks: a minireview with recommendations"* of Moffett[40] (see section 2.6), he presents *"A decision procedure for the selection of an existing MCDA method"* (see Figure 2-8), this procedure delivers an important aid for finding and selecting an appropriate DAM.

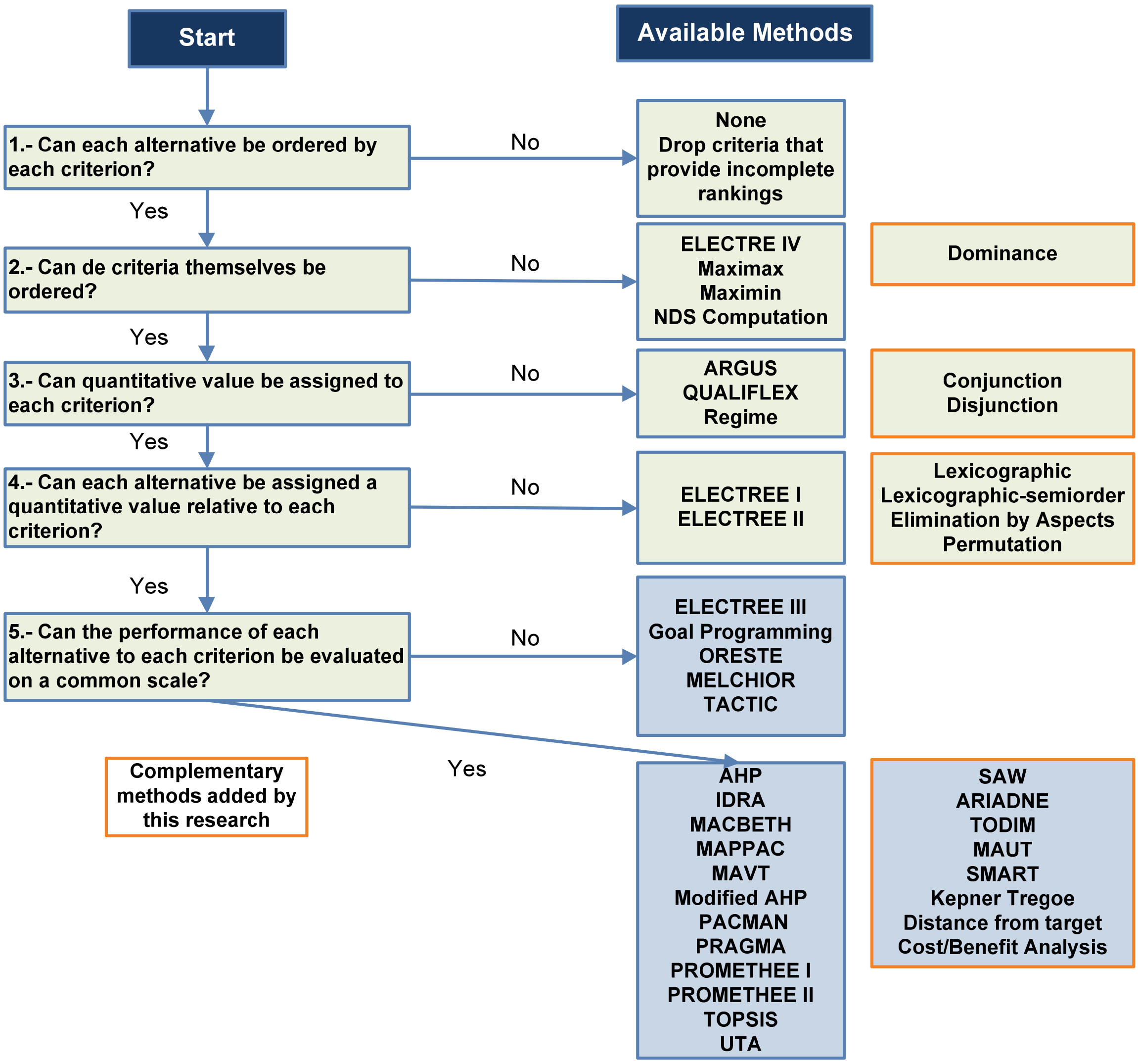

Figure 2-8: Decision procedure for the selection of an existing MCDA method (based on (Moffett, 2006)) with complementary methods.

By the interpretation of the Figure 2-8, the different DAMs are presented according the kind of problem they can solve and the questions to which the DM has to respond during the choosing process.

The mentioned process is presented here with the inclusion of the complementary methods collected by this research. Through the implement of this procedure we can

[40] (Moffett, 2006)

conclude that the kind of problem that this research attempts to solve, are the kind of problems addressed in the 5th question, this means that according to the selection procedure, the DAM choice is reduced to the selection between twenty methods from which a final analysis is performed.

Table 2-3 presents a general overview of the DAM, the table is based in the classifications mentioned before and it contains a summary of the most important characteristics and considerations of the DAM mentioned in this chapter. By the combination of the Figure 2-7 and Figure 2-4, the DM can get a fast overview in relation to the DAM and select more effectively the most promising method to solve his own problematic. This table presents a general summary of the different considerations of this chapter.

As soon as the analysis of the problem is completed the analysis process is structured in hierarchies with an array of indicators; these indicators shall secure quantitative properties measurement for each of the different alternatives; the problem to solve is of a discrete nature.

According the problems requirements for the present research, the Analytic Hierarchy Process (AHP) and its variation the Modified Analytic Hierarchy Process (MAHP) are the most appropriate methods to implement in the abstraction process of the decision analysis model. The MAHP was developed to improve some of the deficiencies of AHP knows as “Rank Reversal”[41], however this problem was not completely solved and it added more mathematical steps into the normal AHP method[42], therefore AHP represents the most suitable alternative.

The Table 2-3 shows that the AHP allows employing cardinal and ordinal values, with a high reliability and is compensatory. The AHP method offers besides a hierarchical allocation of the problem’s criteria, a consistency examination of the comparisons between the alternatives and weights in addition to this, the method is designed for the analysis of discrete problems. A description of the AHP-Methodology is in the Appendix I: AHP Methodology included.

The use of weights in AHP allows the DM to reflect the expectancies for the solutions and to orientate the alternatives to the desired expectative accomplishment. This method applies a simple utility function to the determination of the weights, which allows the DM to establish predetermined scales and criteria measurements meant to perform an effective comparison, along with the simplicity of the calculations; in addition to this it also permits a simple problem’s programming. AHP is particularly suitable for structuring difficult decision problems[43].

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[41] (Pérez, 2002)
[42] (Tung, 1998)
[43] (Thewes, 2010)

Multi Criteria Decision Analysis Methods											
	Decision analysis method	Method Type	Criteria Type	Compen-satory	Method principle	Effort and time	Analysis based on	Reliability	Method Complexity	Program-mability	Method's Problematic
Simple Comparison	Dominance Method	Sr	O	no	Scg	low	DM	low	low	easy	discarded alternatives can be better
	Maximax	Sr	O	no	Scg	low	DM	low	low	easy	just one attribute alternatives
	Maximin	Sr	O	no	Scg	low	DM	low	low	easy	just one attribute alternatives
	Conjunction Method	Sc	O	no	Cp	low	Att	low	low	easy	Alt. rejected for one bad value
	Disjunction Method	Sc	O	no	Cp	low	Att	low	low	easy	Alt. rejected for one bad value
	Lexicographic	Sc	O	no	Scg	middle	Att	low-middle	low-middle	middle	High dependence on preference rankings
	Lexicographic Semi order Method	Sc	O	no	Scg	middle	Att	low-middle	low-middle	middle	High dependence on preference rankings
	Elimination by Aspects	Sc	O	no	Scg	low-middle	Att	low-middle	middle	easy	Alt. rejected for one bad value
	Permutation	Sr	O&C	no	CD	middle	Att	middle	middle	middle	Dominant alt. needed, or accuracy prob.
	Distance from Target	Sc	O	yes	Cp	middle	Att	middle	middle	middle	Ideal most be determinated
	Non Dominated Set (NDS Computation)	NC	O	no	Scg	low	DM	low	low	easy	Cardinality problems on the results
	Argus	Sc	O&C	no	CD	middle	Att	middle	low-middle	middle-hard	Accuracy problems
Aggregation	Linear Assigment Method	Sr	O&C	yes	Scg	middle	Att	low-middle	low-middle	middle	Discrimination problem with small diferences
	Simple Additive Weighting Method (SAW)	Sr	O&C	yes	Scg	middle	Att	middle	low-middle	middle	can go against the principle of separable utility of the attributes
	Analytic Hierarchy Process (AHP)	Sr	O&C	yes	Scg	middle	Att	high	low	easy	can produce "rank reversal" outcomes
	Modified AHP	Sr	O&C	yes	Scg	middle	Att	high	low	easy	rank reversal partially solved, more calculations required
	Measuring Attractiveness by a Categorical Based Evaluation Technique (Macbeth)	Sr	O&C	yes	Cp	middle-high	Att	middle-high	middle	middle-hard	problems by multiple semi-orders in constant thresholds
	Ariadne Method	Sr	O&C	yes	Cp	middle-high	Att	middle-high	middle-hard	middle-hard	Overview lost with high num. Of criteria
	Cost/Benefit Analysis	Sr	C	yes	Scg	middle	Att	middle	middle	easy-middle	Method designed for monetary problems
	Kepner Tregoe (K-T) Decision Analysis	Sr	O&C	yes	Scg	middle	Att	middle-high	low-middle	easy-middle	Discrimination problem with small diferences
	Multi Attribute Utility / Value Theory (MAUT / MAVT)	Sr	O&C	yes	Scg	middle-high	Att	middle-high	middle	middle	Overview lost with high num. Of criteria
	Simple Multi Attribute Rating Technique (SMART)	Sr	O&C	yes	Scg	middle	Att	middle-high	low-middle	middle	Overview lost with high num. Of criteria
	UTA	Sc	O&C	yes	Scg	middle-high	Att	middle-high	middle	easy-middle	Scenario might be not adequate
	Goal Programming	NC	O	yes	Cp	middle	Att	middle	low	easy-middle	Accuracy problems
Outranking comparison	Technique for order Preference by Similarity to Ideal Solution (TOPSIS)	Sr	O&C	yes	Cp	middle-high	Att	middle-high	middle	middle-hard	Ideal most be determinated, but is not real, because of it results can be irrelevant
	Elimination et Choix Traduisant la Réalité (ELECTREE)	Sc	O&C	no	CD	high	Att	high	middle-hard	hard	Partial prioritization of alternatives, calculations can rise rapidly
	Preference Ranking Organization Method for Enrichment Evaluations (PROMETHE)	Sc	O&C	no	CD	high	Att	high	middle-hard	hard	Partial prioritization of alternatives, calculations can rise rapidly
	Tomada de Decisão Interativa Multicriterio (TODIM)	Sc	O&C	no	CD	middle-high	Att	middle-high	middle-hard	middle-hard	Does not allow for Fuzziness with scoring
	ORESTE	Sc	O&C	no	CD	high	Att	middle-high	middle-hard	middle-hard	Target values needed, Accuracy problems
	Qualiflex	Sc	O&C	no	CD	high	Att	middle-high	hard	hard	High dependence on preference rankings, Scenario might be not adequate
	MAPPAC	Sc	O&C	no	CD	high	Att	middle-high	hard	hard	needs values to each criterion and pairs wise
	Regime	Sc	O&C	no	CD	high	Att	middle-high	middle-hard	middle-hard	High dependence on preference rankings
	MELCHIOR	Sc	O&C	no	CD	high	Att	middle-high	middle-hard	middle-hard	needs Target values and indifference thresholds
	IDRA	Sc	O&C	no	CD	middle-high	Att	middle-high	hard	hard	needs values to each criterion and pairs wise
	PACMAN	Sc	O&C	no	CD	high	Att	middle-high	hard	hard	value functions need ti be defined, high complexity and information from DM
	PRAGMA	Sc	O&C	no	CD	high	Att	middle-high	hard	hard	value need ti be defined, high complexity and information from DM
	TACTIC	Sc	O&C	no	CD	high	Att	middle-high	middle-hard	hard	needs indifference thresholds
		Sr = Sorting Sc = Screening NC = Nominal Classification	O = Ordinal C = Cardinal	Sr = Sorting Sc = Screening	Scr = Scoring Cp = Compromising CD = Concordance and discordance		DM = Decision maker Att = Attribute				

Table 2-3: General overview and classification of the decision analysis methods

2.11 Conclusions

The current chapter presents the multi criteria decision analysis methods: their advantages, characteristics, classifications, principle, applications and choosing process among many other topics. It has been proven that the implementation of the decision analysis methods brings many benefits to the analysis process for decisions under conflicting criteria; it also allows the decision maker (DM) and the participants to get involved with the problem and in conclusion achieve better results. Furthermore it emphasises that a systematic structure towards decision analysis procedures is vital to achieve better results in less time and with better effectiveness.

In the construction industry many decisions are normally not correctly scrutinized under quantified predetermined factors[44] or, what is worse, not justified, therefore the implementation of multi criteria decision analysis methods (MCDAM) aims to reduce uncertainties by means of a methodological criteria analysis procedure that supports the decision process, in consequence, transparency is created for every moment and for every task of the process.

However every MCDAM depends on the DM's capabilities. This means that an appropriate training towards the chosen MCDAM together with the DM's own experience shall permit the achievement of the most accurate analysis procedure and finally the best decision.

The classifications of methods presented in this chapter are performed to accomplish the goals of the present work. As previously mentioned the classification is a vast and demanding task, it can't be performed in a general form including a table with all the existing methods, nevertheless it was performed for this work in the form that permits engineers who have never employed such methods, to easily get an overview and to allow them to better structure their own choosing process.

The field of decision analysis is constantly growing and new methods are constantly emerging, the methods amalgamate with the computational sciences to create the DSS (see 2.8), hence it acquires more relevance, strength and possibilities; but simultaneously the complexity of the methods is growing, which creates challenges in itself for engineers.

It is important to understand the principia of the MCDAM for the appropriate use and selection of method and consequently to get involved with the chosen method itself. The Figure 2-6 was introduced in order to allow a selecting process motivated mostly for those in engineering fields to get in contact with these promising methods. The Figure 2-4 and Figure 2-7 serve to support the choosing procedure.

Appendix A presents a collection of different works that applied MCDAM in construction projects, with an analysis of them. From this analysis it showed that the decision

[44] (Kalaiarasan, 2011), (Whelton, 2001)

analysis has become an important field for the development of solutions for the construction industry. The collection of articles presented on Appendix A shows the potential of decision analysis methods (DAM) to support the decision and with this to gain efficiency and certainty in the construction industry. The combination of the DAM together with modern computer tools or applications makes it possible to manage high quantities of information and criteria in a structured form for its further processing, for reducing time and supporting the decisions in a quantitative system.

Worldwide the utilization of different DAM in the construction industry has been growing especially in the last decades of this millennium. Its development combined with the computer applications has become part of decision support systems (DSS, see section 2.8). They offer more efficiency, velocity and security by making a decision, however there are also many other unstructured factors and criteria that must be always considered, mostly uncertainties, hence the DM is always essential to assure a better decision. Nevertheless the future of the MCDAM is completely related with its application as a computer tool, as consequence as a DSS.

As relevant constant in all these works is the need of quantifying the decisions, for operative and even for strategic decisions, accordingly quantification is the key for an appropriate application. Another important topic is the management of uncertainties, no matter how effective a risk management system could be, there will always exist not considered uncertainties. The management of uncertainties is growing in importance and shall be aimed to support the risk management (see 3.2 and 3.3).

The use of web-based technology, computer science, DAM and quantification methods is growing and will assure better decisions in the construction industry. More and more researchers are now occupied in this field.

3 Risk management

3.1 Introduction

Risk management and decision making are significantly attached to each other for the reason that "*Risk management is a particular form of decision making within project management*"[45]. Every time we deal with risks we seek to prepare quantification procedures and/or an evaluation for a determinate situation and according to its analysis, to reach a decision about how to handle risks.

As mentioned in chapter 2 decision analysis is an important aid for decision making, but we can affirm that risk management is a particular application of decision analysis, which consists in reaching the best decision possible concerning the analysis of different risk factors besides their problematic and finally reduce uncertainty and increase profitability.

The previous chapter concentrated on the challenging field of decision analysis, and the way to concur decisions in an effective and systematic approach. The previous chapter opens the door to scrutinize the factors and needs of solving a decision analysis problem; the present chapter performs the same work under the considerations of risk management. The risk management will be treated around means of the civil engineering point of view.

3.2 Risk and Risk Management

The word "risk" has its origins on the Greek-Byzantine word "Rhiziko" and its means "luck", "fortune or coincidence", this word's etymology can be traced to the Greek word "riza", which means "root" or "basis", or the Arabic "risc" which means "fate" or the Italian "risico" which means exposure.

The historical use of this word reflects the fact that, in all of human history, dealing with risks has always been an undertaking with an exposure level. The analysis of risks came into being as mankind started to select and choose between possibilities with a discernment of factors which included desirable results and undesired hazards. Accordingly it's important to accentuate the duality of risk, which consists of the fact that risk enclosures opportunities and hazards (also denoted as chances and dangers). The current risk analysis is dedicated to quantifying these risks[46], the discernment process of risk analysis is aimed at improving the probability of success (increasing the opportunities) as much as an effective detection of goal menaces or threats and consequently, the prevention of negative results (reduction of hazards).

Figure 3-1 presents a clear representation of risk and its duality for the lifecycle of an construction project. As previously mentioned the concept of "Risk" encompasses

[45] (Smith, 2006)

[46] For differentiation between opportunities and hazards

opportunities in its positive variation and hazards (dangers) on its negative variations. Any undertaking implies a certain level of exposure, nonetheless risks with the appropriate handling can result in profit which is desired, and on the other hand all unidentified risks are uncertainties[47]. As conclusion it can be corroborated that normally there are no profits without exposure.

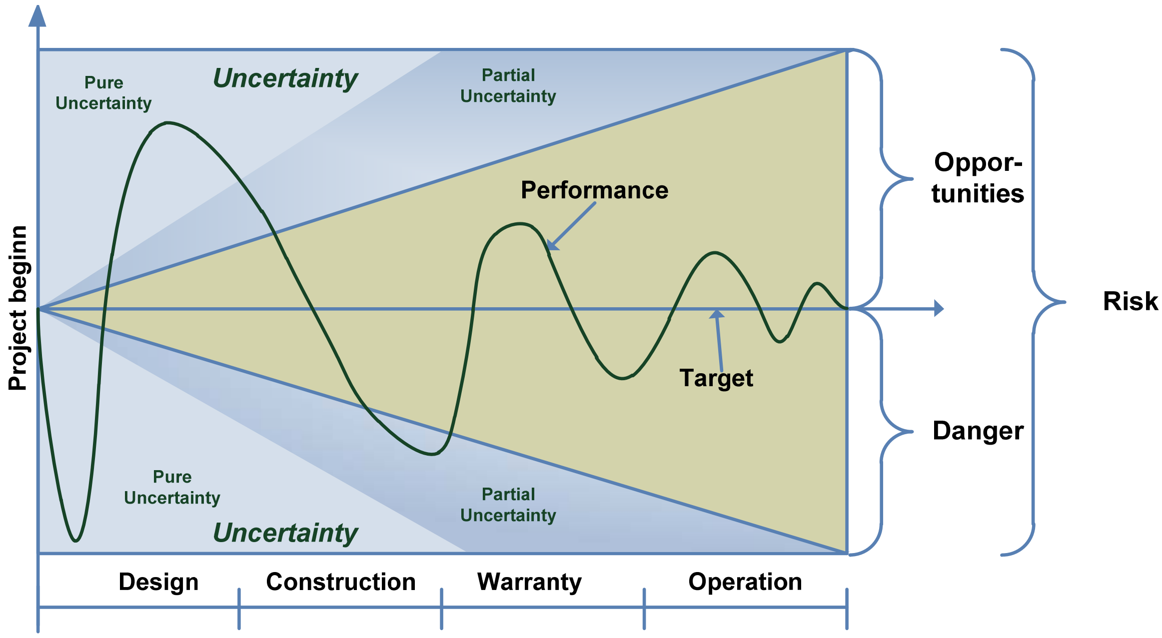

Figure 3-1: Risk's representation.

An example of this profit potentiality is reflected in the German cost estimation regarding to risk and profit (in German "Wagnis" and "Gewinn"), they are added into a single digit a percentage of the total amount of the project cost, which reflects the fact that a correct procedure with risks is associate with profit and vice versa, losses with the inappropriate handling of risks.

Within risk management risk classification is an enormous and demanding task. Risks can be conformed and classified according to many considerations, for example their nature, inside this category it still can be classified in several different subcategories. Therefore it is important to understand the functionality of risks and to perform a classification under the considerations and the specific needs headed for the project's main tasks and goals.

In construction projects risks can be classified in different categories for example; political, market, economic, project, human, criminal, safety, environment, currency and planning. Risks have also subcategories and so on, until many levels of subcategories; in any case risks have a specific relationship to the problem according to their nature and/or origins.

[47] Uncertainty is in chapter 3.3 in detail elucidated; uncertainty is divided in Partial and Pure Uncertainties. "Partial uncertainty" is identified but not quantified criteria; "Pure uncertainty" is not identified and consequently not quantified criteria.

Figure 3-2 shows a simple representation of risks and the way they impact the project; it's easy to see that risks which have their origin in the environment (external risks), have an important influence on the project as well as the risks within the project (internal risks), the difference between environmental risks and the project's risks lies in the form how they impact the project and its controllability, in consequence of this, risks can have an internal or external origin and a totally different incidence into the project.

These categories permit the appreciation of the risks that might occur, nevertheless according to its origin, some of these risks are able to be controlled by the project managers and other risks cannot be controlled, for example earthquakes, these kinds of risks are present in some regions and there's no feasible possibility to control their incidence, the only possibility is how to manage their effects or to be prepared. On the other hand in the project's risks there are controllable risks, these risks are for example technology, it represents an important know how, the better preparation to their implementation the more the dangers can be reduced or eliminated.

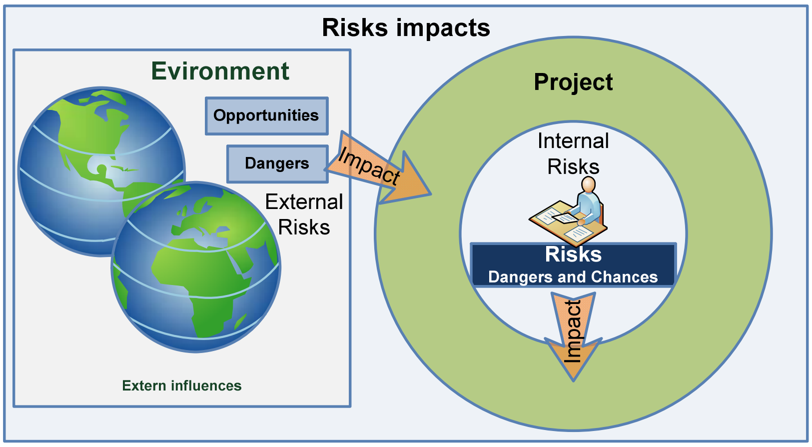

Figure 3-2: Nature and influences of risks

Nevertheless risk can be classify in many different categories (see figure Figure 3-3, Table 3-1 and Table 3-2), the simplest is constituted by two categories: the "Global" and the "Project" risks as shown in Figure 3-2, some others classifications comprehend other factors like high impact risks, political, project and business risks[48]. In any case there are many ways to classify risks according to many different considerations; Figure 3-3, Table 3-1 and Table 3-2 show some of these classifications.

Figure 3-3 highlights the "Project's risks" and the "Global risks", it is simple to perceive that some of the risks are not possible to eliminate, therefore it's important to evaluate and monitor these kind of risks. On the other hand there are risks (project risks) which depend on our capabilities to engage them or/and prevent the identified danger situations to happen. For this reason it becomes important to see how wide the range of the project's risk exposure is.

[48] (Keitsch, 2000)

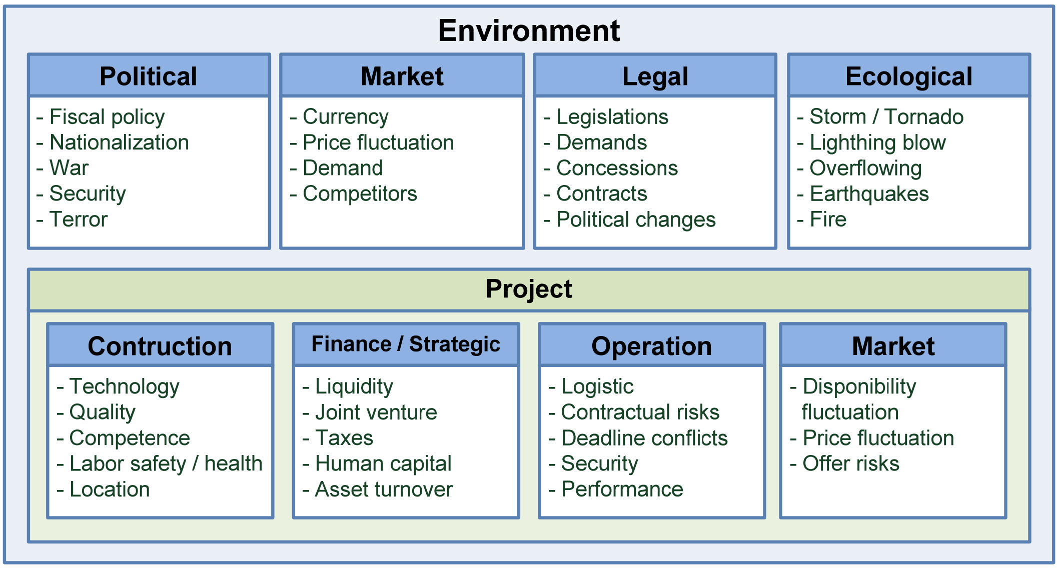

Figure 3-3: Project and risks.

Maria Sanchez 2005 presented in his work some of the most representative project risks for construction companies in different categories (see Table 3-1).

Political Risks	Social Risks	Environmental Risks	Management Risks	Financial Risks
Strikes	Social strikes	Water and air pollution	Organization structure	Currency fluctuation
Foreign corrupt practices	Society support to project	Epidemics	Bad planning decisions	Credit risk
Legislative changes	Real social benefits	Negative Env. Impacts	Contract disputes	Unstable economy
Tariff policies	Unstable society conditions	Fauna diseases	Bad project man-agement	High inflation
Domestic policies	Low security measures at the construction site	Env. Hazards Regulations	Employee relations towards the company	Bad cash flow management

Table 3-1: Project specific risks (Maria-Sanchez, 2005)

Busch presented a classification the *"Main risk types of a general contractor and their possible outcomes"*[49] in a simple table (Table 3-2), which allows one to appreciate the different possibilities of risks in a construction project and its associated results.

In conclusion risks are present in so many different forms and practically in all human activities. That makes important to distinguish their origin, their incidence and the several variations of risk in order of treat them with an appropriate methodology. Risk management was created with the main goal of solving this problematic.

[49] (Busch, 2005)

Strategic Risks						Operative risks		
General strategic company risks						General operative company risks		Project risks
Market risks	**Competitiveion risks**	**Activity risks**	**Organizational risks**	**Social and Environmental risks**	**Financial risks**	**Personal risks**	**Support processes and other risks**	**Goods and services risks**
Risk from the global Economical Market for example. - Economical development - Economical development of the branch - Acquisition cost - Corporate identity - Public - etc.	- Market share - Risks in relation to the own Competitiveness (competivity vantages, SEP's) - Risks in relation to customer satisfaction / loyalty - Marketing risks	Risks based on: - Service offering - Service width ways - Service performance	Risk related to the conduction constitution and operational structuring - Bad problem solving - Bad Leadership - inappropriate division of work - long decision paths - etc.	Risk in relation to the community according to the attainment of social and economical goals. - Ethic and moral representative practices - Emissions - Environmental hazard sources	- Pattern of finance risks - Cost structure risks - loss of receivables - very low yield - very low Cash flow - Overhead charges - variations of the credit terms - financial market risks	- Labor qualification - Labor disposability - Loyalty Labor risks - deficient promotion - deficient safeguarding of jobs - not fair market compensation - poorly work conditions	- Budget risk (f.e. Indirect costs) - investment risk - Risks from marketing, controlling, information processing and documentation - Legal risks - Risk in relation to RM, enterprise and innovation management	Production risks - Legal risks - Deadline risks - Financial risks - Technical risks - Management risks - Enviromental risks
Negative effects of the goal accomplishment								
- very low price levels - poor production activity - lower incomes - liquidity problems - etc.	- Lower market shares - Bad customer retention - Bad customer satisfaction - High acquisition costs - Poor production activity - Decreased gains - Liquidity problems	- Poorly production activity - deficient development - Know-how attrition by high rate of external services - High warranty costs / rectifications - etc.	Risk related to the conduction constitution and operational structuring - Bad problem solving - Bad Leadership - inappropriate division of work - long decision paths - etc.	- Long problem solving process - Negative work environment - High labor fluctuation - Bad performance quality - etc.	- Bad labor motivation - Bad reputation (Image damage) - Environmental damages - Instauration costs - etc.	- High interest expenditures - Liquidity problem by fixed costs - Bad capital return - etc.	- Deficient cost recovery - Bad production activity - Bad service quality - Deficient risk containment - Contention drawbacks - etc.	- Bad project yields - Liquidity problems - Bad service quality -etc.
Goal accomplishment								

Table 3-2: Main risk types of a general contractor and their possible outcomes, translated from (Busch, 2005).

3.3 The rule of uncertainty

The concept of "uncertainty" and its relationship to "risk" is important to address and understand, for a better understanding and handling of risk management and the risk assessment methods.

Frank Knight in 1921 (see section 3.4) was the one who introduced a clarification about risk and uncertainty[50], he made clear that risk can be quantified on the contrary; the principal characteristic of uncertainty is its unquantifiable nature. In other words for risks we can elaborated assumptions and assign probabilities as well as distribution functions, from this basis we can deliver an approximation of risk possibilities and their repercussions. On the other hand, uncertainty might be even completely unknown and no quantification is possible, thus "*uncertainty exists where the consequences of an event cannot be clearly quantify*"[51] [sic], therefore it is not possible to clarify the opportunities or hazards content within.

In construction projects uncertainty and risk have a similar behaviour and as noted before, every risk not considered in the risk identification process will become automatically an uncertainty, thus uncertainties supervision play an important role in order to confer more reliability to the risk management process (see 3.5).

Figure 3-4 shows how the uncertainties behave through the lifecycle of a project, here it is also important to see that the term dynamic uncertainty is introduce; the uncertainty normally doesn't have a constant behaviour, it is always moving together with the amount of risks and because of it, their potentiality must always be considered from a very analytical point of view.

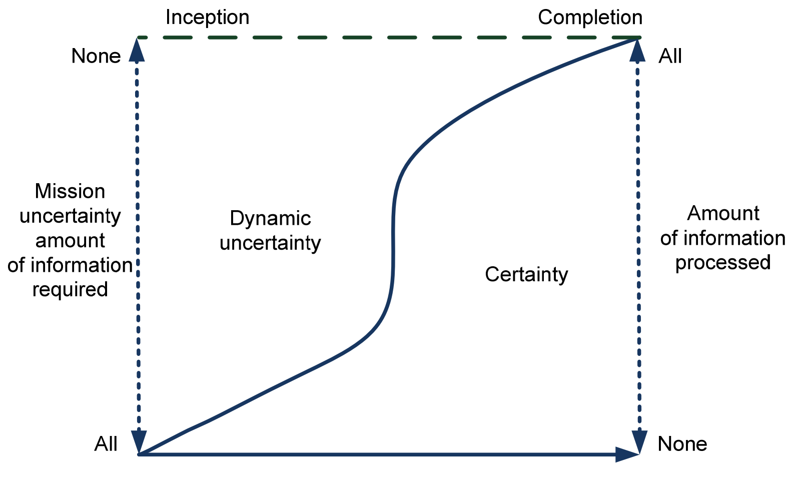

Figure 3-4: Uncertainty over a life-cycle of the project (Winch, 2002).

Uncertainty is defined in this work as in Figure 3-5; all kinds of influences that may have an impact on the project, when they are identified and quantified are known as risks, on the other hand when it's not possible to quantify them, but can be recog-

[50] (Knight, 1921), see chapter 3.3 the considerations of risk and uncertainty.

[51] (Kulkarni, 2005)

nized they are a “Partial Uncertainty”. When the uncertainty it’s totally unknown it’s call “Pure Uncertainty” (see also Figure 3-1).

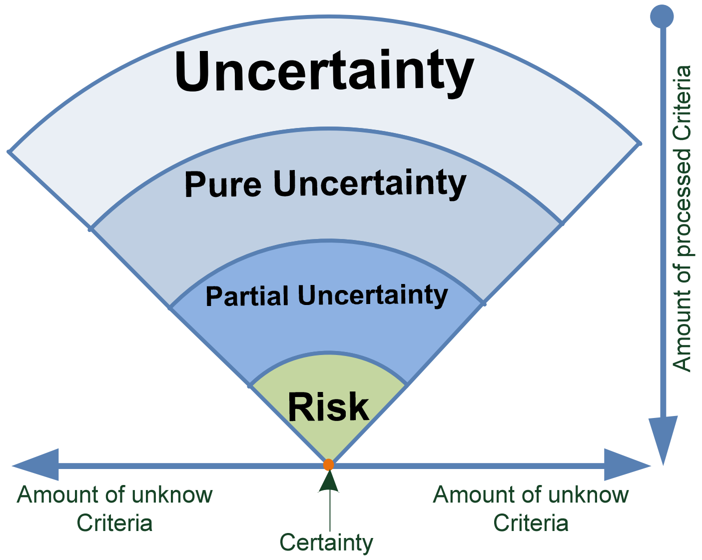

Figure 3-5: Types of uncertainty

Therefore it’s here defined, that uncertainty is divided in:

- **Pure Uncertainty**: not identified and not quantified influences (100% Unknown)
- **Partial uncertainty**: identified but not quantified influences

This difference gives us a better understanding of uncertainty. Even when the nature of the uncertainty does not permit evaluation, the experts and project managers should continuously consider it, in order to assure a better visualization among all the factors not included in the collection of risks that could affect the project, besides when it is possible to quantify it/them and through this to turn it/them into a risk for its future analysis and increase their opportunities and reduce hazards.

Uncertainty is the type of problems confronted with the strategic decisions (see section 3.6, strategic risk management Table 3-4) for the reason that operative uncertainty is normally reduced and filtered by the strategic management (into risks or partial uncertainties), thus the senior management has to deal in a serious way with this problematic and sometimes even the middle management.

Figure 3-6 illustrates risk, uncertainty and its relationship to the management levels. The senior management have the main task of among all the global uncertainties and risks, to identify dangers develop targets, strategies and philosophies that constitute the company’s position and framework (handbooks and procedures) towards risk.

At the beginning of any project the uncertainties are enormous but after the risk management process, the uncertainty has to be reduced to acceptable levels, therefore identification and quantification are important processes. Kulkarni presented a representation of uncertainty from which it can be seen that uncertainty is a result of ambiguity and complexity (Figure 3-7).

Table 3-4 (section 3.6) shows that strategic risk management deals with many non-quantifiable factors and requires an exhaustive analysis in the identification phase, based on the two factors ambiguity and complexity of the company's environment.

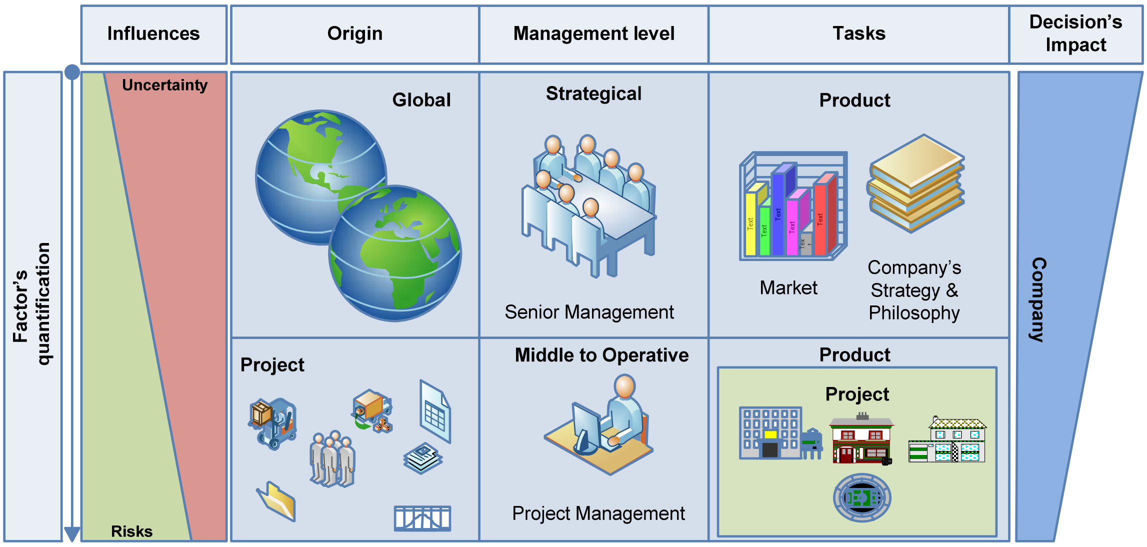

Figure 3-6: Uncertainty, risks and management.

An uncertainty's controlling procedure is always recommended in a similar form of for example the Delphi methodology or Brain storming; for a general uncertainty's overview. In this way uncertainties can be listed (partial uncertainties) and be contemplated without quantification but checking their potentiality.

In this work the considerations about uncertainty are mostly distributed among the middle to operative management levels, hence uncertainties even when they are important, they are normally already reduced by the senior management and they have to be marginalized and controlled by the project managers.

This consideration starkly reduces the amount and quality of the uncertainties and allows one to perform a more accurate uncertainty processing (risk identification).

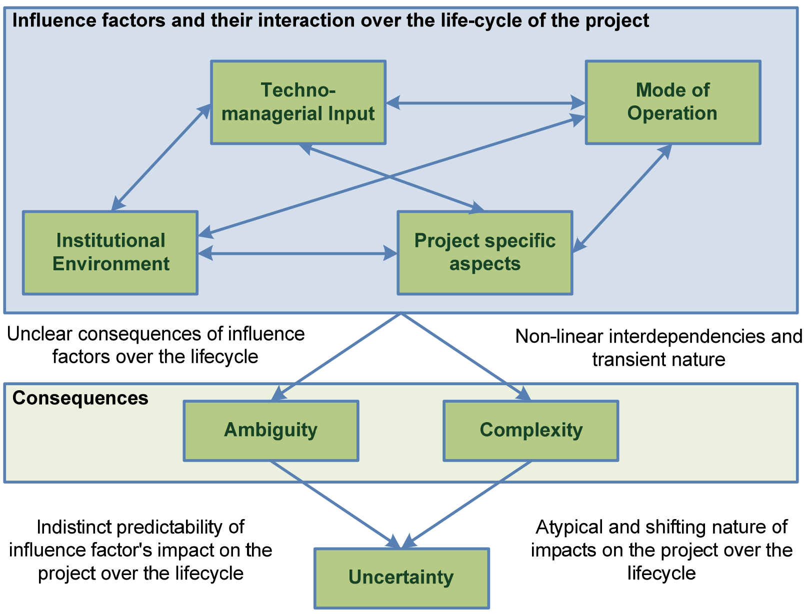

Figure 3-7: Ambiguity, complexity and uncertainty (Kulkarni, 2005).

3.4 Introduction to Risk Management (History)

As already noted, the handling of risks is an issue of high relevance in every kind of human activity through the ages, but not only risks but the management techniques also take a very decisive role. These two complementary disciplines have allowed mankind to develop and to improve our conditions into the present modern era. Solojentsev summarized this accomplishment with the following sentences:

> *"Management and Risk existed at all times from the moment of appearance of mankind. Management provided existence of each human being and the whole human community. First, the management was empirical, it was performed with account of risk on the basis of intuition, experience and common sense. At later stages of mankind history the states appeared. Then management was performed by the Supreme governor of the country on the basis of the code of rules and directives of religion. The basis of such management keeps both in society and engineering up to our days" [sic]* [52].

Management and risk (risk has always been an essential part of management) continued to be a topic of research since the early days of mankind, the very first analysis were made under the considerations of intuitive information and data as well as experience (qualitative analysis); however a better approach could only be achieved with the quantification of the input data. There is evidence of the study of probabilities in risk by gambling and chances in Egyptian tombs from 3500 BCE, in the renaissance Girolamo Cardano philosopher and mathematician (1501 - 1576) presented the "*Libor de Ludo Aleae*" (Book on games of chance) which presents the fundamentals of the probability theory[53].

From the financial and monetary point of view, Aristotle in his essay *"Politics*" presented the concept of "options", to sell and buy goods on decided prices. However the first breakthrough was made by Daniel Bernoulli in 1738, in his work "*Specimen theoriae novae de mensura sortis*" [54] he defined for the first time risk as the result of multiplication of the outcomes with their probabilities, with this he established the basis of the actual risk analysis.

From the insurance perspective there are records about the earliest 1800 B.C.E. with the *"financial tool that reduces risk for a person or party by "sharing" potential financial burdens with others (who are compensated in some way for taking on the added risk)"*[55]. With all this very first knowledge about the required mathematical background, the basis of risk management was conceived. With this the development of

[52] (Solojentsev, 2005)
[53] (Rosenthal)
[54] (Bernoulli, 1954)
[55] (Vesper, 2006)

methodologies and instruments to a superior risk analysis with the appliance of quantitative data and bases was born.

Within the management field the contemplation and determination of risk has always represented an important undertaking, however the first formal considerations of risk under management means were carried out by Frank H. Knight (1885-1972) in 1921 in his work *"Risk, Uncertainty, and Profit"*[56] he analysed the difference between risk and uncertainty and is considered as the founder of the risk analysis.

> *"There are other ambiguities in the term "risk" as well, which will be pointed out; but this is the most important. It will appear that a measurable uncertainty, or "risk" proper, as we shall use the term, is so far different from an unmeasurable one that it is not in effect an uncertainty at all. We shall accordingly restrict the term "uncertainty" to cases of the non-quantitive type. It is this "true" uncertainty, and not risk, as has been argued, which forms the basis of a valid theory of profit and accounts for the divergence between actual and theoretical competition."*[57]

Knight defined risk as a quantifiable or measurable factor, that can be determined under the consideration of known factors, while uncertainty can't be quantified or in other words, not measurable because of its indefinable factors and nature (see section 3.2, 3.3 and Figure 3-1).

John von Neumann (1903–1957) presented in 1928 his first paper the *"Theory of games and strategy"*[58] which allowed further developments of analysis instruments in several fields like operations research, economics, political science, etc.

As already noted risk analysis and management have a long history and relationship with each other, but it was until 1952 when Harry M. Markowitz presented *"Management of risk of investments"*, in this work he present the "Portfolio theory" and he explored *"aspects of return and variance in an investment portfolio, leading to many of the sophisticated measures of financial risk in use today"*[59]. He demonstrates that by means of an optimal risk distribution, higher profit can be achieved with minimal hazards. This work is considered the foundation of "Risk Management".

In 1973 Black Scholes introduced the "options pricing model" which established a model based on stochastic calculus. *"The model is based on the assumption that a trader can suck all the risk out of the market by taking a short position and increasing that position as the market falls, thus protecting against losses, no matter how steep"*[60].

[56] (Knight, 1921)
[57] likewise
[58] (Bochner, 1958)
[59] (Kloman, 2002)
[60] (Lewis, 2008)

In 1979 Kahneman and Tversky presented the "*Prospect Theory*" and they described how to manage risk and uncertainty. They demonstrate "*that people's attitudes toward risks concerning gains may be quite different from their attitudes toward risks concerning losses*"[61], in this way the human factor was included into the evaluations of risk.

In 1994 J.P. Morgan established one important milestone with the development of the "*Value at risk concept*"[62] and is a risk measurement geared to the maximal loss (Downside Risk Measurement) with a given probability defined as the confidence level, over a given period of time.

Since the beginning of the present millennium risk management has growth in importance because of international requirements like Basel I and Basel II and since 2010 the bases of Basel III expected for 2013, therefore risk management nowadays has become an important discipline with well-defined and structured processes, this well-structured array of disciplines, methodologies and philosophies developed into the newest "Enterprise Risk Management" concept (see section 3.6). But before defining this concept and to reach a better comprehension, it's important to address the topic of risk management as a process.

3.5 The Risk management process

Risk management has as one of its main targets the company's success and profit increase through a better control and response to goals deviations, thus risk management is designed according to the company's goals and strategies with the goal of achieving a better functionality, watching over all kind of deviations in the controlled fields. It's clear that risk management is an important instrument to the goal's accomplishment and it helps also to assure a better functionality, comprehension and control of the project's functionality and targeted goals.

Several authors agreed in the specific fact that risk management can be seen as a process cycle (methodology or process), accordingly inside of this cycle there are specific steps to follow, in which analysing, monitoring, controlling and risk treatment are content.

Risk management (as risk management process) is characterized by the interaction of different sub processes. Merna [63] described risk management as the interaction of risk identification, risk analysis, risk response and risk review in this specific order with the regulation functions of risk control. Wolke[64] describes this process as the sequential dealing of; risk analysis, risk measuring & analysis, risk response and risk

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[61] (Watkins)
[62] (Fallon, 1996)
[63] (Smith, 2006)
[64] (Wolke, 2007)

controlling. He describes the first three steps of the process as subordinate processes of the risk controlling process.

The German norm DIN IEC 62198:2002-09 defines the risk management process as risk identification, risk appreciation, risk response & mitigation and risk controlling. Each of these steps comprehends other sub processes. Fischer[65] described risk management as the interaction of the same sub processes in addition to a risk potential analysis and risk communication.

It's easy to see that the risk management process is a defined cycle result of the interaction of its own sub processes on which identification, analysis, response and controlling are considered. Hence the risk management process can be described, by the definitions of this work, as shown in the Figure 3-8.

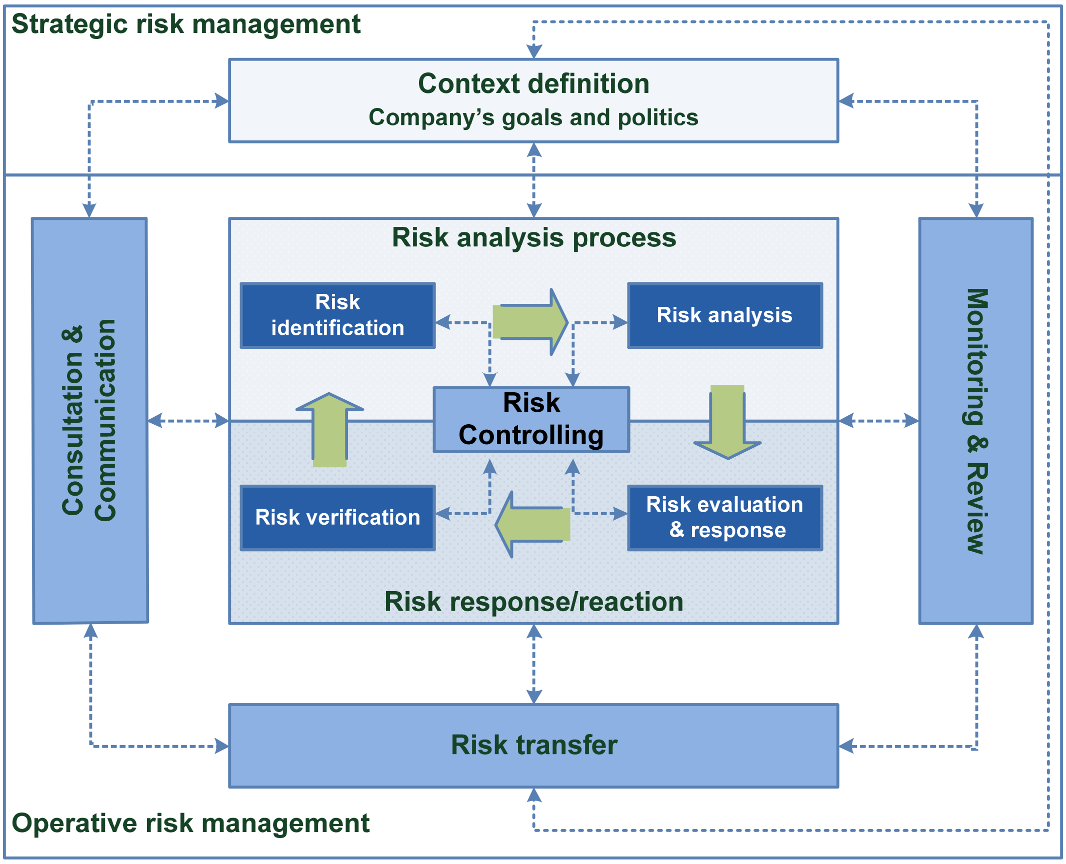

Figure 3-8: Risk management process.

Figure 3-8 shows the risk management process as cycle with defined subprocesses, these sub processes are interconnected to each other, which permits a better reaction to deviations from the company's stated goals. This representation includes important concepts that have shown high relevance in risk management.

In every risk management problem the first step to take is the context definition, in this phase the company's goals and politics are scrutinized and evaluated. As sub

[65] (Fischer, 2007)

sequent to this step the risk management process is broken down into the two sub processes: the “Risk analysis process” and the “Risk response/reaction process” with their own respective sub processes. Hence the risk management process is divided into three phases plus one additional one: the “Context definition”, the “Risk analysis process” together with the “Risk response/reaction” and as the additional process the “Risk transfer process”. This last process is an extra process that takes place when the risk analysis process and the risk response/reaction process determine that transferring or sharing the risk to another participant is a suitable treatment, therefore it is important to keep an appropriate control and communication with the external risk management process, thus the consulting and communication as well as the monitoring and review processes take place.

The transferring of these risks is a feasible solution when risks have to be treated in a more adequate form by a more competent partner or when it is not desirable to be self-performed. For this reason it is required to establish a communication system to supervise and control these external processes, this supervision system must be linked and joined to the company’s goals and politics for a better functionality and congruence.

3.5.1 Context Definition

Contained inside this process is the definition of the most important risk’s positions, tasks and strategies of the company. This process represents the definition of the company’s philosophy about risk for each management level in order to coordinate every kind of project; this definition includes the risk policy, from which the complete risk guidelines and criteria about risk handling is set. Thus the internal and external context are defined (internal and external factors are assigned and analysed to the corresponding management level).

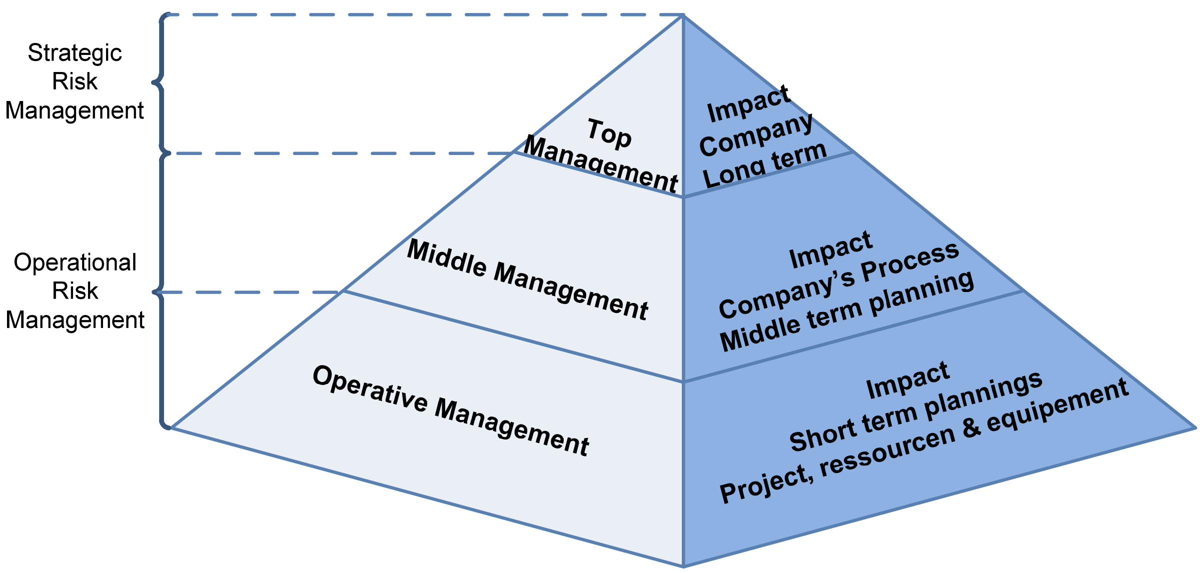

Figure 3-9: Risk management levels.

The risk policy conforms to and delimits functionality as well as the procedures within the company, therefore we can speak of two different processes, the "Strategic Risk Management" and the "Operational Risk Management" (see Figure 3-9).

Strategic risk management defines the company's philosophy towards risks, along with many other company's critical topics. At this stage of management the decisions and philosophies are provide by the "Top Management", these actions are prescribed by the composition of many factors such as; long term planning, company financial cash flows, long term investments, project's correlation, overall decision analysis and subjective decisions among many others; the actions are always performed considering the company's profile, vision and expectations.

Inside the operational risk management there are procedures and structures elaborated based on the guidelines set by the top managers (strategic risk management and philosophies) and with this, the respective tasks for the company's internal functionality are defined. Inside this process there are also two different levels of management, the "middle management" and the "operative management".

In the middle management, the company's practices are described for project control in a middle term planning; company resources, overall company and project cash flows, middle term decisions as well as risk management tools are contemplated. In consequence we can speak here about the company's philosophy towards project execution and their correlation. The operative management is entirely focused on project control in a short term planning for example project cash flows, short investment of resources, personal and equipment, planning techniques and the total project control come into play for this process[66].

In the context definition every task will be assigned to the adequate management level and according to their analysis, the respective actions will be applied to the different risks. In general the context definition is the problem's evaluation and the implementation of the correspondent measurements and/or actions according to the management philosophies. Immediately after the accomplishment of the context definition the consultation and communication has to be defined, this step is prepared for a better functionality of the risk analysis process.

3.5.2 Consult & Communication

The very first step in the problem is the determination of the participants of the different processes (identification, analysis and evaluation) of the risk management process, the definition of their responsibilities and how the communications formats and protocols shall be followed, this is the core of this process. Therefore it's important to review the following facets:

[66] (Maria-Sanchez, 2005)

- Communication strategy and protocols
- Stakeholders (roles, issues and responsibilities)
- Definition of communications media and meeting's schedule
- Elucidation of the main goals
- Integration procedures

Consultation and communication is an important procedure to achieve and as result of this step the complete functionality of the risk management process will be delineated, hence the consultation and communication can be the most difficult task to accomplish, several mistakes have this process as their origin.

It's imperative to update this process continuously to guarantee a better functionality and through it, to complete a successful risk management process. Many authors concur that this procedure is vital and of extreme relevance.

3.5.3 The risk analysis process

The risk analysis process is the most important activity inside the risk management process. In this process the potential risks are detected and stated for its further treatment and mitigation. In the risk analysis process are two different sub processes "risk identification" and the "risk analysis"; these two sub processes represent the first step into the handling with risks and they ought to represent the company's know how and risk philosophy.

Risk identification:

Risk identification is defined by the DIN IEC 62198 as: "to find, list and characterize the risks which jeopardize the project goals or phases"[67]. Werner agrees with this point of view and adds that the risk should be structured according to its sources and eventual repercussions, but above all to its interactions (their correlations)[68]. Wolke accentuates the need of classifying the risk into tables "risk registers" and emphasizes the systematization of this process according to the particularities and interests of the company (to increase the company's value)[69].

Risk identification is defined within this work as "the process in which uncertainty and risk are differentiated"; the most important risks are identified and classified according to their importance and controllability. This process take place at the very beginning of the risk management process and represents the most important step to the solution of the problem. This process is aimed at increasing the success possibilities and structures the most promising solutions for the project. A systematic procedure like in the one presented in Figure 3-10 is recommended.

[67] Translated from the (DIN EC 62128, Deutsches Institut für Normung, 2002)
[68] (Werner, 2002)
[69] (Wolke, 2007)

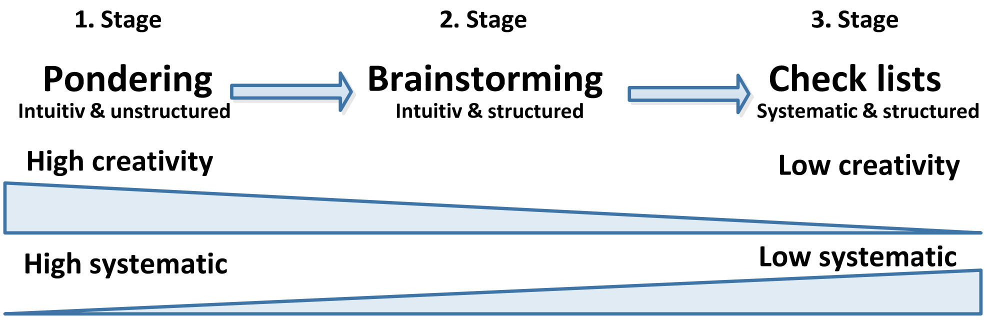

Figure 3-10: Systematic risk identification based on (Schwarz, 2010)

To search and/or find the most probable sources of risk there are many methods to support this risk identification process like:

- Brainstorming
- Pondering
- Interviews to experts
- Questionnaires
- Risk Register
- Historical Databanks
- Checklists

It's important to remark that during the identification process almost the whole data for the analysis is given in a qualitative form, the most important task here is to define strategies for its quantification, however the most significant target in this process is not to overlook any risk. Because every undefined risk becomes an uncertainty, the more uncertainties are reduced, the more possibilities the risk management process has to turn them into opportunities.

The next step in the risk management process is Risk Analysis. In contrast to the risk identification; risk analysis concerns the quantification of the identified risks previously listed in the sub process risk identification.

Risk Analysis:

The DIN IEC 62198 defines risk analysis as a part of risk appraisal, "it establish the boundaries and the differentiation of risk and all its dependencies, it determinate the risk occurrence probabilities as well as their repercussions to the determinate goals"[70]. Mawdesley established that risk analysis *"is the part of the risk management process that determines the expected values for these risks[71]. This is a task for estimators and economists, whose training and experience enable them to estimate the expected values of the various identified variables and their likely ranges"[72].*

[70] Translated from (DIN EC 62128, Deutsches Institut für Normung, 2002)

[71] It's important to mention that Mawdesly utilized the word uncertainties instead of risks, but according the risk and uncertainty definitions use in this work, uncertainties cannot be quantified, Mawdesly refers to risks instead uncertainty.

[72] (Mawdesley, 1997)

The Australian/New Zealand Standard on Risk management defined risk analysis as *“a systematic use of available information to determine how often specified events may occur and the magnitude of their consequences”*[73].

By the means of this work risk analysis is understood as “the quantification and valuation of risks according to the gained information in structured patterns, to its further processing and handling”. Nevertheless it’s important to differentiate between two particularities, there is information that has a quantifiable nature and can be used directly in a quantitative system and on the other hand there is also other type of Information which doesn’t have a quantifiable nature, therefore a conversion is performed to establish a quantification, in this case the conversion procedure has to possess high liability to assure an appropriate functionality.

As an important aid in this procedure we can find some methods that use the gained data to carry out risk evaluations, like the scenario analysis, the probabilistic analysis, the probabilistic sensitivity analysis, the probability impact, the back testing, etc. there are several methods to perform risk analysis (assessment), that are based in many different principles, each of them have their own requirements. In section 3.8 the risk evaluation methods will be explained and contrasted to each other.

3.5.4 Risk response/reaction process

After the implementation of the previous process the “Risk analysis” the most important risks, problematic, incidence probabilities and consequence’s magnitude have been quantified and evaluated and as end result, the data analysis and selection of the appropriate action to handle the risks has to be performed, with this goal the Risk response/reaction process takes place.

The risk response/reaction process is also, like the previous process, divided in two different sub processes, the “risk evaluation and response” and the “risk verification”.

Risk evaluation and response:

The risk evaluation and response shall permit one to classify the diverse risks in different categories and determine the required actions to implement. The evaluation of risks can be understood as described in the following Figure 3-11.

The risk information delivered by the risk analysis is presented in reports that facilitate management decisions as to what kind of action is required for the corresponding risks. Risk evaluation involves comparing the level of hazards, incidence possibilities and costs evaluated during the analysis process and according to previously established risk criteria (company’s risk policies).“*The result of risk evaluation is a prioritized list of hazards that require further action, this step is about deciding whether*

[73] (AS/NZS 4360, 1999)

hazards are acceptable or need treatment"[74] to fit them into the desired hazards levels like shown in the Figure 3-11.

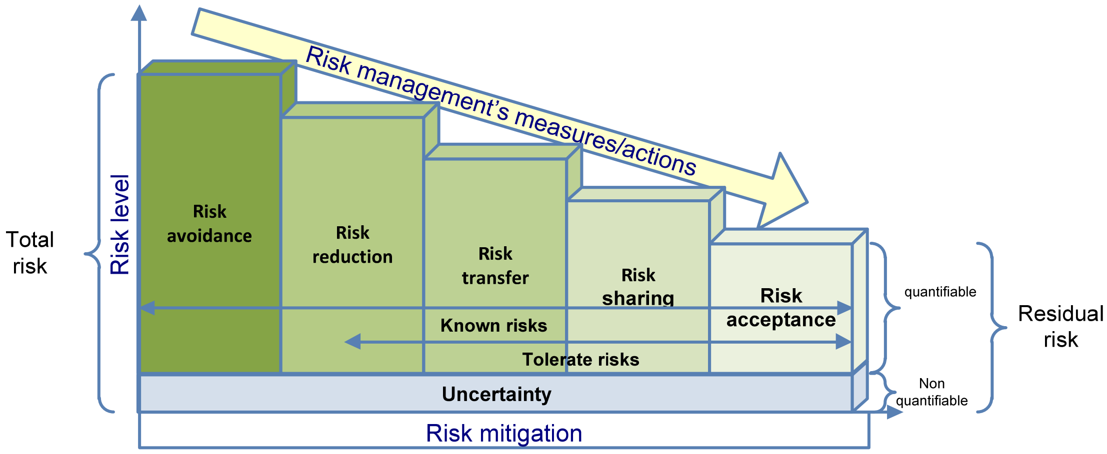

Figure 3-11: Risk evaluation and response.

Basically one must know which hazards can be avoided, treated or accepted, nonetheless each of these decisions requires a justification (normally monetary), however between the avoidance and the acceptance there are different stages for the treatment of hazards. For a better comprehension it is important to understand first the risk avoidance, the risk acceptance and afterwards the different possibilities for dealing with them.

- ***Risk avoidance:***

This indicates is the simplest method of dealing with hazards, when there is no information, methodology or possibility to perform a reliable risk evaluation and finally to control, or in the situation when even the treatment of risk does not reduce the hazard down to an acceptable level or finally, when this could mean a possibility to increase hazards in other fields and no possible opportunities, the risk should be avoided or not accepted.

- ***Risk acceptance:***

Is the quantity of hazards that can be accepted, in this concept the following idea "ALARP" (as low as reasonably practicable) comes into play, which means that the hazards involved are low and the costs of treating these hazards are not more important than the expected benefit, consequently the risk can be taken. Risk can be accepted for the reason that:

- The hazard is low and the treatment costs are higher than the expected benefit, so acceptance is the only possible way.
- The hazard's level is so low that treatment is never needed

[74] (AS/NZS 4360, 1999)

- The benefits outweigh the hazards so much so that the hazard is balanced out and warranted
- The hazards cannot be treated and are low

In risk acceptance it is up to the managers to decide which actions are the most adequate, based on the correlations with other projects and the total amount of hazards possible to be accepted also known as "risk appetite"[75].

- o ***Risk reduction:***

The AS/NZS 4360 defines it as "*a selective application of appropriate techniques and management principles to reduce either the likelihood of an occurrence or its consequences, or both*"[76]. This means the application of actions and strategies to reduce the hazards down to desired levels.

Hazards can be reduced trough:

- Acquisition of more information
- Performing more tests and evaluations (accurate forecasts)
- Reducing the incidence probability (immediate actions)
- Allocating new resources (financial and material)
- Reducing the derogations
- Improving the communication and management conditions

The treatment shall be developed into an action plan by which the strategist or manager gets the most valuable information about the risks, like the level of hazards of the relevant factors, the planned strategy, the plan implementation timeframe, required resources and the responsible persons or departments and finally sets the target goals, and communicates them to the responsible managers.

- o ***Risk sharing/transfer***

In some situations a better option is to share the risk with other entities and in this form to share the responsibilities about the hazards, in this manner the abilities of new partners or experts are gathered for the benefit of the project and increase its value as well as its opportunities.

Between these procedures there are many instruments like: contracts, insurance, partnerships and business alliances, etc., consequently the risk passes into the hands of a more competent risk bearer.

There are two characteristic engagement forms for this kind of practice:

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[75] Risk appetite can be understood like the quantity of risk that the enterprise can deal with or accept. Barfield, Richard (Barfield 2008) defined it as "*the quantum of risk that the firm is willing to accept within its overall capacity*".

[76] (AS/NZS 4360, 1999)

- **Insurance firms:**
  By the payment of an insurance premium the risk can be transferred to an insurer (this normally deals with hazards or acts of god).
- **Contract partners:**
  By the closing of a contract, the risk can also be transferred to another party or partner.

The difference between these two different forms of share/transfer risk is; that with insurance the risks are taken by the insurer via the payment of the insurance premium fixed as result of the risk analysis like risk policies and incidence possibility, while with the contract partners the risk will be covered by the cost changes in the total contract amount.

However in addition to this, in practice many contractors forget this assertion:

> "*It is important to note that risks can never be completely transferred, because there is always the possibility of failures that may impact on the business. Transfer of risk*[77] *may reduce the risk to the original business without changing the overall level of risk*"[78].

Most of the contractors think that they can forget about hazard when there is a partner who carries it, they forget about the correlation about risks and as long as a hazard is not mitigated; the hazard is always present and cannot be deleted, just transferred to another bearer but still may impacts the entire project. The hazard reductions together with the Risk sharing/transfer are to be supervised by the Risk controlling process.

Risk Verification:

This sub process is responsible of performing a constant supervision. After the risks are treated, new targets are settled, therefore the treated risks are to be supervised and screened. Thus the supervision of risks and their deviation reports to the original and/or new targets must be closely controlled.

This sub process closely follows the main risk management process and as soon as a new deviation is detected, this is reported to the Risk controlling process and with this the new risks can be evaluated and the process can start again.

Risk controlling:

Risk controlling is along with risk identification, one of the most important processes inside of the risk management process. This sub process addresses the information and communication between the other sub processes, its most important task is to

[77] With risk is here Hazard meant.

[78] (Government NSW New South Wales, 2008), the risk consideration here refers to Hazards and not to opportunities.

coordinate them. This process builds bridges between the different sub processes for a better reaction and response to risks.

Risk controlling permits also the development of “data banks”, every piece of information treated by any of the other sub processes, can be used for further projects. This information can be used in a risk register and for the development and improvement of check lists and data banks, furthermore, it can also be used as precedent for the handling of risks (to increase opportunities and reduce hazards) in any new project.

Through these two last sub processes, the effectiveness of the actions on the treated risks can be evaluated as well as their repercussions. This information can be used for statistical analysis and development of scenarios for the risk management process. Through this analysis new strategies can be developed to assure the better accomplishment of new projects and evolution of the risk management process itself.

3.5.5 Monitor and review

The Monitor and review process is important and indispensable in risk management in order to control and review risk that are carried by external partners or processes, they ought to stay in constant communication with the main core of the risk management process, risk controlling. This monitoring process has to be conducted constantly so that it will be effectively managed and integrated in each of its processes and sub processes of the risk management process.

With these considerations, new strategic forms have revolutionised risk management since the beginning of the present millennium, thus risk management will in the future be understood by different methods, procedures and even philosophies. As already noted in section 3.3 and to give a better comprehension of the new developments about risks and risk management, it is important to define the Enterprise Risk Management.

3.6 Enterprise Risk Management (ERM)

Risk management has become nowadays an important discipline in every kind of enterprise; these days risk management has been developed in several methodologies designed to be applied in different management levels and they are based in different quantification approaches (quantitative and qualitative) of risk, among all the variety of methods philosophies and approaches, a new organisation concerning risk has emerged the “Enterprise Risk Management”.

According to the Casualty Actuarial Society, Enterprise Risk Management can be described as:

> “*the discipline by which an organization in any industry assesses, controls, exploits, finances and monitors risk from all sources for the pur-*

poses of increasing the organization's short- and long-term value to its stakeholders"[79].

On the other hand the Committee of Sponsoring Organizations of the Treadway Commission (COSO) in USA defines ERM as:

"*A process, affected by an entity's board of directors, management and other personnel, applied in a strategy setting and across the enterprise, designed to identify potential events that may affect the entity, and manage risk to be within its risk appetite, to provide reasonable assurance regarding the achievement of entity goals*"[80].

DeLoach describes Enterprise Risk Management as:

"*A way of managing risk and uncertainty in the new economy. It is a new way of thinking about risk. It means aligning and organization strategies, processes, people, technology and knowledge to meet its risk management purpose. Managing risks on an enterprise-wide basis means making an entire organization aware of risk and equipping everyone to thrive on uncertainty*"[81].

These definitions of enterprise risk management permit one to see that enterprise risk management is a new risk management organization form, meant to create a global risk management procedure. Enterprise risk management affirms that the different risk managers are able to perform a better and more accurate day-by-day risk controlling, due to their expertise as well as their refined knowledge of risks and consequently to elaborate more efficient and adequate strategies.

Enterprise risk management can be defined in this work as:

"A strategic risk management framework oriented to optimize the risk management functions in an enterprise, by the appropriate classification and finally a more precise utilization of risk methods, risk philosophies as well as resources and with this to distribute the responsibilities to the correspondent operative management levels, hence to perform the day-by-day interaction with risks in every management level, for an improved global performance towards risks".

The mentality of enterprise risk management is reflected in the fact that it's conceived of as applying to all kind of organizations. Enterprise risk management sustains that developed risk management systems are not limited only to the financial and insurance branches.

[79] (Casualty Actuarial Society, 2005)
[80] (Committee of Sponsoring Organizations of the Treadway Commission , 2004)
[81] (DeLoach, 2000)

The Protiviti “Guide to Enterprise Risk Management” remarked that many enterprise risk management practitioners find out that they have a lot in common with other practitioners from fields dissimilar to financial and insurance, which means that they work with similar approaches towards risk and that they do address a global interaction between risk factors[82]. Protivity introduces also a representation of the different stages in the evolution of risk management presented in Table 3-3.

This table allows us to contemplate how risk management has developed into the current Enterprise risk management, we can appreciate an intermediate stage, the Business risk management.

Business risk management is discussed as the current risk management, it is grounded in manager’s decisions (mostly middle management) and includes appreciations of facts related to logistic and corporate functions like suppliers, labour factors and the costumer, and the interactions within the management itself.

	Risk management process		Global coordination functions
	Risk management	Business Risk Management	Enterprise Risk Management
Focus	Financial and hazard risks and internal controls	Business risk and internal controls, taking a risk-by-risk approach	Business risk and internal controls, taking an entity-level portfolio view of risk
Objective	Protect enterprise value	Protec enterprise value	Protect and enhance enterprise value
Scope	Treasury, insurance and operations promarily responsible	Business managers accountable	Applied across the enterprise, at every level and unit
Emphasis	Finance and operations	Management	Strategy-setting
Application	Selected risk areas, units and processes	Selected risk areas, units and processes	Enterprise to all sources of value
	“Current State“ Capabilities		“Future State“ Vision
	Physical Assets; Financial Assets	Physical Assets; Costumer Assets; Financial Assets; Employee/ Supplier Assets	Physical Assets; Costumer Assets; Organizational Assets; Financial Assets; Employee/ Supplier Assets
	Tipical Operative management	Operative till Strategic risk management	Strategic and operative risk management integration and total controlling

Table 3-3: Risk management evolution, based on the “future goal state” (Protiviti, 2006).

However this representation shows that the new tendency of risk management, Enterprise risk management is a global risk management system focused in the improvement of risk functions and a better elaboration of enterprise strategies and visions with the corresponding value improvement.

[82] (Protiviti, 2006)

In 2005 Mikes presented a paper entitled, "*Enterprise Risk Management in Action*"[83] which provided results from an evaluation of the new tendencies of enterprise risk management. In this work Mikes recognized the basic composition fields of enterprise risk management backed in the analysis and interviews of two different bank groups; the BWT group and the Fraser bank. Mikes defines the enterprise risk management as a combination of four ideal risk management types:

- Type 1: "Risk silo management"

"*Risk silo can be defined as the measurement and control of market, credit and operational risks in "silos" across the organization*"[84], this concept is concentrated in the pure and systematic measurement and control of risks within the organization or operative risks.

- Type 2: "Integrated risk management"

"*Integrated risk management is defined at this juncture as a risk management approach that applies the Economic Capital framework for the measurement, comparison, aggregation and control of risks*"[85].

- Type 3. "Risk and value management"

"*Risk and value management part form the idea of using risk-based internal capital allocation for performance measurements and control….. Is an application of risk and Value based management by the creation of shareholders value by earning returns in excess of the cost of capital*"[86] [sic].

- Type 4: "Strategic risk management"

"*This conception of enterprise risk management encompasses risks that cannot be readily quantified or aggregate*"[87], it incorporate the risks that need to be considered for the risk management framework on a senior basis. These kinds of risks have normally an extreme qualitative nature or present the need of reviewing uncertainties.

As result of these classifications Mikes presents the Table 3-4 as an illustrative representation of the four ideal risk management types and their characteristics, it is easy to see that the quantification of risks is an important characteristic in Risk Silo management while Strategic Risk management deals mostly with subjective risks and uncertainties, because of it the nature of their philosophies and techniques (to each type) vary in its processing. It can be said that the ideal risk types can be applied in different areas, according to the appropriate and correspondent management level and goals.

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[83] (Mikes, 2005), even when this document was directed to the analysis of two different banks, there are the most important ideas, structures and methodologies towards enterprise risk management explained, which can be applied to any enterprise.
[84] (Mikes, 2005)
[85] Likewise
[86] Likewise
[87] Likewise, see uncertainties in section 3.3

The Casualty Actuarial Society presents in its work "*Overview of Enterprise Risk Management*"[88] an illustration (Table 3-5) of some of the most relevant risk management areas to be scrutinized and controlled in every enterprise. This sample of factors shows how the enterprise risk management has an interdisciplinary behaviour within risk management.

	Risk Silo Management	**Integrated Risk Management**	**Risk and Value Management**	**Strategic Risk Management**
Institutional Background	International regulation of bank capital adequacy	Rating agency expectations of bank capital adequacy	Rise of the shareholder value imperative	Rise of risk-based internal control (Anglo-Saxon and German corporate governance)
Related theme in the literature	Risk quantification	Risk aggregation	Risk-based performance measurement	Management of non-quantifiable risks (Uncertainties)*
Focus on	Measurement and Controls of risk Silos; Calculation of regulatory capital; Tuning Capital to the regulatory standard	Assigning a common denominator of risk to the risk Silos (Economic Capital); Fine-Tuning capital to a given solvency standard; risk limit setting	Calculation of shareholder value created; Linking risk management with performance measurement	Inclusion of non-quantifiable risks* into the risk management framework; Providing senior management with a strategic view of risks
Techniques	Loss distributions; Value-at-Risk; Credit rating models; Standardized and Advanced measurement approaches set by regulators	Economic Capital	RAROC; Shareholder Values Added; Risk Pricing; Risk Transfer; portfolio risk management	Scenario analysis; Sensitivity analyses: Control self assessment; special risk reviews

*non quantifiable risks are uncertainties

Table 3-4: Four ideal types of enterprise risk management (Mikes, 2005).

Marketing

- New Business sold
- Retention of old business
- Mix of business: new and renewal
- Market share by costumer type
- Average premium or assets by per custumer
- % high-yield customers
- Costumer satisfaction
- Average # of products per costumer

Underwriting

- Price achieved vs. Target price
- Exposure data (number of cars, payroll, etc.)
- Exposure mix
- Quotes accepted/declined
- Variance analysis
- Premium persistency
- Loss ratio
- Loss Adjustment expense

Financial

- Revenue
- Underwriting profit
- Investment profit
- Pre-tax operating income
- Net income
- Return of equity and total capital
- Economic value added

Sales/Distribution

- Acquisition cost per sale
- Sales by distribution channel
- Growth/retention of agents

Investments

- Cash flow
- Yield on new investments
- Yield on portfolio by class and duration
- Convexity of assets
- Duration of assets
- Investment mix: new and portfolio
- Credit default
- Total return

Human Resources

- Agency composition (number, age service)
- Total employment by department
  - Number and percentage leaving the company
  - Vacancy rates
  - Average salary increase vs. Plan
- Employee commitment and engagement

Claims

- Frequency and severity of claims
- Claims department productivity

External Data

- Audit compliance
- Inflation rates
- Interest rates
- GNP
- Competitor pricing

Table 3-5: Example of controlling domains by enterprise risk management (Casualty Actuarial Society, 2005).

88 (Casualty Actuarial Society, 2005)

The Committee of Sponsoring Organizations of the Treadway Commission (COSO) presented also an overall representation of the enterprise risk management (Figure 3-12); this representation illustrates it as a compound of four categories (on the top), eight components (at the front) and four entities (at the right side), the representation is focused in an entity's enterprise risk management. It's important to appreciate that the risk management process (here presented as the eight components) is the core of the enterprise risk management.

It's possible to say that according to the task, management level, kind of data and problem requirements, the liability of the analysis is defined by the application of the adequate risk evaluation method, which is normally set by the correspondent type of enterprise risk management; therefore it is important to be acquainted with the description and classification of the principles and uses of the Risk evaluation (assessment) methods.

Around the risk evaluation methods we can find many different risk assessment procedures which are developed with the knowledge of different principles and techniques dedicated to achieve an appropriate risk appraisal.

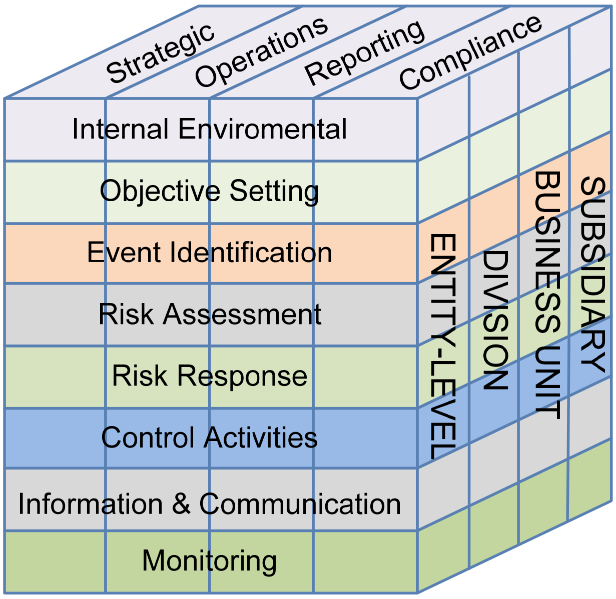

Figure 3-12: Entity's enterprise risk management (Committee of Sponsoring Organizations of the Treadway Commission , 2004).

Most of the risk analysis methods can be classified in two different groups, the "Qualitative Methods" and the "Quantitative Methods", the difference lies in the nature of the information to assess or inputs (qualitative, quantitative, statistical, fuzzy, etc.); another important characteristic normally reflected in the methods is the way in which the information comes in to being (natural factors, human, mechanical, etc.).

The new risk management developments as shown in Table 3-4, identify these two different methods and divide them into the four different ideal types of risk management. For example while risk silo management is totally dedicated to the quantification of operative risk, strategic risk management is performed mostly by qualitative analysis and on the other hand, the integrated risk management and the risk and value management are based almost wholly on economical or financial criteria.

3.7 Risk analysis/assessment methods and classification

The qualitative methods are usually the first step in risk assessment and they are commonly used at the beginning for the very first risk approximations to any endeavour. Therefore in the qualitative risk management methods it is very important to define and identify risks then respectively to determine also the first estimations of their probabilities, impacts, ranking and their allocation.

Strohmeier (Figure 3-13) classifies the risk management methods (instruments as he call them), in five different groups: the “Model analysis based methods”, the “Event based methods”, the “Indicator based methods”, the “Narrative methods” and finally the “Methods of risk aggregation”[89].

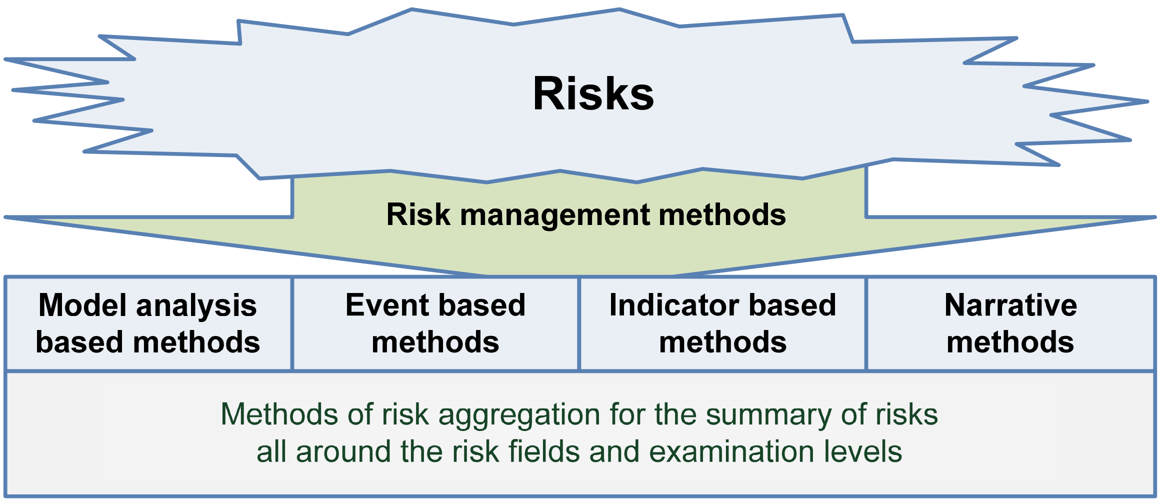

Figure 3-13: Risk management methods overview (Strohmeier, 2007).

Strohmeier describes risks as the result of a chain of events and refers to the fact that risks are a combination of linked facts (a kind of events tree); therefore risks are sometimes extremely complicated and one can attain a better comprehension of them (the correlation between risks), the risk classification shall permit to distinguish in which of the four different categories of Table 3-6 is the risk located for its further analysis and risk comprehension[90].

“The Event based methods” apply in to the cases in which the event chain (the combination of facts from which the risk is provoked) can be followed and tracked, thus to determine their influence on the problem.

[89] (Strohmeier, 2007)

[90] This principle of “chain events” is handle in a better shape by the Markov Chain Monte Carlo (MCMC), see chapter 3.8.11

"*The indicator based methods"* are a simplification of the general problem, this simplification consists of the analysis of key indicators, which are critically important to the risk evaluation and exert much influence on the problem.

"*The model analysis based methods"* require the elaboration of models or algorithms to perform the analysis of inputs and transform them into the required outputs in mathematical form for its analysis, in this way the reality is represented in a partial form, for the reason that the elaborated model is just a problem specific situation and targeted to the explicit problem requirements.

"*The narrative methods"* are concentrated in the performance of qualitative methods and the procedure of how to achieve an efficient and secure appraisal of risks under subjective considerations or data.

"The risk aggregations" methods are mostly the elaboration of simulations procedures to achieve a global risk appraisal and in this way to give a general overview and analysis to all kinds of risk variations; they can be a mix of the four different methods, dependency and correlation between risks are important for this method.

According to this last method (the aggregation methods), the nature of today's quotidian problems are a complicated mixture of many disciplines and knowledge fields, thus to achieve a better and appropriate appraisal of risks, the risk analysis process should contemplate a simultaneous valuation of risk from many different risk fields under the consideration of their own philosophies and correlations. "Enterprise risk management" is conceived with this principle in mind and allows the separation of risks into different fields to ensure a better analysis.

The task of knowing what kind of tool or in other words which risk analysis method is the most appropriate to apply, is important for the solution of any risk analysis problem. Smith described the risk appraisal methods according to their characteristics and principia, he separates the methods in risk identification (for their identification and priorities), and risk analysis (for its estimation)[91].

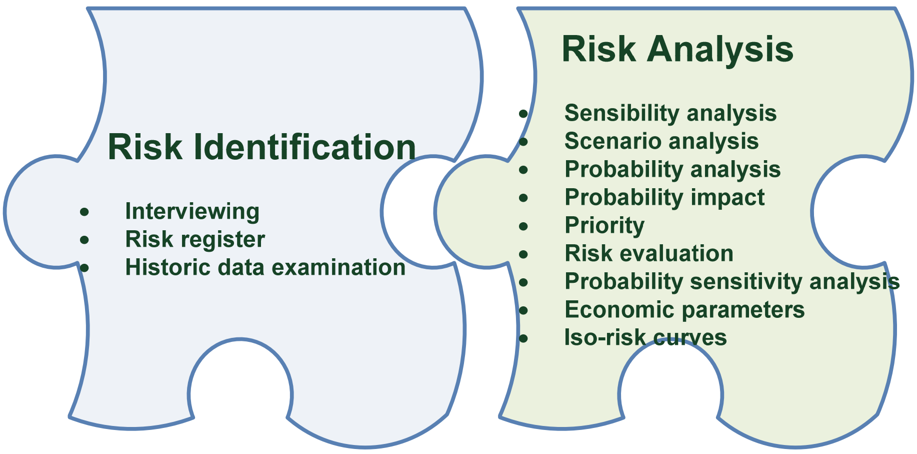

Table 3-6: Risk management methods based in Smith et all. (Smith, 2006).

[91] (Smith, 2006)

In Table 3-6 we can recognise the classification presented by Smith; this classification is based on the basic discernment principles of each method. Every method except the sensibility analysis[92], can group different risk appraisal methods, therefore we are speaking of classification groups for risk assessment methods.

Smith shows in Table 3-6 the three most important methods for risk identification. Many authors consider the use of more than three methods as beneficial for a successful accomplish of this task, in fact the praxis have proved that this practise is really helpful. The methods mentioned by Smith have shown effectiveness and should be applied together with other methods to achieve a better identification and reduce uncertainties[93].

a. ***Interviewing***: Consists of a direct consultation with experts and/or advisors that have a verified appropiate knowledge and experience of the thematic or worked in similar projects, in order to identify risks together with the project's stakeholders and/or project managers in charge. The main target of this method is to assure better identification of risks through the utilization of the earned information and experience from the advisors. This method encourages more personal involvement in the project by allowing the involved partners and managers to have the chance to express their opinions about the project.
b. ***The examination of historical data:*** this method demands an adequate procedure by the procurement of data. An appraisal and consideration of previous projects has to be developed to be of assistance to the identification process, however the difficulty of this method lies in the data procurement (data banks), consequently a systematic must be introduced, especially in the specific case that a similar project has never been done before, the method has to concentrate on finding similar projects and to glean the required information.
c. ***Risk register:*** this is a compilation of documents, spread sheets or data base information in compacted form to support the risk identification and risk analysis procedures. They are normally grouped in a list with an approximation of their probabilities. This method provides an adequate assistance, nevertheless sometimes the list can be vast and could complicate the general overview, therefore it has to be tailored to the project's needs and requirements.

By the risk analysis methods Smith identifies nine different principal methods:

i) ***Sensibility analysis:*** is a non-probabilistic method that permits the identification in a project the variables of high, middle or low repercussion, according to the provided limits and ratio variations of the variables. The method allows one to distinguish to which variables the project is sensible and to rank them. This method is helpful for project managers it permits them to evaluate the importance of the dif-

[92] Sensibility analysis shall never be considered as risk analysis method, (Smith, 2006), this method permits to analyse criteria interactions but not to simulate risks. The method is just an aid for the risk analysis (see next page i) and Chapter 3.8.3).
[93] The 12 methods presented here are a resume of the Smith research.

ferent project's variables, the main problem of this method is that it presents the "[ceteris paribus] *which means that when a variable is changed, the rest remains the same; also that only the variable can only be known within a certain range, it is defined by the person who performs the analysis*"[94]. However this method shall not be classified as risk analysis method, but as an instrument for the results valuation of risk analysis methods.

ii) ***Scenario analysis:*** this method refers to a combined valuation of risks factors targeted to avert the "*ceteris paribus*" problematic (this method is not oriented to correct the sensibility analysis), this means many simultaneous variations of the different factors are considered on the risk variables, these variations shall be carefully predetermined by the risks specialists as well as the methods to analyse these variables. The group of methods, variables as well as specialists shall be composed from many different fields and thematic. This kind of analysis is oriented to respond to the different questions with predetermined possible situations and is widely used to simulate changes around the economic factors and review the worst case scenario. However the efficiency of the method depends on the project manager abilities.

iii) ***Probability analysis:*** this kind of methods utilizes a stochastic background to perform its appraisal; it normally confers a probabilistic analysis with a respective probability distribution to the different variables, consequently according to a number of iterations that have to be performed, it delivers an analysis of the outcomes (usually an economical one). When the information is vague or not sufficient, this methodology can present some accuracy limitations, thus the varying nature of risks, it normally complicates its usability for inexperienced analysts.

iv) ***Probability sensibility analysis:*** is a refinement of the sensitivity analysis and consequently a more elaborated procedure, this method allows one to assign probabilities to a possible outcomes and permits one to verify how sensitive the conclusions to the performed variations are. Therefore a strong knowledge of the project as well as an appropriate level of experience is required.

v) ***Probability impact:*** the elaboration of two different matrixes on which the probability of occurrence and the magnitude of the impact on the project are elaborated. These matrixes could have either a qualitative or a quantitative nature and are normally elaborated from historic reviews, statistical analysis or simple experience evaluations. From these matrixes a grid pattern is elaborated from which a risk assessment is performed; this pattern allows one to decide which risks demand a special prosecution, a detailed definition and/or a better pursuit. For the implementation of this method it's important to justify and scrutinize the elaboration of the matrixes, hence adequate experience beyond knowledge of the method and project is essential.

vi) ***Priority:*** across the different variables (independent to their basis or scale) a weighted estimation of risks is evaluated based on their probability of occurrence, impact and objective affected on its occurrence; through this estimation a risks im-

[94] (Smith, 2006)

portance rank is elaborated. This method is conceived to come along throughout every project procedure and to set which risks require more attention or analysis. This method allows the project managers to focus on the most relevant risks and reduce the decision analysis to overriding risks, but it also reduces the possibility of performing changes to the project, the changes normally impact costs in a strongly impact costs.

vii) ***Risk evaluation:*** Smith refers in this category to the base case models with the application of qualitative and quantitative data, stakeholders and clients should secure the origin and use of the data. The stakeholders shall take care of the management of risks and the clients of where the services needed. One of the most important details is also the source of risks and their scales. To a better uniformity and robustness for any appraisal is the correct definition of scales to the measurement of risks. This is indispensible.

viii) ***Economic parameters:*** by the handling of qualitative information and data as well as their influence on the project, some of the most important facts are the financial information like: the cash-flow analysis, cash-luck up, internal rate of return, net present value, payback period, debt service coverage ratios and return on equity, among many others. They all permit one to reflect the inference of risks in a financial form[95]. Thus the use of the economic parameters make possible a better pursuance and control of the monetary variables and many other implicit variables for an adequate risk management procedure.

ix) ***Iso-risk curves:*** this method is based on the mapping of the possibilities of occurrence against the impact. Through this mapping iso-curves has to be delineated and in this form to deliver a representation of which risks have to be attended with more priority. These iso-risk curves separate different areas and in this way low middle and high risks are able to be clearly seen. This method requires a good graphic interpretation skills as well as a high liability about the required data to its elaboration. The Figure 3-14 presents an example of the iso-risk curves; it shows its simplicity by the classification of the different variables and classification.

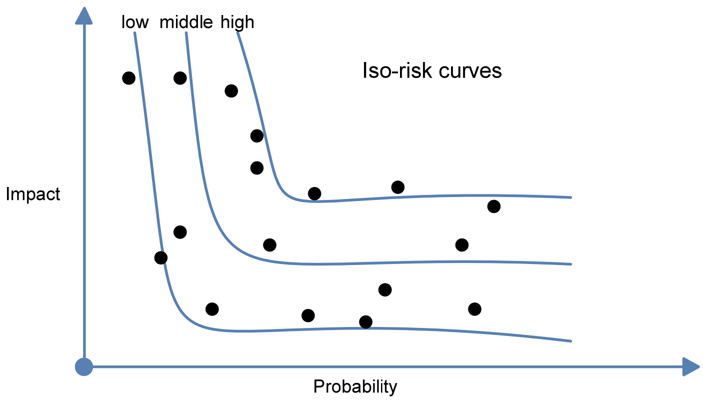

Figure 3-14: Iso-risk curves (Smith, 2006).

These risk methods classification by Smith permits one to distinguish between the principia and functionality of the risk methods and to group them. It's important to

95 (Smith, 2006)

mention that for very different risk considerations several methods either quantitative or qualitative can be applied, many methods considerer mostly economic parameters and sometimes don't allow another type of evaluation.

To facilitate the overview among different risk assessment methods that are contained in the previous classifications groups, the following table was elaborated; these methods represent a viable option in the present work.

Type	Complexity	Principle	Method
Qualitative methods	Simple	graphic/ documentary	• Pondering • Checklists • Brainstorming • Historic review • Risk register • Interviewing
	middle	graphic/ document	• Analysis of inter-connected decision areas (AIDA) • Strategic options development and analysis (SODA) • Strategic choice method • Soft systems methodology (SSM)
Quantitative methods	middle	Index	• Delphi Method • Key Indicator Method • Risk Potential Method
	middle	non probabilistic	• Sensibility Analysis
	middle-high	Statitistical	• Volatility Method • Value at Risk • Quantitativity Risk Analysis
	middle-high	Stochastic	• Program Evaluation and Review Technique (PERT) • Monte Carlo Simulation • Latin Hyper-Cube Sampling • Probability Sensitivity Analysis • Markov Chains Monte Carlo (MCMC)
	High	Artificial Intelligence	• Neuronal Risk Assessment System (NRAS) • Support Vector Machine

Table 3-7: Classification of the risk analysis methods.

The methods listed in Table 3-7 are some of the most important methods in risk management nowadays; they offer high potential to the support of the main objective for the present work.

3.8 Description of the risk evaluation methods

For a better comprehension of the risk assessment methods listed on the Table 3-7 as well as their principia and characteristics, it is important to present a brief description of the most relevant of these methods.

3.8.1 Delphi Method

The Delphi method has the simplest principle between the risk assessment methods; this technique is developed to assure a consensus through a communication exercise among a group of experts. It establishes the collaboration between a number of specialists (normally from many different fields), under the coordination and control of a Delphi-Moderator, the main goal is to identify and evaluate risk in a complex problem.

In order to achieve an efficient valuation the experts are provided with sufficient information about the different project particularities and topics, every new development in the project is updated to an information's core, this core has the main task of facilitating a general information flow between the experts.

The information's core and the Delphi-Moderator shall facilitate the consensus in the risk's identification along with the risk evaluation and through this estimation determine the probability of occurrence and impacts on the project. As soon as the consensus is achieved, the experts set the risk values and from these estimations; the mean, the standard deviation, the probability, etc. are calculated.

This method has been shown to be appropriate for projects on which there is not much information available or which have never been done before, though is totally conditioned to the experts' experience and skills; therefore the selection of the appropriate experts is the main task for a successful problem solution.

On the other hand the time and the costs of this method can be extremely high and the number of experts depends on the complexity of the problem (e.g. Figure 2-1 number of experts against number of Knockout Risks[96]). The effectiveness of the method is clearly based on the quality of the questionnaire, the quality of the experts and the abilities of the Delphi-Moderator, thus the structure of the questionnaire and experience of the Moderator are extreme important to define during all the process of the risk evaluation.

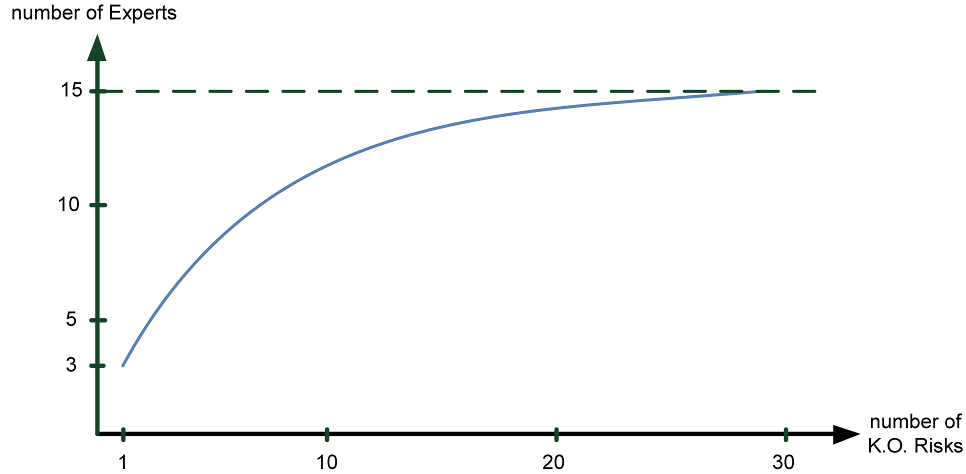

Figure 3-15: Number of the require experts according to (Schnorrenberg, 1997).

Normally the advice and deliberations of the experts are extended and require time and monetary resources, that's why projects with low budgets and not much time available shouldn't use this method.

[96] Knockout risks are the risk that can shut down the project in the case they occur.

A particularity of this method is that it can be treated as qualitative or as quantitative method, by the meaning that the experts can make use of both data to deliver their estimations. Another characteristic is that the method can be developed in anonymous form or by the development of different teams based in disciplinary or multidisciplinary experts.

3.8.2 Volatility Method

The Volatility method is a simple financial method for risk assessment, it is based on the principles of the expected losses method, which consists in elaborating two matrices, one matrix composed with different parameters and their respective asset variations and the second matrix with the correspondent probability of occurrence for each parameter.

The multiplication of the parameters with their probabilities will deliver an estimation of the simple expected losses and consequently a risk valuation. The volatility method makes use of a volatility index function, through which the fluctuation around the effective assets variation is evaluated.

$$s = \boldsymbol{\sigma} = \sqrt{\frac{\mathbf{1}}{\boldsymbol{T} - \mathbf{1}} \sum_{t=1}^{r} (\boldsymbol{r_1} - \boldsymbol{r})^2}$$

The volatility function with:

s = Volatility
T = time period
r = Asset

This method is very simple and is used worldwide; it delivers a fast evaluation of risk and is very helpful for constantly evaluation and compare. However a problematic for this method is the fluctuation measurement, this method does not present a clear differentiation about the chances of losing or earning, it just delivers a dimensionless risk fluctuation value. In other words dangers and opportunities are not differentiated in a representative unit (e.g.: €).

Another problematic is the considerations of time, this method works only with predetermined periods of time and not with variable periods of time. One of the greatest problems of this method is that doesn't include any risk appreciation from the decision maker, this means that is based totally on the input data, and it doesn't allow any subjective influence, what in reality has shown to be meaningful in many risk analysis problems.

3.8.3 Sensibility Analysis Method

As mentioned previously (section 4.6) this is one of the most popular methods in the field, however it has a non-probabilistic basis and it shouldn't be considered a risk analysis method[97]. This method is used to determine how sensible the variables are to established responses and their correlations. This method is utilized to scrutinize the variables and isolate key variables to predefined situations and with this to deliver accurate influence or impact measurement, for a better trace of the changes and variations.

Nevertheless a reliable risk analysis never should be based only on sensibility analysis, because it never considers probabilistic valuations and delivers just a subjective appraisal of correlations, this method shall be used to control the responses, influences and impact to the variables as much are their relationship[98], it's also helpful in the controlling process and in risk response (controlling of the treatment measurements).

3.8.4 Key Indicators

Key Indicator is a group of methodologies that includes the following procedures: the Key Risk Indicator (KRI), the Key Performance Indicator (KPI) and the Key Control indicator, they represent a systematic approach to risk assessment and a decision making method towards risk.

- The Key Risk Indicator is used to define how much risk is present in different activities, it's a measure process used by management to indicate how exposed each activity is. The Victorian Managed Insurance Authority (VMIA) defines it as *"relate to a specific risk and demonstrate a change in the likelihood or impact of the risk event occurring"*[99] [sic].
- The Key Performance Indicator can be used for financial or non-financial risk measurements to describe the progress according to the determined goals, it is used to "*monitor changes in business performance in relation to specific business objectives (e.g. volumes of business, revenue etc.)"*[100].
- The Key Control Indicator is defined as: *"demonstrate a change in a specific control's effectiveness"* [sic], this procedure completes the process of the key indicators[101].

The key indicators principles are similar to the priority method mentioned by Smith, the key indicator method permits managers to deal with risk, making use of the most significant factors and consequently to provide an effective risk management. The evaluations are focused on current characteristics and unique project particularities.

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[97] According to the research (Alfen, 2010), this method is widely used in the German construction industry as Risk analysis method.
[98] (Wolke, 2007)
[99] (Victorian Managed Insurance Authority, 2008)
[100] Likewise
[101] Likewise

Essential for this method is to create a methodology and risk mentality for the managers as well as for the whole organisation around the project, headed for an efficient functionality and proper response to risks; therefore Key indicators must be always bound to the organisation's strategy. One drawback of this method is that the key indicators are developed in special particular projects, therefore a general model is almost impossible to achieve.

Another possible problem is that the methods for risk assessment are not defined, this means that the decision maker can decide which risk assessment method to apply, which increases the complexity, hence experience and skills are required for the development of the method, in addition when the methods are not adequate, might lead to the risk analysis delivering superfluous results.

3.8.5 Risk Potential Assessment

The Risk Potential Assessment (RPA) is according to the Office of Government Commerce in UK (OGC) a "*spreadsheet tool which provides a standard set of high-level criteria for assessing the degree of complexity of a programme/project and consequently the risk to successful delivery*"[102].

It's helpful for the very first stages of risk evaluation in a project; it delivers a project score defined in three stages:

- Total score of 30 or less indicates that the programme/project is relatively low risk.
- Total score in the range of 31- 40 indicates that the programme/project is medium risk
- Total Score of 41 or more indicates that the programme/project is high risk

This method distinguishes between "programme" and "project"; Programme refers to strategic vision and management and the way to achieve these visions, while projects have definite start and finish dates, a defined output as well as its development path. The benefits take place when the project is finished.

The risk potentials assessment method was develop for Office of Government Commerce in UK (OGC) "*to be widely applied to programmes and projects that procure services, property/construction programmes/projects (including workspace acquisition/disposal /renegotiation of terms of use/occupation where these have been formally organized as programmes/projects), IT-enabled business change programmes/projects and procurements utilising framework contracts*"[103].

This method delivers a quantitative risk assessment from qualitative risk data evaluation, however this assessment method is vague and does not effectuate an adequate

[102] (Moorhouse Consulting, 2008)
[103] (Office of Goverment Commerce, 2008)

(stochastic) risk evaluation, therefore it can be used in the early phases of a project to elaborate the earliest project deliberations.

This method is just a “Check list evaluation” and still does not deliver any stochastic result, mostly because it attempts to introduce risk analysis into the construction industry in the UK.

In any case for a better risk management the application of more accurate risk methods, with use of probabilistic or stochastic data in adequate structures is required. This method was developed as a requirement for British projects, and permits only early deliberations of risks.

RISK POTENTIAL ASSESSMENT	
When completed please forward to your Departmental Gateway Coordinator	click here for guidance on completing this assessment
Programme/Project Details	
Programme/project name or title	
Programme/project description	
Programme/project type	☐ IT enabled ☐ Property & Construction enabled ☐ Other Acquisition ☐ Other
For programmes only, list name of supporting projects	Click here to enter details
If a project, provide, where applicable, the name of the overarching programme	
Department, Agency or NDPB name	
Name of parent department	
Total (whole life) costs of the programme/project to be OGC Gateway Reviewed	
Proposed contract/service length (yrs)	
Proposed procurement arrangements (e.g. conventional/PFI/PPP/design & build/PRIME)	
Expected next OGC Gateway review	☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
OGC Gateway review requested for week commencing dd/mm/yyyy (8 weeks after the assessment meeting)	
Date of first issue of RPA dd/mm/yyyy	
Date of current update/version number	

Figure 3-16: Risk potential spread sheet/partial view (Office of Goverment Commerce, 2008).

3.8.6 Value at Risk (VaR)

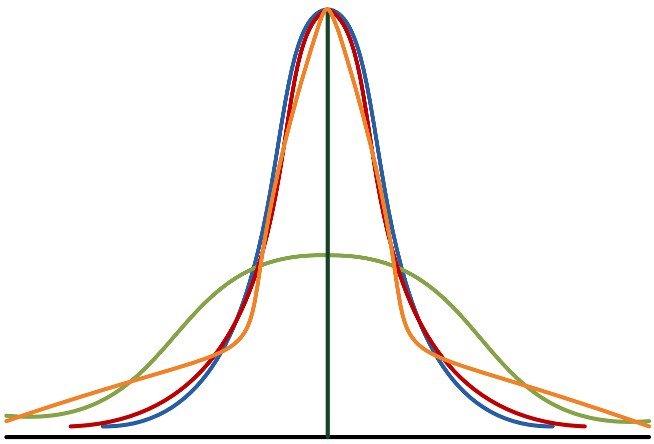
Value at risk is a method developed by JP Morgan Chase, “*Its origins can be traced back as far as 1922 to capital requirements the New York Stock Exchange imposed on member firms*”[104]. Value at risk encloses a group of applications based on the same principle, these methods work with the same methodology and the difference lies in the type of variable that is evaluated. The methods are the:

- Capital at Risk: it deals with the development of capital
- Credit Value at Risk: it deals with the development of credits
- Cash Flow at Risk: deals with the development of the economical behaviour
- Operational value at Risk: it deals with the development of a measurement of the operation risks

This method makes use of stochastic principles and is concerned with the maximal loss in a given time period with a specific confidence interval.

[104] (Holton, 2004)

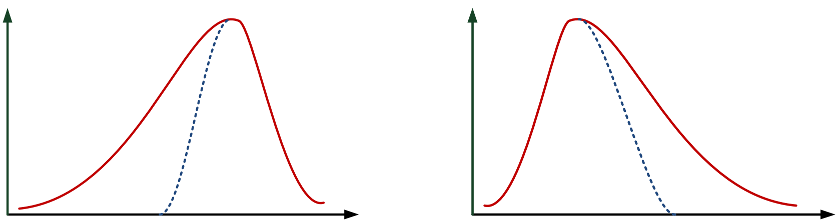
To accomplish the risk measurement this method utilizes the volatility, variance, covariance (in case of portfolio) and the standard deviation. Through the variance risk is valuated and with the use of the covariance the behaviour between different options can be described, which is all quite important for portfolio analysis. This is a financial method utilized mostly by banks.



Leptokurtosis

Blue curve	→	Observed data (short period)
Green curve	→	Observed data (long period)
Red curve	→	Combination of the blue and green curves *(very similar to the bell curve but not equal).*

Orange curve → Fat tails



Negative Skewness **Positive Skewness**

Figure 3-17: Examples of leptokurtosis and skewness.

One of the most important drawbacks of the Value at Risk method is the assumption that the data behaves in form of distribution function (e.g. like the Normal distribution), even when it's know that the leptokurtosis[105] (data behaves rarely as the bell curve, see Figure 3-17) is comprised and provokes fat tails and "skewness"[106]. The problem arises because the criteria are idealized for their empirical assessment (behaviour assumptions). Though this method has shown to be adequate and is widely used. Nevertheless this problematic can be mitigated by some new developments of

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[105] Leptokurtosis refers to the cases on which the data is similar to the bell distribution but is not the same, in extreme cases produce fat tails.*" The volatility of stocks usually finds that the variance of a stock is leptokurtic. This means that most of the time the stock moves around somewhat randomly. But when it deviates from this random pattern, when for example it suddenly starts running in one direction or the other, it runs a lot further and a lot faster than you would expect".* (30.09.2008), http://www.trade-ideas.com/Glossary/Leptokurtosis.html)

[106] Skewness is a measure of the degree of asymmetry in a distribution (Weisstein).

the method. However requires specialized knowledge of the market and it's used in the financial field.

3.8.7 Quantitative Risk Analysis (QRA)

The principles of quantitative risk analysis are very simple, three different evaluations are prepared; "the Optimistic Outcome", "the Pessimistic Outcome" and a simple "Middle or Normal Outcome", this last one shall represent the expected outcome. Through these three values a serial of computer simulations are executed in several scenarios to evaluate the behaviour of the system, and finally choose the most likely outcome.

This method can be used in cases in which there is not much information available (no Data Banks available) and enable one to utilize the experience of experts as e.g. the Delphi methodology, it also allows one to perform quantitative evaluations from qualitative data, the inputs (treated here as expected outcomes) employed for the simulation may have quantitative or qualitative nature, therefore it is possible to involve the experience and personal criteria from the experts. Still the method (depending on how the outcomes are evaluate) has an extremely qualitative nature, this can be considered as a shortcoming, thus it chooses one of the three values and consequently excludes two thirds of the gathered information.

This method shows how risk and uncertainty are intricately linked to each other, and the use of more sophisticated methods for the evaluations of the outcomes (this means the quantification of the inputs) permits one to reach better risk assessments (e.g. see section 5.4.2).

3.8.8 Program Evaluation and Review Technique (PERT)

This was developed in 1958 within the Polaris missile project[107]. The main goal of the method is to determine the most likely total activity duration concerning the risks comprehended in each activity. This method is a variation of the Critical Path method, developed two years before.

The functionality of this method is simple; the different activities are organized in a network with the different steps and procedures of the project. The network diagram consists of an array of arrows and nodes and is organized leading from the beginning to the end of the project. The most risky activities are identified in its analysis, a pessimistic, an optimistic and a most likely are considered. The time evaluation is set for each of the identified activities and through this the most probable duration is determined.

This method permits one to determine the most possible duration of each activity, thus the expected duration of the project viewed from the risk point of view analysing

[107] (Spolsky, 1972)

each risky activity. It permits the combination of risk assessment with activities with high costs, high complexity or with high demand on resources or complicated logistics. Through the corresponding risk analysis the duration can be determined in a more accurate form.

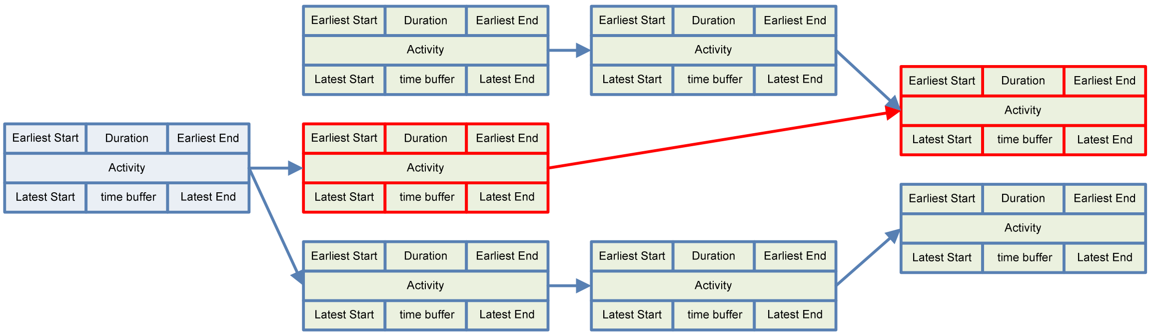

Figure 3-18: Example of PERT with critical path.

This method provides the managers with a graphical tool that allows them to display the different activities and their most possible durations evaluated from their very own risks. A variation consists of evaluating just the activities comprehended in the critical path. A weakness for this method is the determination of the inputs; the determination of the pessimistic, optimistic and most likely data may demand a high investment of resources and time, therefore the costs and efficiency can be too high for a small project.

3.8.9 Monte Carlo Simulation (MCS)

This is maybe together with its new development the “Latin Hyper-Cube Sampling” (see section 3.8.10) the risk assessment method most widely used around the world; it has shown an appropriate functionality and flexibility in its procedure. Monte Carlo was developed by Stanislaw Ulam in 1946[108], he used the statistical sampling created from W.S. Gossett; Ulam turned Gossett’s method into computer algorithms applications[109].

Monte Carlo “*is a technique employing random numbers in order to combine distributed variables*”[110]. For the method’s procedure it’s important to simulate the project and its most important parts, from which a randomization of the variable’s values will be delivered, headed to calculate the most likely outcome of the project.

The method is based on the following steps:

1. Elaboration of the model
2. Determination of the required data (Risk factors, possible impacts, expected outcomes and correlations between the criteria)
3. Identification of the required Distributions

[108] (Metropolis, 1949)
[109] (Riskglossary, 2008)
[110] (Maria-Sanchez, 2005)

4. Determination of the required runs (iterations)
5. Generation of data by random number generation (simulations)
6. Analysis of the results using histograms, cumulative curves, confidence intervals, sensitivity analysis, etc.

Figure 3-19 shows the procedure of the Monte Carlo Simulation, it delivers an overview about the interactivity of the method and how the distributions are applied in the core of the model (the generation of the data).

The criteria behaviour (assumptions) will be described by the different distributions: e.g. Triangular, Pareto, Beta, Normal and Rectangular distribution. As result of the random generation numbers a histogram and cumulative curve for each variable is delivered.

With Monte Carlo it is possible to perform variations on the distribution for each variable, however the use of random numbers implies that the variables are independent from each other, this is normally not true (e.g. by delays in calendar linked activities), thus correlations must be defined for the model.

To support the quality of the evaluations a foundational collection of data is needed, which normally is based on historical observations and know-how. Nonetheless for some projects there is no data available, in this case the know-how and experience are extremely important.

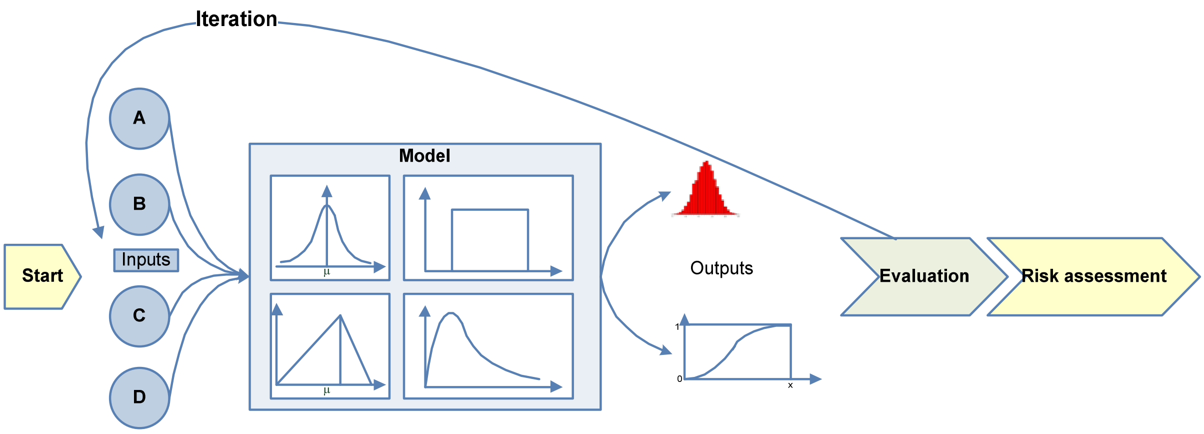

Figure 3-19: Monte carlo simulation (MCS).

Finally the choice of the appropriate distribution represents an important step towards the success of the method; therefore it's critical to pay attention to the distribution selection process and also to accept that in practice, there are normally not ideal distributions, hence the chosen distribution must be the most likely variable's behaviour, and always remember to bear in mind correlation between factors. Problems of Leptokurtosis and Fat tails are also drawbacks for this method.

3.8.10 Latin Hyper-Cube Sampling and Descriptive sampling

The Latin Hyper-Cube Sampling is a variation of the Monte Carlo Simulation, it was first described by McKay in 1979[111] and developed by Ronald L. Iman in 1981[112]; this method is recommended when a wide number of parameters are to be valued, also for problems with a high amount of parameters and where a huge number of conceivable combinations are possible.

> "*Latin Hypercube sampling is generally more precise for producing random samples than conventional Monte Carlo sampling, because the full range of the distribution is sampled more evenly and consistently*"[113].

The difference between Monte Carlo Simulation and Latin Hyper-Cube Sampling lies in the convergence of randomly generated numbers, which makes it possible to reduce the numbers of runs, the Monte Carlo Simulation does not consider the previously generated numbers while the Latin Hypercube divides the space in subspaces and ensures that random generated numbers are representative of the real variability of the random sampling (see Figure 3-20).

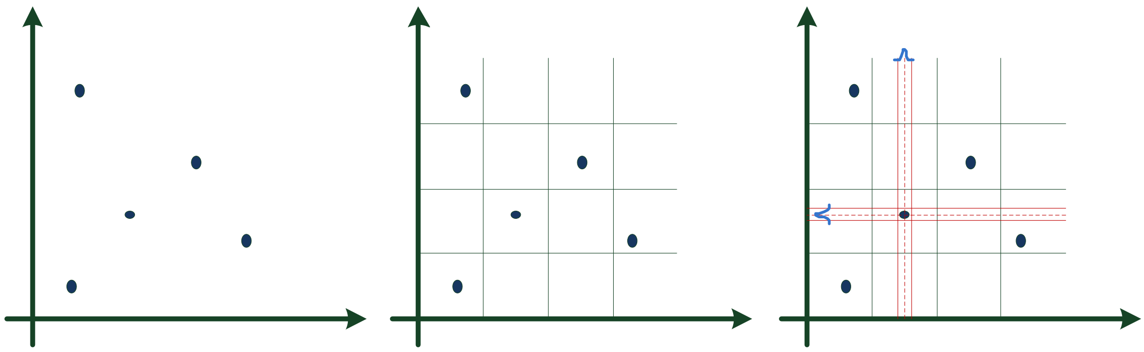

Figure 3-20: Latin hypercube functionality.

In conclusion Latin Hyper-Cube Sampling permits one to perform the same procedure of the Monte Carlo Simulation with fewer runs and with the same advantages.

In 1997 Saliby proposed an improvement for the Latin Hyper-Cube Sampling (LHS) in his work "*Descriptive sampling: an improvement over Latin hypercube sampling*"[114], he proposed a variation including Descriptive Sampling (DS), in this form it also applies a systematic selection of sample values in order to increase the convergence rate. The difference lies in the way these values are selected. The author concluded that: "*DS represents an improvement over LHS, being more efficient both in statistical terms as well as in computing terms, since it avoids the unnecessary step of randomly sample the set values*"[115] [sic]. However the method makes use of the

[111] (Saliby, 1997)
[112] (Swiler, 2004)
[113] (Maria-Sanchez, 2005)
[114] (Saliby, 1997)
[115] (Saliby, 1997)

same assumptions of MCS and presents the same advantages and drawbacks as LHS.

3.8.11 Markov Chain Monte Carlo (MCMC)

The Markov Chain Monte Carlo is a combination of two different methods, the Markov Chains created by Andrei Andrejewitsch Markow (1856 – 1922) and the Monte Carlo Simulation (see 3.8.9). The Markov Chains is a method based on the precise description of a determinate system and the description of its current state and the posterior changes.

The system (the initial state or the present state) represents also the interaction between all the different factors to each other, hence it is important to describe the system's behavior, which describes how the system interacts. When these steps are established, the initial state is set (the array of rules and criteria which the present represents), subsequently the following step is to represent the future[116].

The future depends only on the present, in other words every change or variation depends on the present circumstances (the array of rules and criteria). The variations on the systems depend of external influences and their interactions are defined by the system itself[117].

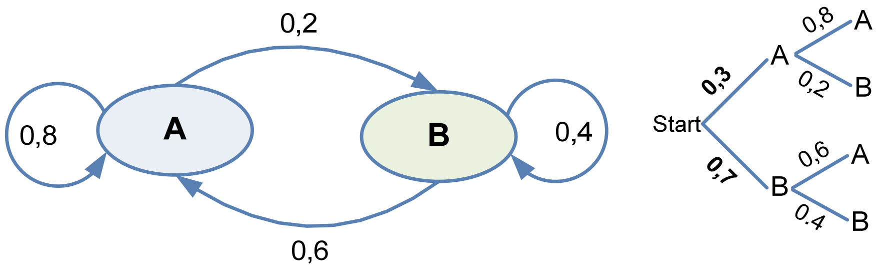

Figure 3-21: Markov chain

The Figure 3-21 presents an example of a simple Markov Chain. For example, let's say that we have a product "A" and of this product we have a Market share around the 30% of the total Market. We want to improve our sales and we compare it against all other products "B". If we do a better publicity of our product we can expect with a probability of 80% that our customers will stay with our product and that other customers with a probability of 60% will change to our product.

In figure, we percieve the two options; our Product "A" and other competitors are "B", we can easily see the 80% probabilities that our customers stay with our product "A" and only 20% could change to any other product "B". On the other hand there are probabilities of 60% that we attrac more customers for our product "A" and 40% probabilities that those customers stay with the other products "B". The same can we

[116] (Hermanns, 2002)
[117] Likewise

appreciate in a hierarchical representation, in which the market share is included (30% for A and 70% for B).

If we want to determinate the probabilities we can represent them in a mathematical form, it looks as follows:

Initial state Distribution Matrix: $S_0 = [0{,}3\ ,0{,}7]$, where A = 0,3 Market share

Transition Probability Matrix: $P = \begin{bmatrix} 0{,}8 & 0{,}2 \\ 0{,}6 & 0{,}4 \end{bmatrix}$,

Where $\begin{matrix} & A & B \\ A & 0{,}8 & 0{,}2 \\ B & 0{,}6 & 0{,}4 \end{matrix}$ the first column represent the present state and the top row the next state

If we want to determine how our probabilities are after a period of time, we just have to multiply $S_1 = S_0\ x\ P$, where is our new state.

$$S_1 = [0{,}3\ ,0{,}7]\ x\ \begin{bmatrix} 0{,}8 & 0{,}2 \\ 0{,}6 & 0{,}4 \end{bmatrix}$$

$S_1 = [0{,}66\ ,0{,}34]$, where A = 0,66 Market share

If we take the action A, we can expect that our market share will increase.

All the advantages of the Markov's chains were combined with the advantages of the Monte Carlo Simulation. In 1953 a new algorithm was presented the "Metropolis algorithm"[118], this algorithm means also the origin of the MCMC method and its associated with the computer "MANIAC"[119], this method earned more relevance at 90's through the utilisation of PC's.

> *"This algorithm is an instance of a large class of sampling algorithms, known as Markov chain Monte Carlo (MCMC). These algorithms have played a significant role in statistics, econometrics, physics and computing science over the last two decades"[120].*

The application of Monte Carlo in to the Markov Chains enables to improve numerical algorithms by means of statistical information or background, in other word MCS makes it possible to simulate different situations from the given information. One of the typical applications of this method is for the numerically calculating multi-dimensional integrals.

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118 (Andrieu, 2010)

119 (Christian, 2008), MANIAC I (Mathematical Analyzer Numerical Integrator And Computer Model I), the first Computer. Project under the Direction of Nicholas Metropolis for los Alamos National Laboratory

120 (Andrieu, 2010)

The field of MCMC is enormous and has been growing in importance in the last years, through the utilization of PC's and the development of new and different algorithms, its applications expands constantly. However this method requires suitable mathematical skills and the appropriate representation of the system as well as their interactions, in other words experience and knowledge of the system to model.

3.8.12 Neuronal-Risk Assessment System (NRAS)

The Neuronal-Risk assessment system was developed by Pedro Maria-Sanchez in 2005[121], this method presents an application of the Artificial Neuronal Networks method (ANNs) developed around the late 1950's into an application within the risk management for the construction industry.

The principal idea of the ANNs (on which the NRAS is based) is to represent from a biological neuronal network in to a mathematical form; therefore ANNs:

> *"are collections of mathematical models that emulate some of the observed properties of biological nervous systems and draw on the analogies of adaptive biological learning"*[122].

The ANNs allow one to recognize patterns and works with high levels of countenance to imprecise data, the most promising advantage is the fact that this method presents the ability of learning (artificial intelligence) and its resilience against distortions[123]. An example of this method is the "Neuron", the neuron and/or the group of them, are delimitated by three different connection structures:

- Micro structure: Functionality of a single neuron
- Meso structure: Physical organization of the neurons
- Macro structure: Union of different meso structures

The microstructure indicates the ways in which the neuron works, accordingly an array of different neurons are grouped on a meso structure, finally the macro structure comprehend many arrays of neurons or (meso structures), these array forms are also called architecture and are aimed to solve a determinate problem (see Figure 3-22).

The learning process is determined by a learning rate, dictated as a result of a transfer function, which are the: Loig-Sigmond transfer function, Tan-Sigmond function and the linear transfer function also known like Purelin. The learning forms are; supervised, unsupervised and the reinforcement learning.

In an ANNs a group of neuronal layers are elaborated for the solution of the main or particular task, normally a general pattern is observed, three different layers are distinguishable, the Input Layer, the Hidden layer and the Output Layer (see Figure

[121] (Maria-Sanchez, 2005)
[122] Likewise
[123] Likewise

3-23). The connectivity and functionality between the neurons is determined by the learning form, as well as the neuronal data flow, like the back propagation and the forward propagation, these two factors (connectivity and functionality) are denominated as the Net Architecture.

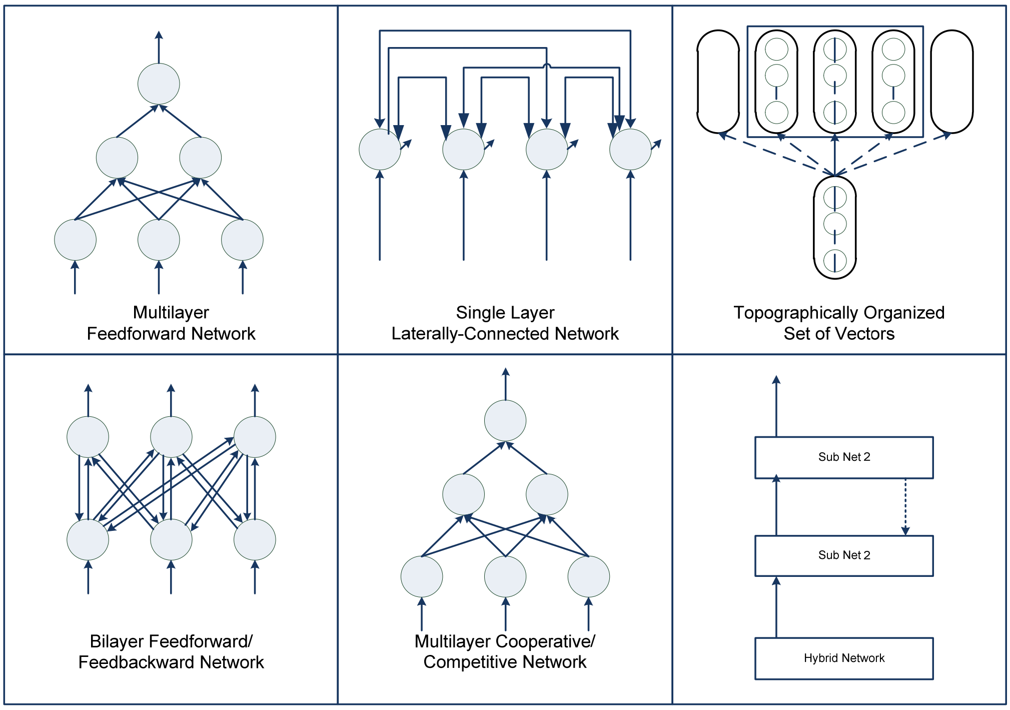

Figure 3-22: Six basic topologies of ANN meso structures; Himanen at al (Maria-Sanchez, 2005)

In Figure 3-23 we can appreciate a general representation of a neural network; according to the problem to solve, the elaboration of the architecture will determine the efficiency of the solution proposed, therefore it has to be elaborated tried and validated. The Neuronal-Risk Assessment System (NRAS) represents a solution to risk management in construction problems.

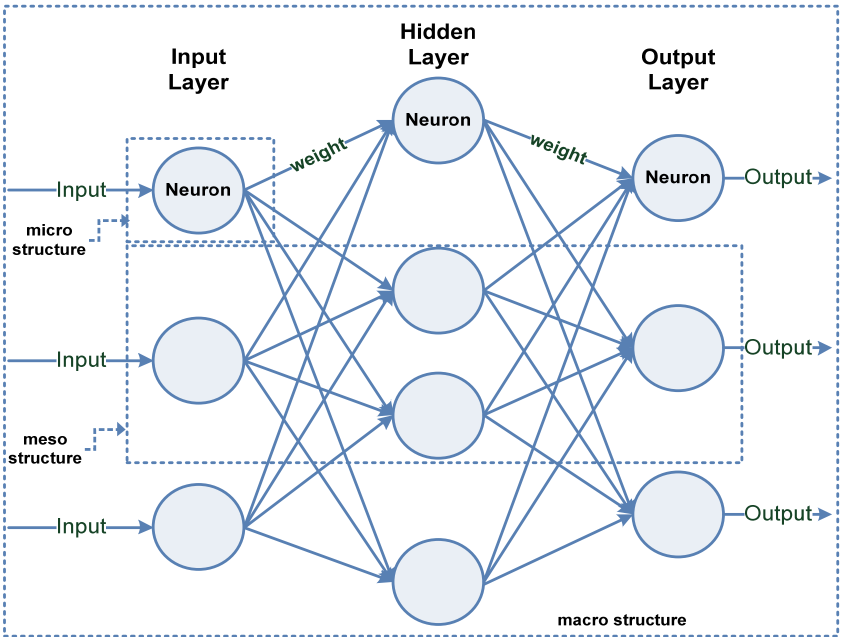

Figure 3-23: General neural network architecture (Maria-Sanchez, 2005).

The author defines it as:

> *"a human-intuition approach which integrates the tools of Artificial Neural Network and Risk Management for the use and benefits of the contractor"[124].*

And its main task is:

> "*to provide assistance to construction contractors in predicting the extra project cost (risk). This will assist the contractor in keeping capital expenditure and delivery time to predetermined values and takes necessary managerial action to avoid a shortage of cash, bankruptcy, and gives early warning of cost overruns"*[125].

The NRAS developed by Maria-Sanchez, permits one to valuate risks in monetary terms for construction projects and is supported by the functionality of the ANNs with the back propagation principia; however the method requires a high quantity of data from several previously developed projects prepared to calculate the project's total risk.

To accomplish the main goal (total risk value in monetary terms) the creation of several neuronal models has to be carried out and their functionality must also be evaluated against the actual project's performance. Therefore the training and testing phases are the most crucial steps for this method, to assure an adequate functionality and forecast.

The main achievement of the NRAS is the ability to recognize patterns and reproduce them into the project forecast itself. Even when the monetary value (given in % of the project's offer amount) might not be correct, the method permits one to follow the risk tendency of the project and predict possible losses and wins. In other words this method differentiates between opportunities and hazards.

Another strong advantage of the method is the resilience against distortions that permits with minimal information to develop accurate results, all this when a trained neuronal net is utilized in a new project; for the reason that the learning ability would add the trained ANNs to interact with the new Inputs. The method's functionality is described by the author in Figure 3-24.

A shortcoming for the ANNs is the requirement of high amounts of data (to train the net, which can be complicated in practice) and the results might vary around a small margin when the results are known, however this method does not require mathematical relationships between the criteria and it can also utilize numbers or text, this confers more flexibility to the method. Nowadays there is commercial software that

[124] (Maria-Sanchez, 2005)
[125] Likewise

can be utilized for the application of ANNs that enforce the possibilities to utilize ANNs and the development of the NRAS of Maria-Sanchez.

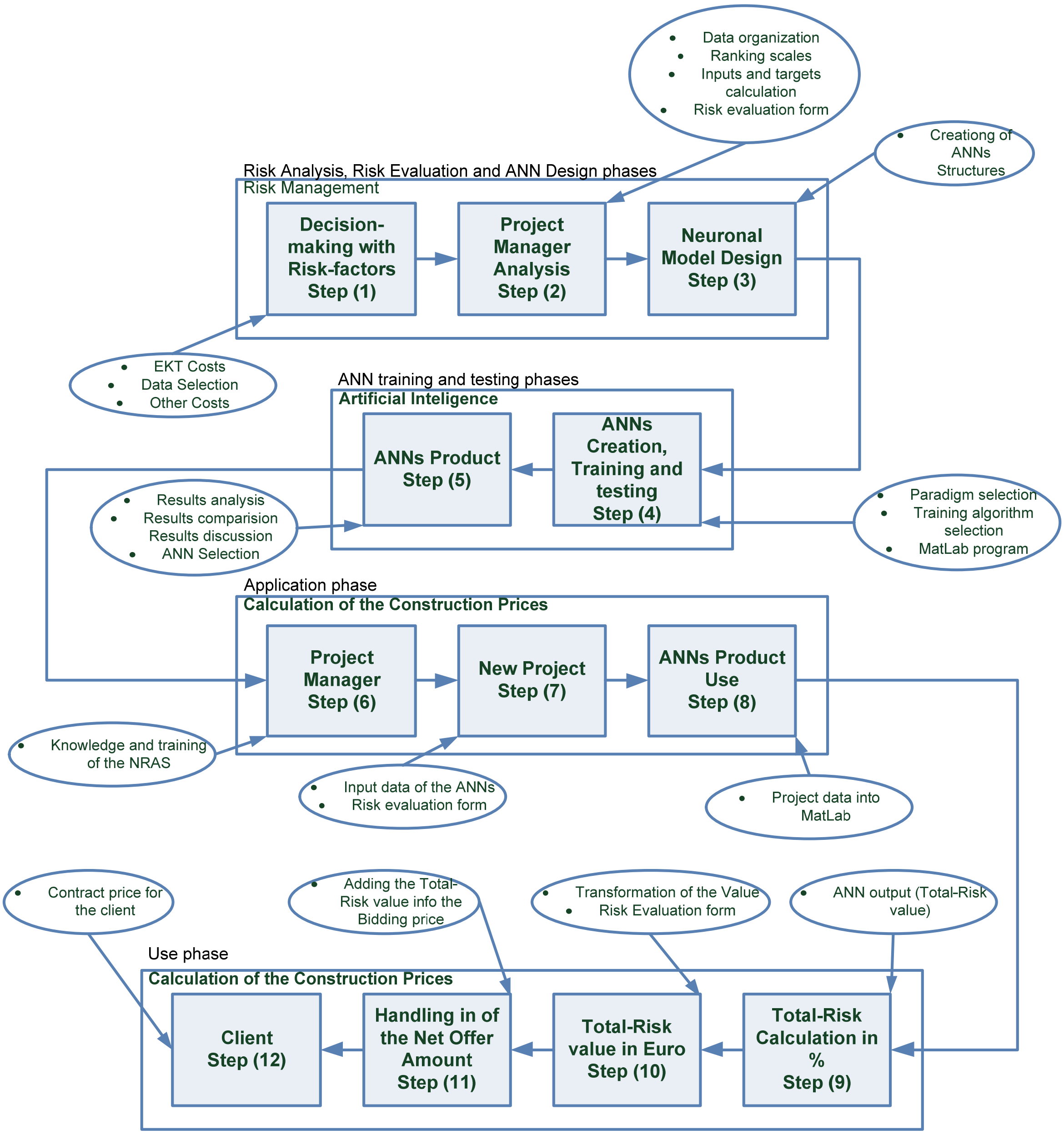

Figure 3-24: Basic activities of the neuronal-risk-assessment system (Maria-Sanchez, 2005).

As an important advantage is the fact that it doesn't require any mathematical relationships for the criteria, the method learns and finds the relationship between the results and the criteria itself. Thus it indirectly enables one to integrate considerations about uncertainty.

When data is not fixed by mathematical formulas and just real data from the praxis as result is loaded to the model, the ANNs will implicitly include these considerations and might be closer to reality. However because of the uniqueness of every construction project it is important to implement more runs of ANNs to deliver a better judgment of the results, even so NRAS possess high potentiality and would be interesting to add (as the author proposed) the utilization of fuzzy logic and the use of random numbers generator for the inputs.

3.8.13 Support Vector Machines (SVM) & Risk Analysis

The support vector machines is a technique based in the research *"Theory of Pattern Recognition"* carried out by Vapnik, V. and Chervonenkis, A. in 1974 and in the work of Vapnik, V. in 1979 *"Estimation of Dependences Based on Empirical Data"*[126], from these two works the basics of support vector machines was created.

The Support Vector Machine is defined as:

> *"a new type of learning machine for pattern recognition and regression problems which constructs its solution in terms of a subset of the training data, the Support Vectors"*[127].

Härdle defined the Support Vector Machines as:

> *"a relatively new technique and builds on the principles of statistical learning theory. It is easier to handle compared to neural networks…. SVMs are a non-parametric technique that learns the separating function from the data, they are based on a sound theoretical concept, do not require a particular distribution of the data, and deliver an optimal solution for the expected loss from misclassication"*[128].

This methodology is listed in the artificial intelligence methods like the previously NRAS and it presents also the characteristic of learning through the utilization of training sets that allow the method to perform better recognition procedures.

The basic principle is to separate the information content in the space through n-Hyper planes built by the support vector machine, each hype plane is defined by the normal vector "*w*" and its adjustment "*b*". Through the creation of many different hyper planes the data can be more simply recognized and differentiated.

The hyper plane is given by:

$$H = \{x \mid < w, x > \ + b = 0\}$$

Figure 3-25 shows how in a training phase "w" and "b" will be selected in order that the hyper plane adequately separates the data, the support vectors are elaborated for the delimitation of the margins and in this form to assist the support vector machine, they consist in finding maximal distance from the hyper plane to the nearest data point.

After the training phase the main task is to perform a forecast which will say on which side of the hyper plane the new data will be comprehended, this is also known like the linear classifier.

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[126] (Vapnik, 1982)
[127] (Schölkopf)
[128] (Härdle, 2007)

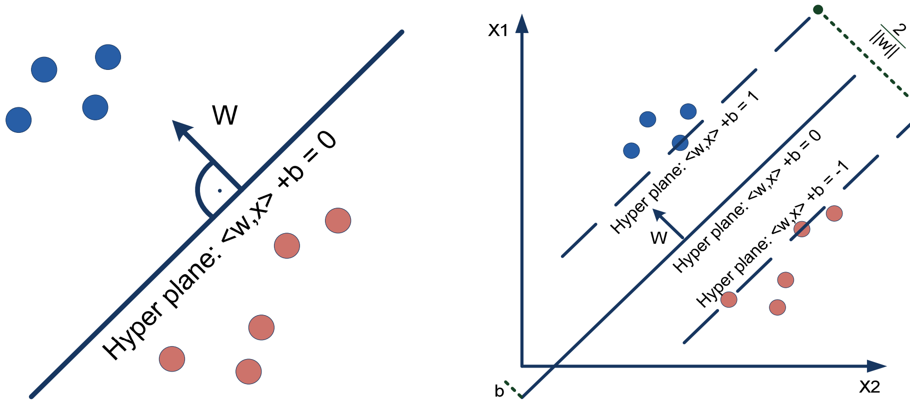

Figure 3-25: Principia of support vector machines (Markowetz, 2003).

> *"The constrained optimization calculus of SVM gives a unique optimal separating hyper plane and adjusts it in such a way that the elements of distinct classes possess the largest distance to the hyper plane"*[129].

The main concept is that, the more hyper planes there are the better the classification is, for example the data in direction of the normal vector will be positive and the data placed on the other side will be negative, for correction the error "c" will be used (see Figure 3-26). Thus do more hyper planes and fewer errors directly lead to a better recognition process.

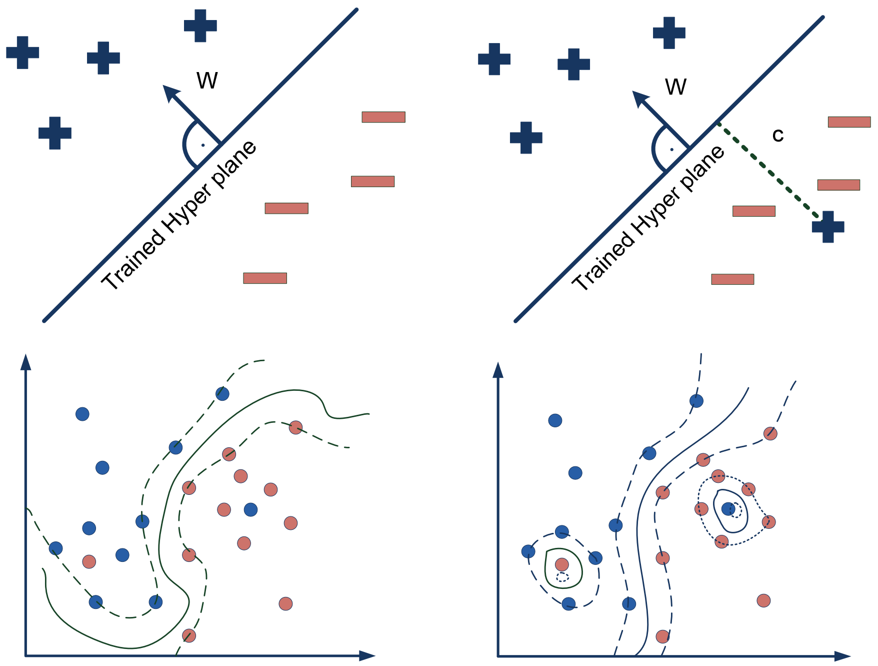

Figure 3-26: Trained hyper plane

As already seen the support vector machines are a new instrument in the risk assessment field, nevertheless it has shown very adequate performance and promising results in its use.

[129] (Härdle, 2007)

In 2006 Wang published *"Credit Risk Evaluation with Least Square Support Vector Machine"*[130] and Härdle presented *"The Default Risk of Firms Examined with Smooth Support Vector Machines"*[131], in these two works they utilized the properties and advantages of the support vector machines to analyze risk assessment problems for financial risks. They proved that risk assessment through support vector machines represents a new tool with high potential that has to be developed and research for further applications. They delivered results that outperformed their expectations.

The support vector machines method and the NRAS show high potentiality and require more research. Because both are part of the latest developments in artificial intelligence methods on risk assessment fields, there is still not much information and application tools (software applications specially for SVM) that allows the inexperienced directly to use them, therefore good knowledge of the methods is highly recommended and also a high quantity of data is required for better results.

3.9 Risk management in the construction industry/projects

3.9.1 Risk management systems

Risk management has become an important instrument for the current construction industry; however its use is more extensive in scientific research, than its use in the real world. In the practice one finds mostly qualitative risk management moreover this is still not developed in a satisfactory form and is sometime vague. Many contractors don't quantify risks because for them the methods are not even known[132]. Thus many contractors don't know about risk management and the large advantages to be had by its implementation.

A bigger problem is the fact that risk is confused with "Dangers" (see section 1), risks are associated with danger or are considered in very different forms depending on the company even the different departments. This misunderstanding leads to the fact that many contractors refuse to approach this topic, by the reason that to accept risk means to accept mistakes, this belief is far away from risk management.

Furthermore this problematic was investigated by a German real estate firm and discovered that at least six different meanings of the word "risk" exist in the German market[133], from goal deviation until uncertainty. Thus there is a pressing need to speak the same language at least with the participants in a project.

A study about the current implementations of risk analysis methods by German contractors and project developers showed that most of them don't utilize adequate risk

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130 (Lai, 2006)
131 (Härdle, 2007)
132 (Meinen, 2005)
133 (Managers AXA Investment, 2010), Risk is from goal deviation, over hazard until uncertainty understood.

analysis methods; they still do not apply the improvements from the current state of arts to the state of the praxis (see Figure 3-27).

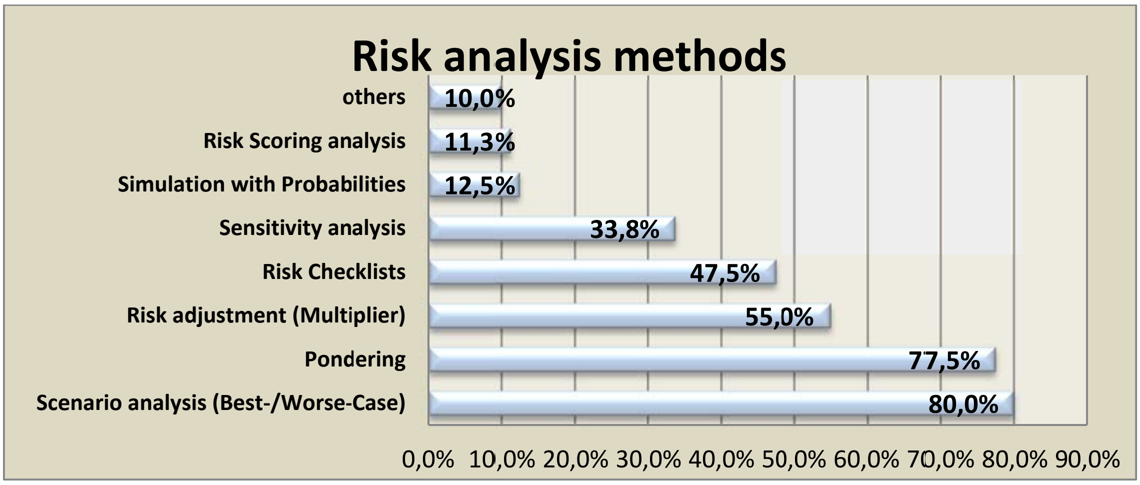

Figure 3-27: Risk analysis-methods on the real state – project development (Wiedenmann, 2005)

The study revealed that just the 12.5 % of the interviewed contractors use methods based on probability considerations, 77.5 % on pondering and 80 % employ a limited scenario analysis[134], Sensitivity analysis with 33.8 %[135].

Other recent research has shown the same trend[136]; risk analysis is performed in very qualitative form and is normally misunderstood. While Monte Carlo Simulation stochastic risk valuations delivers, most of the German contractors employ simple costs analysis and sensitivity analysis, even when they are not considered like a risk analysis method (see Figure 3-28).

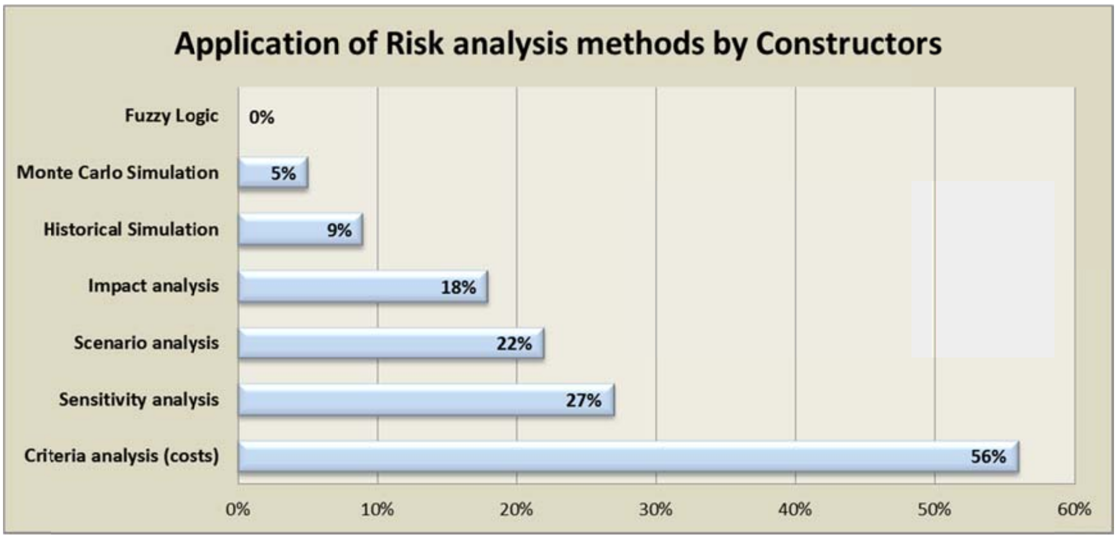

Figure 3-28: Application of risk analysis methods by constructors (Alfen, 2010)

[134] (Wiedenmann, 2005), The scenario analysis considered here is mostly the appraisal of the Worst Case Scenario and the utilization of probabilities is not considered.

[135] Even when Sensitivity analysis is not a risk analysis method see section 3.7

[136] (Alfen, 2010)

This problematic was also identified by the development of the present research, through contact and interviews with different contractors in Germany and USA, thus it's possible to affirm that new developments of risk analysis methods like the Neuronal-Risk assessment system (NRAS) and the Support Vector Machines (SVM) are far ahead of the current state of the Praxis, even common methods like the Monte Carlo Simulation are still not utilized as expected.

Most of the contractors conduct their analysis based on simple check lists, portfolio analysis, pondering and questionnaires in which normally probabilities are not considered. The use of databanks and scenario analysis based on probabilities are still not developed, hence it is imperative to develop of risk analysis methods based on probabilities and their quantified effects.

3.9.2 Risks and Opportunities in Risk Assessment Methods

In the course of the present work many of the advantages of using risk management have been shown, for example, strategy development, goal definitions, task's delimitation for the different management levels, diminution of uncertainties, participant's involvement in the project and in the firm's tasks, etc., hence risk management is nowadays an important entity for any company to assure better analysis and pursuit of goals.

Risk management has as its main goal "to assure the company's success and profit increase through a better control, comprehension and response to goal deviations" (see section 3.5), however the tasks of risk management have to be delineated to prevent misunderstanding, recognize responsibilities and improve efficacy to the RMP. However as in every discipline there are different risks and opportunities associated with the implementation of any procedure. It's important at this part of the present work to mention where the sources for dangers are and also the factors that originate them.

It is crucial to emphasize the fact that risk management has the function of providing information to the top managers in order to facilitate their analysis procedure; risk managers should never decide by themselves, if risks are to be taken or not. Top and senior managers are in charge of making such decisions and to clarify the important criteria. One of the most important criterions is "risk appetite" (see section 3.6).

Risk appetite determination is a complicated and vital task that has to be elaborated under the consideration of financial and market parameters combined with the company's strategy, this task should be developed by the enterprise's risk management, it is also important to remark that risk appetite has also a variable nature.

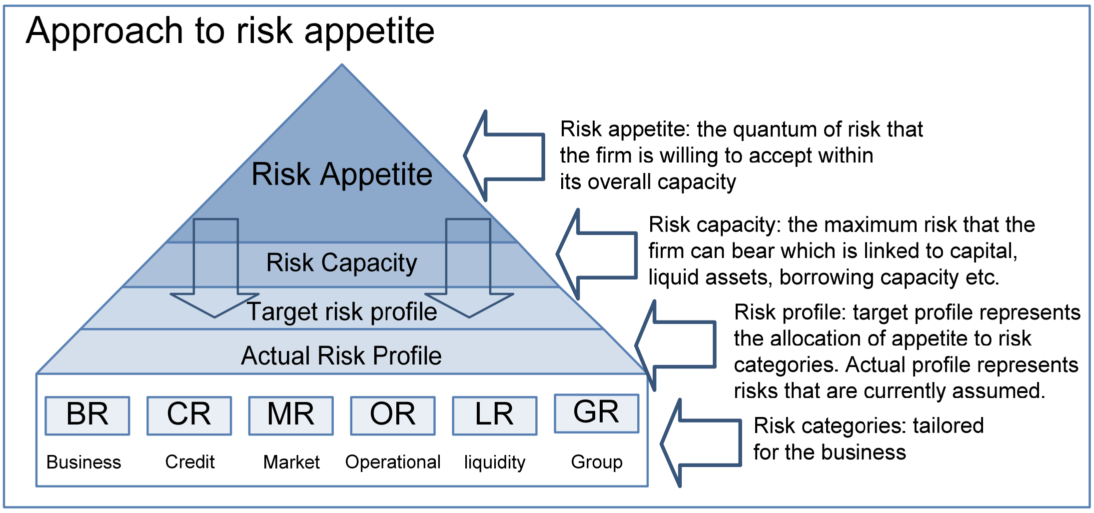

Figure 3-29: Approach to risk appetite (Barfield, 2008).

Barfield defines risk appetite as follows:

> "*risk appetite translates risk metrics and methods into business decisions, reporting and day-to-day business discussions. It sets the boundaries which form a dynamic link between strategy, target setting and risk management*"[137].

Furthermore the concept of risk is dynamic and the controlling and monitoring process have to deal with a constant factors evaluation which increases the complexity of risk management and risk appetite (see Figure 3-29).

Many authors concur with the fact that one of the main problems is the interpretation of risk data together with the company's politics and philosophies towards risks. There are more possibilities of success for a company with careful appreciation of risks even when it doesn't possess highly developed risk models, than for a company with highly developed risk models and almost no risk politics and philosophies. Thus it is imperative for any company to develop a risk culture for a better accomplishment of the goals based on risks.

Stulz listed some of the most important risks failures in his work *"Risk Management Failures: What Are They and When Do They Happen?"*[138] he presents a list of the most typical failure sources of risk management:

1) Mismeasurement of known risks:

This kind of failure is attributed to errors by the development of the quantification of risks as for example by assessing false probability distributions in MCS, which can lead to false expectations of earnings or losses. Also important is the correlation of different assets or projects to each other. This measurement shall deliver the compa-

[137] (Barfield, 2008)
[138] (Stulz, 2008)

ny's performance and effects around all the enclosure risks taken by the enterprise (portfolio misinterpretations).

He classified mismeasurement in the following ways:

- Mismeasurement due to ignored risks:
  When a risk is known by some participant on the project but it has not been integrated into the model.
- Ignored known risks:
  When risks are underestimated and not valuated, but they turn into strong and relevant factors to be consider.

2) Failure to take risks into account:

It refers to the risk identification process, when during the collection of risks, many of them are not quantified and forgotten, therefore not followed, and the monitoring process of new possible risks is not performed adequately. Consequently the company has a strong tendency to expand to unmonitored risks (uncertainties).

Stulz affirms:

> *"Accounting for all the risks in risk measurement is a difficult and costly task. However, not performing that task for an organization means that the firm's top executives are managing the company with blinders on – they see only part of the big picture they have to understand to manage effectively. There are well-known examples of incomplete risk aggregation leading to large losses from risks that were not accounted for"*[139].

Therefore the risk identification process and the constant scrutiny of uncertainties are crucial for successful risk management.

3) Failure in communicating risks to top management:

A large number of authors mention this failure as very important and extremely complicated task within risk management; one must bear in mind that risk management is performed for the top managers as well as for many other different entities inside the enterprise and for this reason, the results should be delivered in comprehensible form and in the required time in clear and definite reports.

It is vital to present the data in the form that the recipient will understand. The information must be delivered without distortions at the right time.

4) Failure in monitoring risks:

As indicated before the monitoring process is a very significant endeavor for the risk management process, the first deliberations of risk normally show how the risks are

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[139] (Stulz, 2008)

and in light of this, the top managers decide how to manage the risk and which actions are to be taken, thus the monitoring procedure has to confirm that the handled risks conduct inside of the performance. Therefore the monitoring system must be defined and linked to the RMP.

One of the most important failure reasons is the risk's variability, the velocity on which the risks vary can provoke retarded reactions to risks variations and because of it a failure in the monitoring procedure and in the worst case in the complete risk management procedure. The monitoring procedure should always be as dynamic as the monitored risks. Therefore *"risks management might be structured to know all at all times"*[140].

5) Failure in managing risks:

Managing failures are intimately associated with the risk metrics as well as the comprehension of the nature of the risks; their misunderstandings can lead to erratic interpretations and as a result false treatment and/or actions. That's why the use of the appropriate risk metrics and clear comprehension of the risks is the first step for their solution.

False information or deficiencies in the communication, risk identification and monitoring are a key factor for this failure.

6) Failure to use appropriate risk metrics:

The use of risks assessment methods which are too marginal might lead to the result that risks that are important could be underestimated, unmeasured or lead to the result. Another problem is the nature of the methods, quantitative and/or qualitative methods are appropriate for different kind of problems (see Table 3-4), for operational risk are mostly quantitative methods appropriated, while for strategical qualitative methods have shown more efficiency.

Crisis is other important criterion that can hardly be integrated in any risk model. The consideration of crisis comes in to being in very exceptional cases but it can be hardly quantified (its moment of incidence and duration). Therefore crisis as a factor is normally not contemplated and it doesn't allow a simple consideration in any model, this problematic is coupled with the fact that these periods of times are composed even for many years, the last crisis in 2008 is a clear example of this consideration.

> *"Crises involve complicated interactions across risks and across institutions. Statistical risk models typically take returns to be exogenous to the firm and ignore risk concentrations across institutions"*[141].

[140] (Stulz, 2008)
[141] (Stulz, 2008)

Statistical methods alone do not deliver the required accuracy and mostly the scenario models perform better results under the consideration of many factors from several fields, guided by risk management considerations. Therefore crisis can be consider as a partial uncertainty and treated as such.

The abovementioned risk failures are some of the most representative risk management error sources that could occur during the development of the risk management process. They can appear very simple in some cases, but they are in general a framework for risk management projects, they have to be considered, understood and completed by any risk management department within any organization, for a better function and model development.

3.10 Selection of a risk assessment method

Throughout the classification and analysis of the different risk assessment methods it was observed that for the construction projects the use of more than one risk assessment method is required. Risk identification, risk evaluation and risk controlling have special needs, therefore different methods offer adequate support and represent a better performance due their functionality and readiness.

This applicability is also delimitated by the experience of the risk assessment developer, especially according to their own risk philosophy (see section 3.6). Thus the selection of the required risk assessment method or methods will be delivered in the following section 4 based on real requirements from the praxis.

3.11 Conclusions

This chapter attempted to present risks and risk management and their development until our days. Risk management has become an important tool to any project for any enterprise, the new regulatory frameworks like Basel II, Basel III and KonTraG in Germany demand the development of risk management systems in order to elaborate an early warning system for the recognition of potential risks that could affect the enterprise performance, however such instruments (risk management systems) are never described and they are completely open to their elaboration without the specification of their requirements and structures. And even worse risk is sometimes understood differently between partners and risk bearers.

For that reason many companies don’t realize its importance and consequently they dispose of inadequate risks management systems mainly based on subjective data and with several contradictions to the company’s strategies and philosophies.

More seriously, in some cases management is not present to define those strategies and philosophies and in some cases is even worst, there is no presence of management to define those strategies and philosophies. The results are deficient and/or primitive risk management systems developed to fulfil the legal requirements and not to increase the company’s value, which in many situations could be counterproductive.

Many of the deficient risk management systems are mostly based on check lists and subjective evaluations under not very structured and not well developed systematics. There are also the situations in which the risk managers do not have formal risk training, which can result in significant losses.

Many firms are focused solely on earnings and they do not understand that risk management does not have the task of preventing losses; it just presents the evaluations of risk to permit the managers to decide if those risks will increase the companies' profits. The main task lies in the control of every goal deviation. Even when risks can become losses, they have to be controlled (see cases of the German companies Walter Bau in 2005 and Phillip Holzmann in 2002)[142].

It must always be remembered that the correlation between projects taken by a company has to be added into the evaluation of some risks and to be observed, this consideration must be reflected in risk appetite. On the other hand the latent possibility of crisis together with its high complexity leads to the consideration of uncertainties obtaining a relevant role. Uncertainties should be monitored during the duration of the project and during the day by day performance of the company.

The methods listed in this chapter present an adequate performance and are widely used around the world, many risk managers make use of a combination of methods for the analysis of risks, for the reason that some methods are better for different types of problems and finally it is important to incorporate the results into a general valuation. This have become one of the main tasks of the present work for the reason that many of this risk evaluation methods are scored separate from each other, which leads to a loss of perspective.

Nevertheless in the last years artificial intelligence (in this case the neuronal networks and the support vector machines) applied to risk management considerations have shown that this is a field that requires more research and the result of this first analysis is very promising.

One of the reasons is that the probabilistic methods which are normally used nowadays, perform their evaluations under strong data assumptions known as the distribution functions. The real data normally doesn't have an ideal behaviour and often leads to fat tails and leptokurtosis. By methods using historical data high continuousness is required, because the data does not include today's reality, therefore deviations take place.

The methodologies elaborated with artificial intelligence methods are more robust and present more resilience against distortions, which allow them to perform better.

[142] According to studies, 60% of their losses on construction projects had their origin already in the preliminary phases (Fischer, 2007)

Lai mentioned that the support vector machines can deliver better results than the neuronal networks for the reason that:

> "*In the AI techniques, ANN model often suffers local minima and overfitting problems, while SVM model first proposed by Vapnik has a large computational complexity when solving large scale quadratic programming problem*"[143].

However it has to be always recognized that every risk management system has to be flexible mainly because there will always be uncertainties, they have to be supervised and monitored besides when is required, to include the uncertainties converted as risks into the project evaluations.

Communication is most important; the world crisis in 2008 has shown many of the problems begin by hiding the information and distorting the reality, mainly as failures in the communication of risks or manipulation. *"In some cases, hierarchical structures tended to serve as filters when information was sent up the management chain, leading to delays or distortions in sharing important data with senior management*"[144]. For this reason mechanisms to avoid manipulation of data shall be integrated into a risk management information/communication process and to consider that almost any firm never reflects its real status. Risk management is in constant development and it's composed of several fields (legal, natural social, technical, financial, etc.), every crisis situation presents a new opportunity to its evaluation by the delimitations of new threshold criteria and security systems.

There are many methods for risk evaluation, their integration into an effective system that assembles the information and transmits it in comprehensible way for the top/project managers has become a main problem in the industry and for the present work. Figure 3-30 presents the reality of risk management in the construction industry. There are several stages in its evolution from simple risk management considerations until the current enterprise risk management and for the construction industry there is a high necessity of quantitative development.

[143] (Lai, 2006)
[144] (Senior Supervisors Group, 2008)

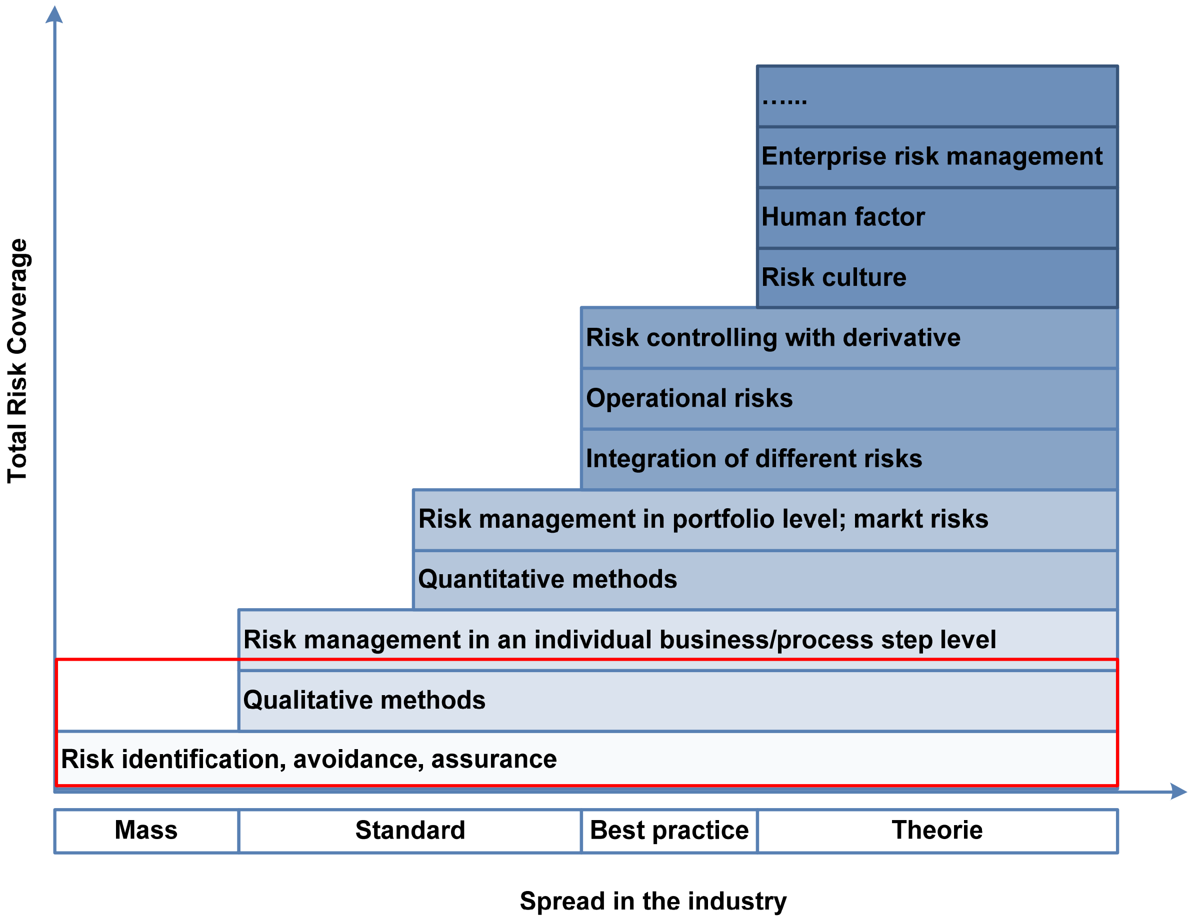

Figure 3-30: Risk management spread in the industry based on (Lausberg, 2008).

4 Defining the system's framing and requirements

The previous chapters presented the state of arts in the main fields of risk management and multi criteria decision analysis. These chapters were meant to capture and understand the possibilities in addition to the capabilities of each field and apply them to the particular needs of the decision assessment model.

In the construction industry, project management (PM) is the field in which the planning and definition of construction projects take place. Therefore this field needs to be understood aimed to define the functionality and requirements to be applied into the system proposed in this work, consequently this chapter presents briefly overview of this challenging field and especially on the requirements given by the life cycle and sustainability considerations in construction projects.

4.1 Introduction to project management

Since man started to use his reason for planning, he began to analyse how to complete his own endeavours in a more sophisticated and effective form. Every planned endeavour in the history of mankind can be considered as a kind of project management; however it was only in the latter part of the 20th century that the term "Project Management" was coined[145]. The need of control on different and complicated endeavours boosted the creation of instruments aimed to procure the project success and support the main goals (quality, time and costs).

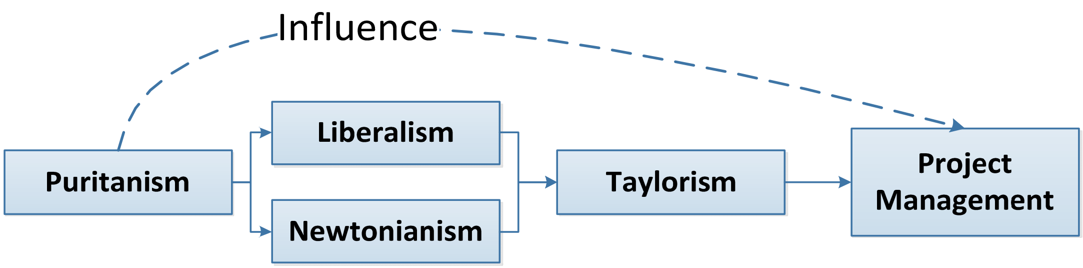

Figure 4-1: Creation of project management (Weaver, 2007).

Weaver explains that the origins of project management can be traced back to the Protestant Reformation on the 15th century; the Protestants and later the Puritans (see Figure 4-1) introduced the idea of reductionism, which means to remove all unnecessary elements of a process and in this way, to concentrate in the most important elements of the process[146]. Also the concept of individualism was introduced, which establishes that all elements or agents are independent.

These two last concepts were incorporated in two new different concepts Liberalism and Newtonianism. The first concept included the ideas of capitalism (division of labour and industry) and the second of applying science for a complete understanding of the whole endeavour. These two concepts influenced Frederick Winslow Taylor

[145] (Weaver, 2007)

[146] Process was for the Protestants in this case the ceremony.

(1856 - 1915) who created the Classic School of Scientific Management; from this school Henry Gannt developed the Gantt charts[147].

Around 1940 with the development of the Manhattan Project began project management, but it wasn't until 1950's that project management gained importance along with the development of Operations Research, the creation of the Critical Path Method and PERT charts and with the development of IBM's Project Control System software. "*In the 1970s, the military began the broad use of project management software, as did the construction industry. By the 1990s, virtually every industry was using some form of project management*"[148]. Project management deals with the main task of separating an endeavour into small elements for the implementation of control tools based on new scientific developments, in order to facilitate the project's guidance towards its goals.

Looking back at history, humans have been able to complete impressive projects, even before the creation of the formal project management, like the pyramids in Egypt, Mexico, Peru or the construction of big cities like Mesopotamia, Greece, Rome, etc., all these projects were not possible without some kind of planning and vision.

The current management of projects has become a complicated multi-disciplinary task with high levels of complexity and huge number of factors, but at the same time the PMs dispose of more possibilities of analysis as well as control a project and finally to achieve its main goals.

A project can be easily understood as "*a group of activities undertaken to meet one or more specific objectives*"[149]. The Project Management Institute (PMI) defines it as: "*a temporary endeavour undertaken to accomplish a unique product or service*"[150]. The German norm DIN 699001-5 defines a project as "*enterprise that is essentially characterized through its uniqueness and the totality of its conditions*"[151]. In general the project has a defined start and end point with specific objectives, when these objectives are achieved, it is considered as completed.

For the present work we can equate a project in terms of decision analysis with an amount of expectations (defined criteria) that describe a desired object, when these expectations are reached; the project is defined and therefore the solution is found. Consequently the process of defining a project, is a decision process in which defined expectations and goals are grouped and evaluated to find a solution that fulfils the expectations, this is nothing else than project management.

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[147] (Weaver, 2007)
[148] (Phinney, 2010)
[149] (GSAM, Handbook Condensed, 2003)
[150] (PMI, Project Management Institute, 2000)
[151] (DIN 699001-5, Deutsches Institut für Normung, 2009)

Project management is a systematic dealing with goals and it is defined by the PMI as "*the application of knowledge, skills, tools, and techniques applied to project activities in order to meet or exceed stakeholder needs and expectations from a project*"[152].

The PMI establishes also that: "*the Project team manages the work of the projects, and the work typically involves:*

- *Competing demands for: scope, time, cost, risk and quality.*
- *Stakeholders with differing needs and expectations.*
- *Identified requirements*"[153]

The PMI emphasize that project management is an iterative process due the integration of life cycle criteria for the project in its elaboration. This assertion also allows to declare that project management is nothing but a decision analysis process (see Figure 2-1 and section 4).

4.2 Project management and life cycle evaluation systems

Project management is a process in which the project is separated in partial tasks in order to evaluate the performing results; these tasks are attached to life cycle considerations and they set the main and partial goals for the whole project.

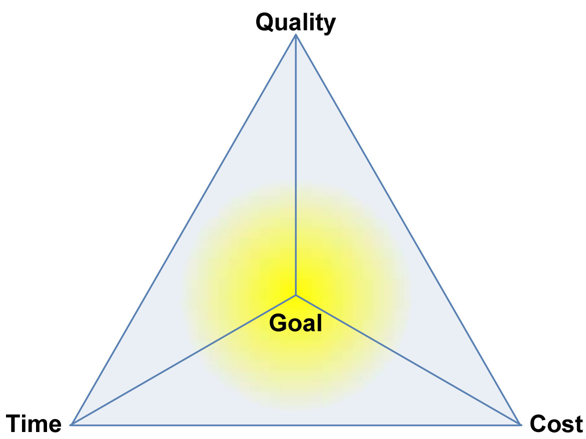

Figure 4-2: Magical triangle.

Normally in every construction project the main criteria to be controlled are: quality, costs and time, besides the scope and risks, these criteria must be set into balance by the project managers (see Figure 4-2). In the today's construction industry life cycle considerations are continuously gaining in relevance.

The PMI groups the different types of information within project management in "Knowledge Areas" presented in the Figure 4-3. This schema elucidates the functionality of project management; we can separate the main goal in several sub goals

[152] (PMI, Project Management Institute, 2000)

[153] Likewise

ordered in a hierarchy. Inside these sub goals we can group several evaluation methods for the general analysis of the project, for this reason the main goals and criteria have to be defined.

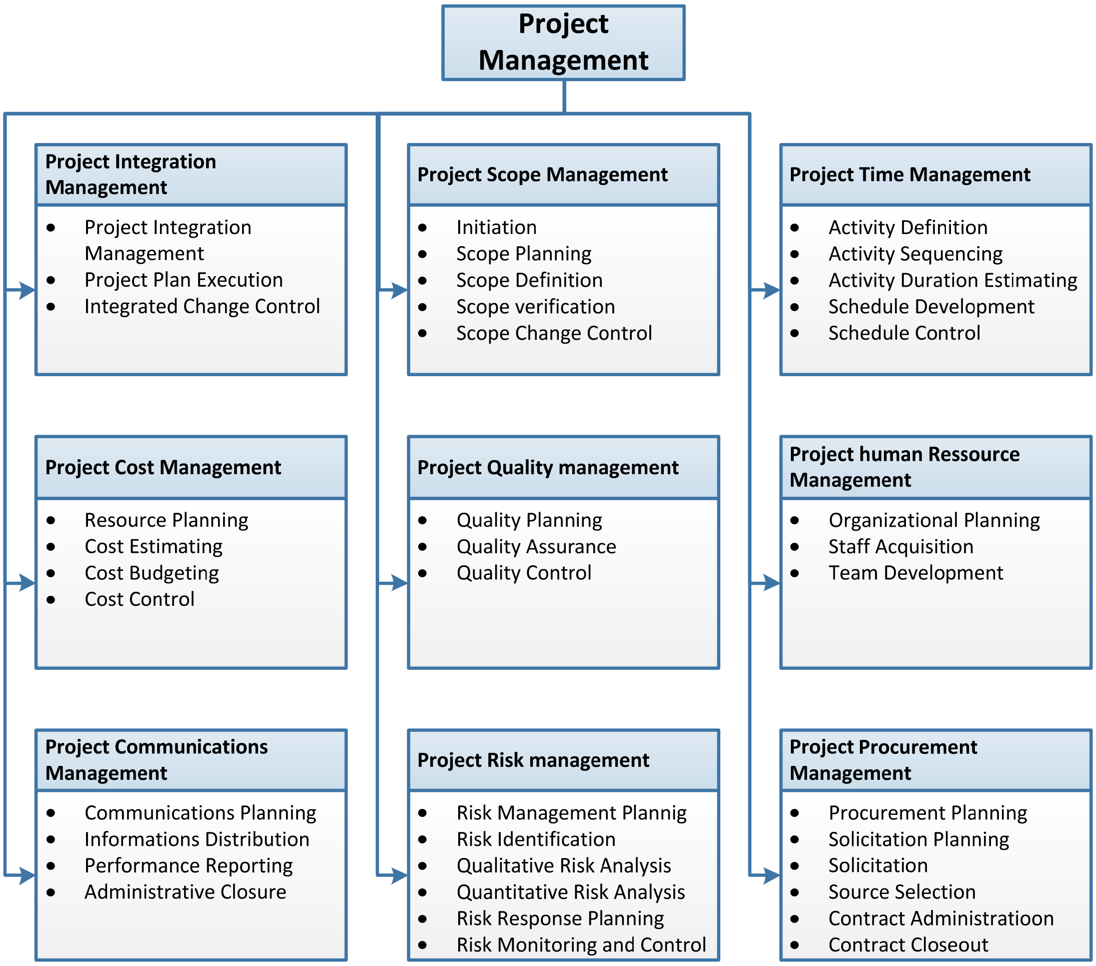

Figure 4-3: Project management knowledge areas (PMI, Project Management Institute, 2000).

The current project management integrates a high number of new criteria to be evaluated together with the traditional criteria (magical triangle Figure 4-2). The new requirements of sustainability and life cycle increased the complexity of the construction projects; under these requirements many different certification systems have been created. It's important to accentuate that certifications systems were originally elaborated for buildings and not for construction projects in general, nevertheless the main difference in the systems is how they separate their criteria for the evaluation process[154]. Figure 4-4 presents some of the most important systems all over the world.

The quantity of certified projects is growing and this reflects the demand of evaluation systems or in other words, controlling systems. One of the main reasons is that the client or owner wants to assure the quality of the project, as consequence the pro-

[154] (Gang, 2010)

ject's development is transmitted to experts (as a some kind of outsourcing); these experts make use of defined criteria to perform evaluations (certification system) and with this to increase the possibilities to achieve a successful project. A certification shall deliver more benefits to the investment besides reducing hazards and on the other side, to secure the quality of the object.

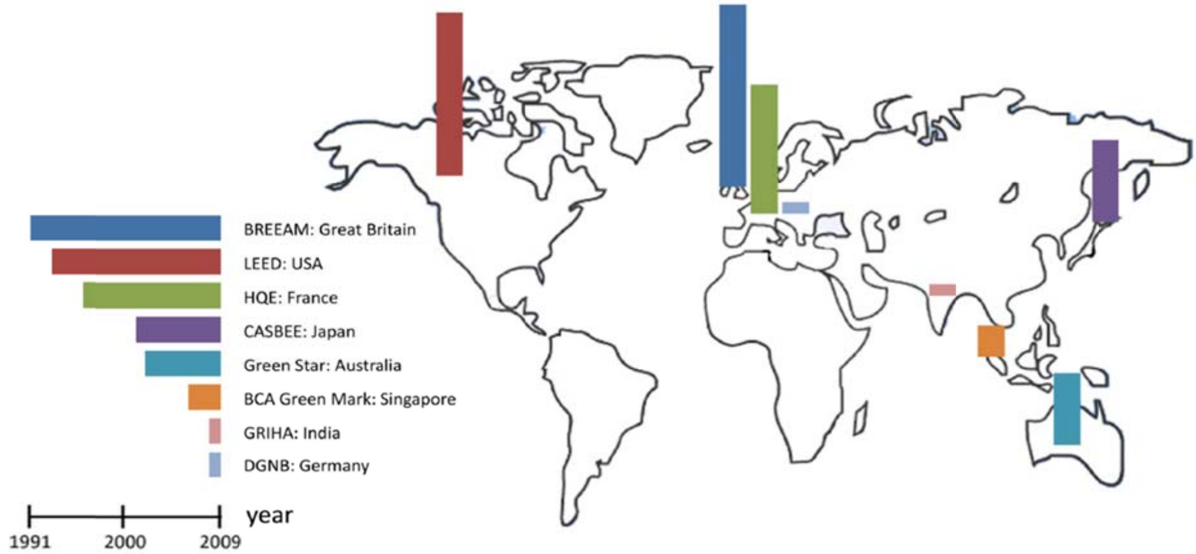

Figure 4-4: Worldwide sustainable system according to their lifetime in 2009 (Longlife, 2009).

As a conclusion we can see that the certification systems are just instruments used for the procurement of a project. They are a collection of criteria with their corresponding assessment method; they reflect the need of control and with this to confer higher liability to the project development. These certifications systems permit investors to delegate construction projects to more competent experts and in this form to increase the profitability of the project.

4.3 Project management in the construction industry

In the construction industry, project management is the core in the development of any construction project. The complexity and quantity of criteria involved in their procurement are enormous, therefore the life cycle evaluation systems mentioned before are intended to bring some clearness and to unify the criteria for their further analysis. Nevertheless all the evaluations and considerations performed in the evaluation systems are based on the original magic triangle "cost, time and quality".

These three concepts are the milestones of project development, they are considered to be functional and efficient for the whole life time of the project, thus it is imperative to understand the concept of life cycle in the construction industry. Rudloff defined it simply as "*the general timeframe of an object, from its creation (construction) until its end (fall down)*"[155]. This definition permits us to see, that inside this timeframe several phases with their correspondent targets must be combined in or-

[155] (Rudloff, 2010)

der to archive a functional product from the conception, utilization and until its final demolition.

Under these life cycle considerations the whole object's lifetime is meant, however lifetime in any construction projects can be also understood, according to Rudloff in three different ways.

- "***Functional lifetime***: *is the timeframe in which the object can be utilized completely functionaly as requested*[156].
- ***Technical lifetime***: *it can be defined as the timeframe between the construction and the demolition*[157].
- ***Economical lifetime***: *it can be defined as the minimum of the total costs curve (understood here as useful life, see Figure 4-5)*"[158].

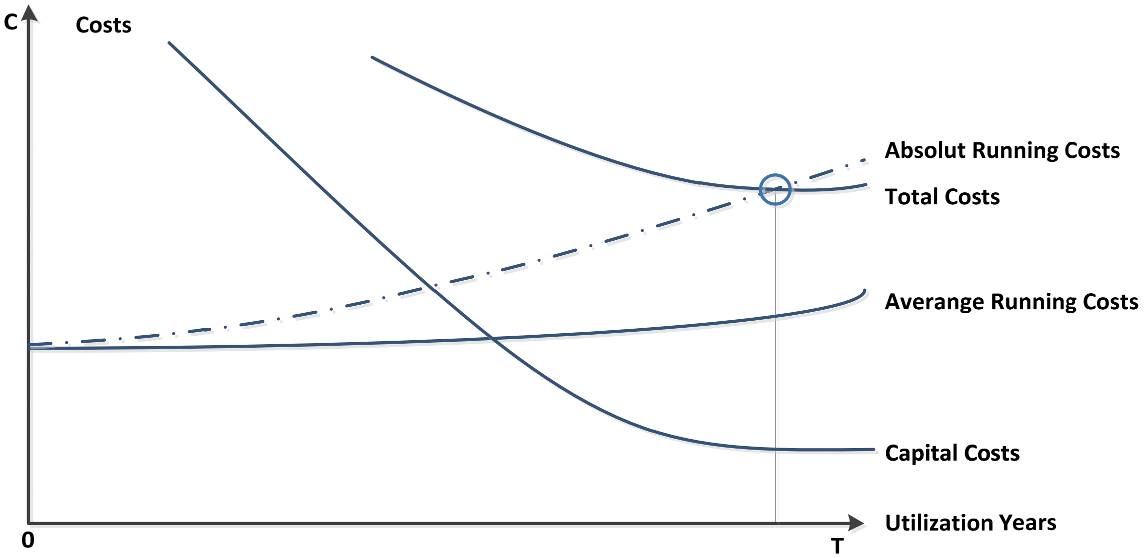

Figure 4-5: Annual operation costs of a construction (Schub, 1985).

From the definitions and Figure 4-5 we can appreciate that the different concepts are understood regarding to the goals in the project's lifetime, however the three of them must be considered nowadays in project development.

Project development is the creation process of the required object as concept, Diederichs divides the process in two different concepts. "*Project development is to combine factors such as, location, project conception and capital in order to create a project that as consequence results competitive and job-creating for the microeconomic and therefore is permanent rentable for macroeconomic, social and environmental matters*"[159].

Diederichs divides project development according to its goals in:

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[156] (Rudloff, 2010)
[157] Likewise
[158] Likewise
[159] (Diederichs, 1999), Direct translated from German.The considerations made by Diederichs were oriented for real estates (Buildings).

- ***"Project development in the wider sense**: it contains the whole life cycle of an object, from the project conception to the planning process, construction, utilization (operation), redesign until its termination or demolition. So that the facility management and object's profitability are considered*.
- ***Project development in the narrower sense**: it comprises the areas from the project conception until the point, that the project's economic efficiency is reached, so that it is possible to assign further planning processes; all this before the realization of the project"*.

These two definitions of project development permit one to see that two main processes or tasks are included in project management the "planning" and the "operation" processes. These main processes take place before and after the realization of the project. Hence we can define the realization as the fusion of the main processes; the solution's conception and development (planning) with its operation and utilization (operation) the construction is the link to each other (see Figure 4-6).

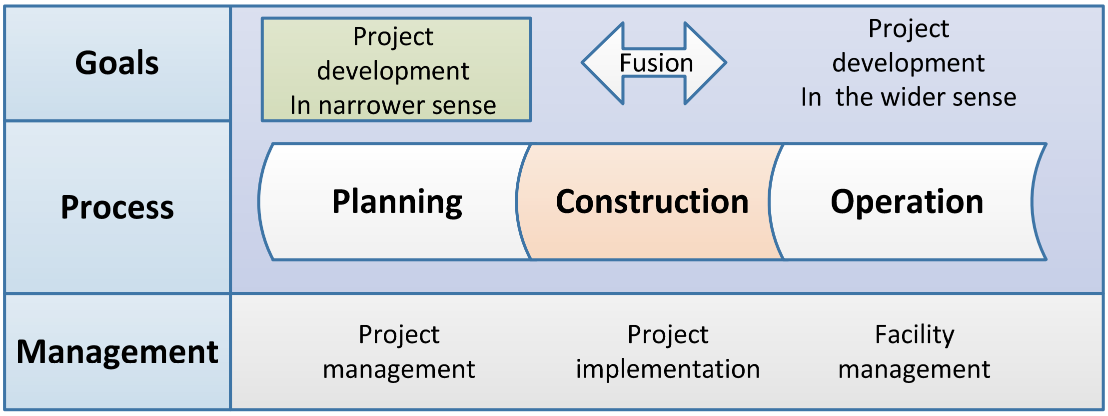

Figure 4-6: Project management and project development.

The project development in the narrower sense permits one to separate the project in its conception process and define the desired expectations, characteristics and requirements to achieve; these characteristics will always be stamped on the end object.

As a result the owner or user can dispose of the object after its completion to his own initial goals (need or profit). These goals have to be defined and procured by the planning (narrower sense) in the way that after the project completion the operation leads to the owner's/user's desired initial goals.

The organization of project management in the project development is normally performed in phases. It's clear that the main principle of project management attempts to separate the project into small tasks, these tasks are normally known as project phases. Diederichs describes six main phases in project development, it begins with the project initiation and ends with the demolition and recycling (see Figure 4-7). From this figure we can appreciate that each of these six phases are performed with different goals and targets, but they must be congruent with the project development in the wider sense.

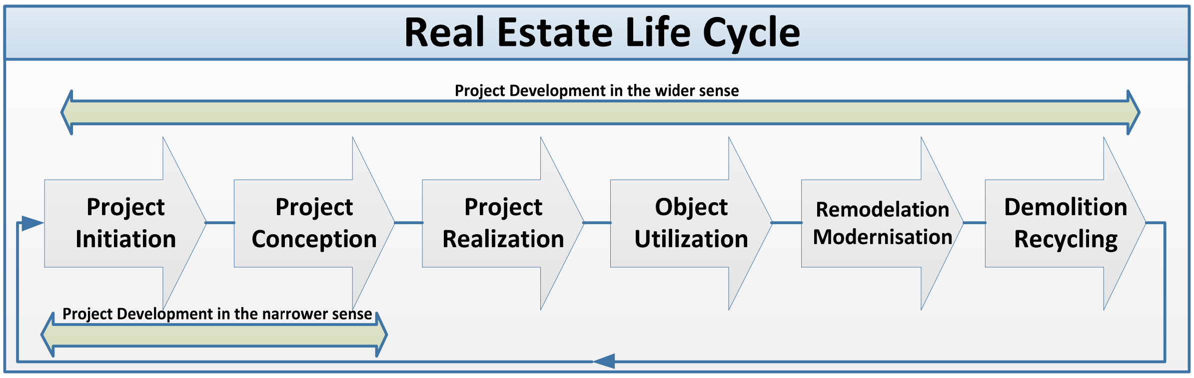

Figure 4-7: Project development in the life cycle of a real estate[160] (Diederichs, 1999).

Figure 4-7 is just one form to differentiate or separate the project in smaller tasks. There are many other arrangements to perform this task's separation. The following Figure 4-8 presents three different arrangements considered by the client, by the German Fee Scales for Architects and Engineers (HOAI) and by the German Association of Project Managers (DVP).

Mana-gement	Project phases client	Phases of the HOAI	Project levels DVP
Project Development	Project programm definition		Project preparation
	Conception phase	Basic evaluation	
		Preliminary planning	Planning
Project Management	Planing phases	Design planning	
		Approval planning	
		Execution planning	Construction preparation
	Implementation phase	Preparation of tender	
		Assisting at the evaluation of the bid	
		Object supervision	Execution
	Initial operation	Control and documentation	Project completion
Facility Management	Utilization and operational phase		

Figure 4-8: Project phases

These phases presented by the Figure 4-8 allows one to perceive, that each phase is associated with different goals, thus different evaluations shall be performed to secure the best results for the project. However some processes can be repeated (e.g.: modernization or renovation) and just the conception of the original object and the demolition are unique phases.

[160] Even when the phases were conceived for real estate, they can be considered for any construction project.

Rudloff presented these phases in a simple figure, valid for the realization of any construction project; there are two unique phases which are the conception of the object (original planning) and the demolition (see also Figure 5-4). In between there are more other phases that can take place many times regarding to the operation and lifetime of the project, Rudloff call them respectively “One time phases” and “Recurring phases”[161]. These phases influence the planning requirements for the project and risk management.

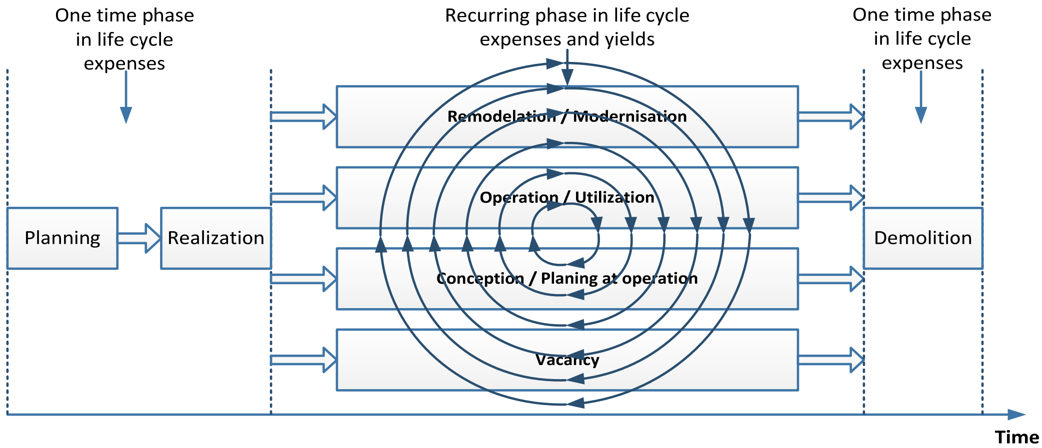

Figure 4-9: Phases principle - one time and recurrent phases in life cycle (Rudloff, 2010).

According to the utilization and conditions of the object, the owner might require modernization, restoration, renovation, etc.; consequently for the development of the desired object is necessary to interact with a number of experts in a corresponding organization system, to procure a successful project. Figure 4-10 presents the classical management organization systems.

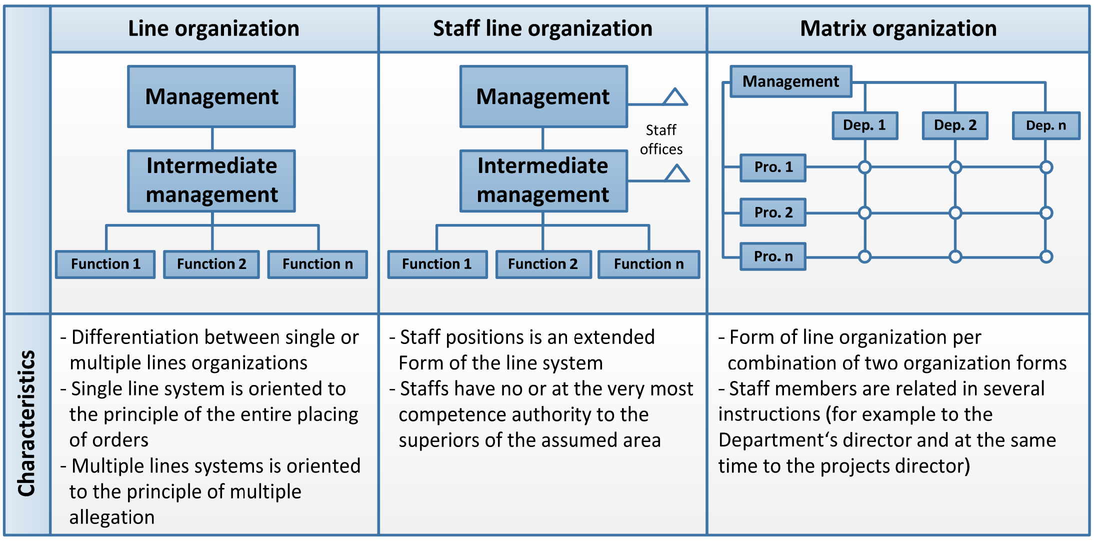

Figure 4-10: Characterization of the management systems (Held, 2010)

The adequate management system must be selected according to the project requirements and experience of the managers. The most important thing to recognize is that every management system is developed for a different interaction among the

161 (Rudloff, 2010)

participants and it disposes of different characteristics. However they are created to increase the quantity and quality of information between all the concerned parties, thus the information paths and communications procedures must be always be clearly described and supported. Therefore systematically approaches are required to be calibrated to the main goals of the project. The main task for project managers is to evaluate the several project factors according to the goals and to the fulfilling of the project objectives[162].

Line Organization	Staff line organization	Matrix organization
Advantages	**Advantages**	**Advantages**
• Maximal project resource allocation • Explicit definition of structures and communication ways • Clearness in the organization structure • Clout and efficiency with vertical leadership. Specially with projects of high priority or under high external exposure • Authoritarian leadership is for personalities with weak value and goals orientation subordinate positions recommended • Optimal in aggressive market conditions	• No assential alteration by the start or end of projects • Cost-effective • Promp to establish • Optimal information utilization and processing by the experts in the different staffs • Management support through Staffs • Mitigation of the one line system, typical in authoritarian systems due to cooperation enforcement with the Staffs positions	• Formal elegant and „theoretical sufficient“ Solution for Large and very Large enterprises with a wide product programme, to consolidate and central to administrate • Better utilization of coworker's creativity and special knowledge • Holistic mentality • Better linkage of divergent project's tasks and • Job interests balance
Disadvantages	**Disadvantages**	**Disadvantages**
• Authoritarian leadership demotivate some coworkers • Possible overload of the management instances. Every Information channel ended here and every decision is also here made • High leadership skill required in the top manager levels. A weak leadership conducts to poor systems results • Potentiality to bureaucratization, coworker dissociation and fossilization	• Blurring exposure between the Staffs authority Staff's configuration. It might lead to multiple line of leadership • Staffs information and experts authority might provoke manipulation of information and Management without responsibility • The abuse of Staffs as spokespersons of the Management, emphasize the Bureaucratization and coworker dissociation	• Management inconsistencies and involved disadvantages • Very bureaucratic and often very awkward management style, due to many countless enervating meetings and conferences • Frequent just failure and return to original Staffs line system, this might be fatal for the organization

Table 4-1: Advantages and disadvantages of the management organizations forms (Zingel, 2009)

Zingel prepared a resume with the advantages and disadvantages for the different management systems (Table 4-1) [163], this resume permits one to appreciate a general overview and also to understand the most important characteristics and differences for each of the three mentioned organizations, consequently enables one to select the adequate organization for the corresponding project.

However it's imperative to notice that management has two different facets, Zingel divided them in the "interpersonal management" and the "optimization problem"[164].

[162] (Kochendörfer, 2007)
[163] Translated from (Zingel, 2009)
[164] (Zingel, 2009)

These are two different management aspects that are normally handled with different instruments inside of every project.

These two different facets can be understood as follows:

- ***Interpersonal Management***: Takes care of every human aspect inside of a project, therefore is related to the communication and social interaction between all participants in the project.
- ***Optimization Problem***: this part of management is attached to the operational resources and procedures to procure the whole project.

Interpersonal management is an important task for an adequate development of any project, thus conflict management is a part of this topic. Kellermann[165] presented some of the most typical approaches to conflict management from the psychological side.

Approaches	Theoretical basis	Main Objective
Emotional	Frustration-agression	Expression of pent-up agression
Intrapsychic	Transference displacement	Correction of perceptual distortion
Interpersonal	Interaction	Communication
Group-as-a-whole	Social psycology of groups	Transformation of group dynamics

Table 4-2: Model of conflict management approaches in group psychotherapy (Kellermann, 1995)

In the Table 4-2 we can appreciate four types of conflict management approaches with their corresponding theoretical basis and main objectives. As already noted the kind of management we are engaged in by development of construction projects is the interpersonal approach, hence the interaction between at least two project participants is the basis. Consequently the main goal is to facilitate the communication between them. Communication is vital for the project's success; many projects flopped due the lack or poor communication[166]. However several factors influence project success, it is for this reason that a methodical procedure is recommended to support the project's success; some of these are listed in Table 4-3.

Factors that Support the Project's Success	
• *Definition of project objectives*	• *Delegation of authority*
• *Risks*	• *Changes to responsibilities, project scope and plans*
• *Early decisions*	• *Control*
• *Project planning*	• *Reasons for decisions*
• *Time and money*	• *Using past experience*
• *Emergencies and urgency*	• *Contract strategy*
• *A committed project team*	• *Adapting to extern al changes*
• *Representation in decisions*	• *Induction team building and counselling*
• *Communications*	• *Training*
• *Promoter and the Leader*	• *Towards perfect projects*

Table 4-3: Factors that support the project's success (Smith, 2000)

[165] (Kellermann, 1995)
[166] (Smith, 2000)

4.4 Planning the system and requirements

As already noted project management is a challenging field on which different project's procedures and requirements are integrated and assessed in order to fulfil the project's expectations. In every construction project it is indispensable to evaluate and procure the three main criteria: quality, costs and time. On the other hand, these criteria can be considered just as a group or array of evaluations and considerations developed by all participants inside of the project, in order to fulfil the project's expectations.

The project managers are in charge of achieving the goals of the project, nevertheless it's also imperative to understand that every participant in the project pursues their own goals; the project is just an instrument to achieve them. The more participants there are working on the project, the more independent goals exist in the project and these independent goals have normally nothing to do with the project's goals. The PMs are in charge of linking up the goals according to the project goals and requirements. In some cases the different interest of the participants (goals) might be conflicting to each other and provoke direct confrontation between them.

In these cases the PM has the main goal of facilitating the communication and to reduce this conflict potentiality. By choosing the adequate organization management system some of these conflicts can be reduced. But not only the management system assists in solving this problematic, the transparency and clear quantifications systems provide an important help.

Communication and evaluation are the main tasks in pursuing the project goals. Matheu defined these tasks as:

> "***Communication***, *…., deals with producing, issuing and transmitting reports/documents, and with holding occasional meetings among the project participants so that the proposed timing, method and strategy are made available and understood. In essence, the collaboration of the various participants in a project is measured by how effectively the communication channels were managed.*
>
> ***Evaluation*** *of the outcomes are critical to improve current practices. Communicating and feeding back information and messages to the project team is also essential to the achievement of the project goals by all the participants. Thus, the effectiveness of the project manager to communicate with, evaluate, and feedback to the rest of the project team during each stage of the life cycle determines how efficiently the project's goals will be achieved*"[167].

[167] (Matheu, 2005)

The constant comparison of the evaluation instruments against their expectations and their communication helps the PMs to achieve the desired results of the project. Thus the evaluation most succeeds according to suitable systematics and/or methodologies, accordingly these evaluations should be communicated to the managers and other participants for its further evaluation. These evaluations can be appraised under the considerations of not only time, cost and quality, but scope, risk, client satisfaction among many others. Hence the criteria planning, communicating, monitoring and control in a quantitative form have become an important challenge for every project.

4.4.1 Decision analysis and project management

In this work it's already been proved that decision analysis and project management are two linked fields, they separate and scrutinize criteria for the development of the whole main undertaking, by choosing the best alternative. PM cares about the communication and evaluation of the gathered criteria and decision analysis provides a group of methodologies aimed to assist this assignment. "*Decisions determine how far the future company's success as decision's consequence is defined*"[168]. Smith added also that "*most of the design and supporting development work for a project usually follows the decision to proceed*"[169]. Figure 4-11 presents how the decisions impact direct on the project's cost.

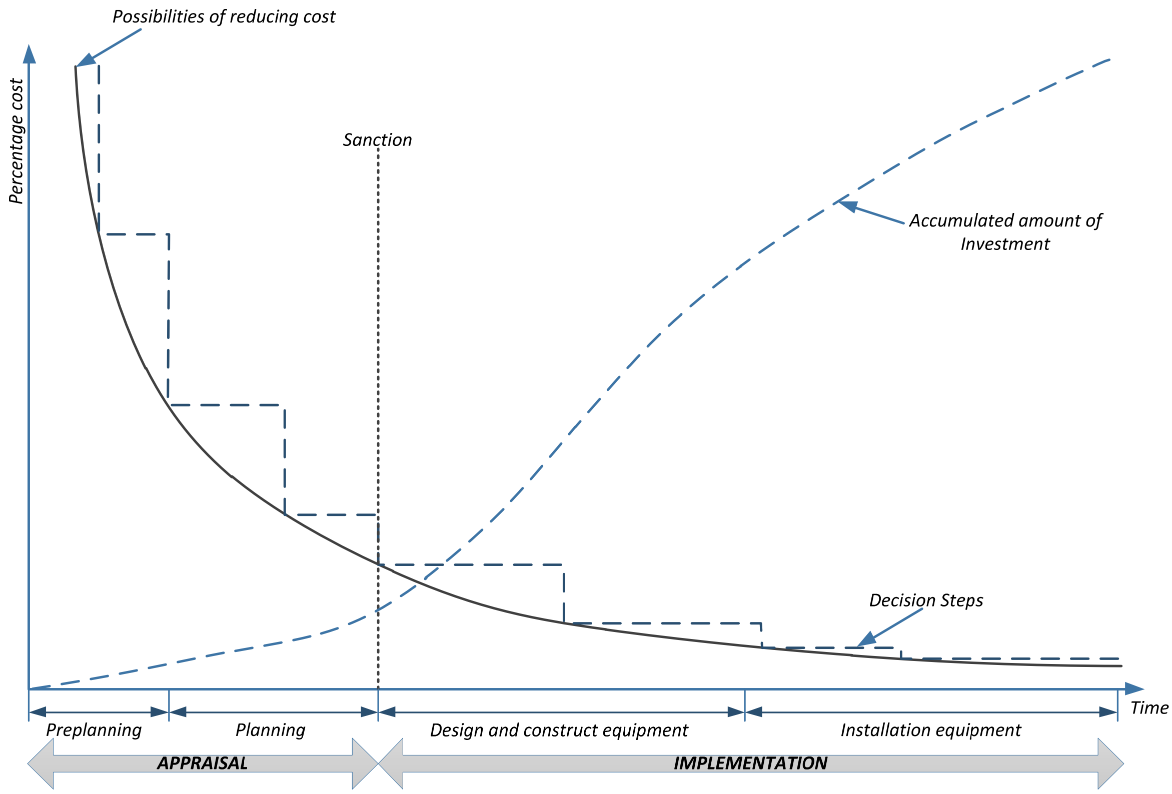

Figure 4-11: Change in the cost of decision making with time (Smith, 2000)

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[168] (Dittfach, 2006)
[169] (Smith, 2000)

The particularity of the construction projects in contrast to the series production projects, is that the product as a result is unique and for the production of a second one the conditions, milieu and even the management and participants are different, in addition the costs for these kind of projects are normally high. On the other hand many of the criteria remain the same, which means that mostly just the evaluation of the criteria and the weights change. This characteristic is where decision analysis provides support via the introduction of systematic methodologies to the decisions of project management.

Decision analysis not only provides a system for criteria evaluation, it also permits the unification of project goals among all the project participants. Through its utilization transparency is achieved by defining communications systems and ways, criteria, quantification procedures, main goals and objectives for the criteria. Finally a mathematical procedure is delivered that permits a better understanding of the decision making process.

In conclusion, the utilization of decision analysis in project management permits us to define clear rules and procedures to the evaluation and analysis of the criteria and consequently to better achieve the main project goals. These rules and systems permit all projects participants to accelerate project development and to avoid potential conflicts.

4.4.2 Basic Parameters / Operational requirements

The present work makes use of decision analysis considerations to support the criteria evaluation for project development in the narrower sense. In this way communication is improved by introducing a methodology for all the participants. This methodology is developed for the evaluation of drafts and alternative variations (the development phase in Figure 4-12); consequently this methodology permits one to achieve transparency in the project development process.

Figure 4-12 describes the four different phases of project management and the required information and tasks. Every construction project starts with an initial requisition or in other words, there is a need that must be justified for its approval. At this stage there is only a raw idea of the required object and a vague notion of its characteristics, but the main goal is clear. From this moment a formal project requisition is prepared and after its approval the project management takes place.

As soon as the project development starts more information is required consequently the object is conceived and the possibility of changes starts to be reduced; mostly because the alternative takes a determined form, therefore many variation options are excluded (see also Figure 4-11). It is for this reason that the main core in the project development is the “Draft’s Valuation” or “Project Conception Process”. This process synthetizes the utilization of the evaluation and communication instruments in the definition of the final concept.

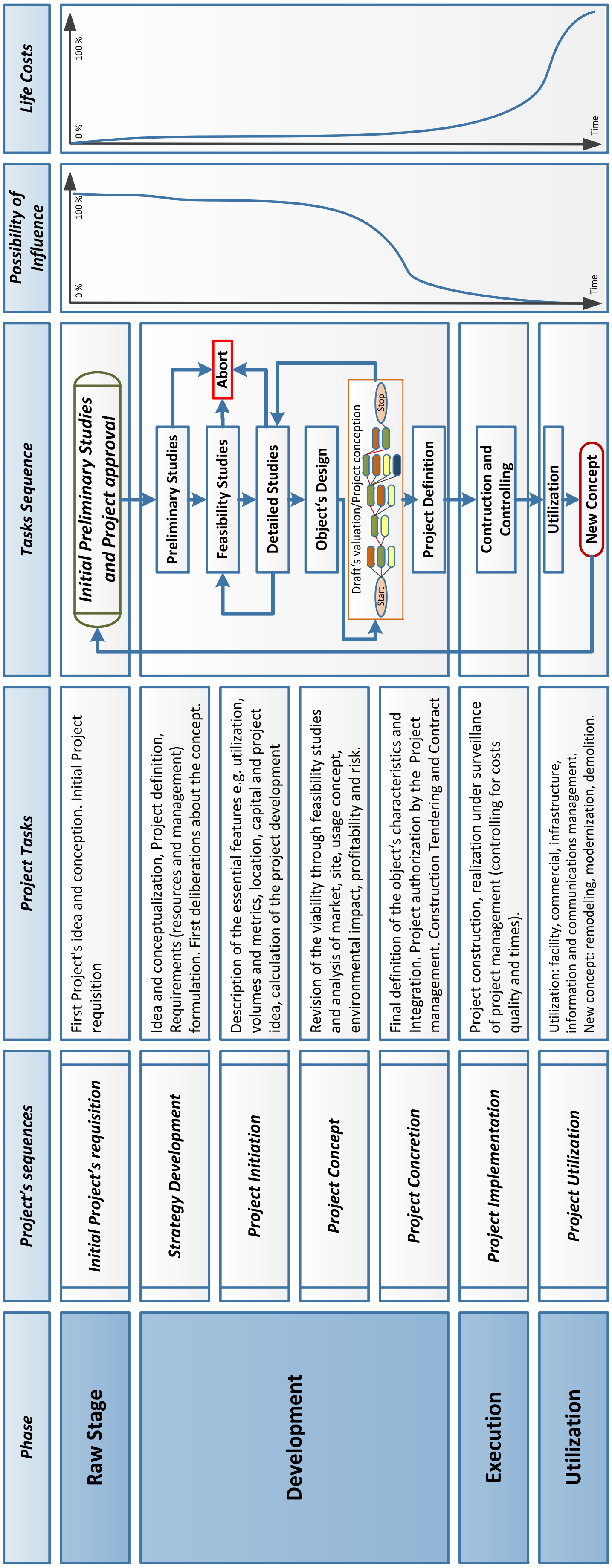


Figure 4-12: Projects phases and tasks

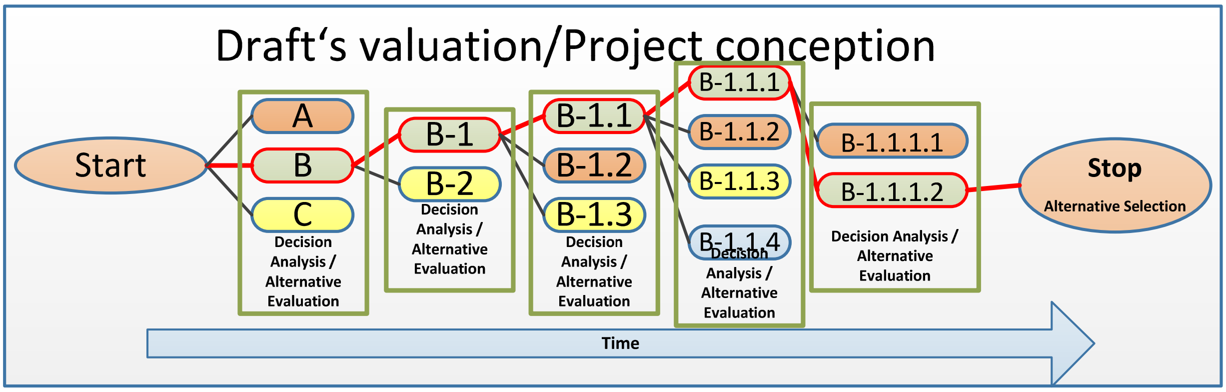


Figure 4-13: Alternative evaluation in project development

This evaluation process is presented in Figure 4-13. It is easy to appreciate that the development is a dynamic procedure in which alternatives are created for their analysis, comparing their expectations and functionality to each other to select the most promising alternative and consequently to continue with its further development, however the number of alternatives is finite. This process can be equated with an evolution procedure, the alternatives that don't meet the expectations are discarded and the most plausible will be improved.

This procedure is repeated until the expectations are reached, therefore its relation to the decision analysis process (see Figure 2-1 in section 2.2). We can conclude that this procedure is dynamic and the criteria, weights and alternatives are normally not deterministic, they are constantly in motion. However this dynamic procedure is contained in a finite number of alternatives, as result of the actions of the project management.

Normally for construction projects there are a finite number of alternatives to be considered, these alternatives are mostly variations of an original concept and in very exceptional situations completely different alternatives are developed.

The main reasons are the expenses involved in the development of each alternative, thus it is typical in the construction industry to evaluate the evolution of a project based on the evaluation of its variations and consequently the selection of the most promising of them. In this procedure the project management gather and evaluate the alternatives in for example "jour fixes"[170].

Inside the very first deliberations in project development exists the requirement and initial idea, for example, a building, high way, bridge, stadium, etc.; see Figure 4-14; from this idea the main expectations of the project are defined. Since these first deliberations the most important characteristics, expected costs and times are defined (e.g.: for a hotel, how many rooms, location, budget, etc.) in preliminary studies.

[170] Stipulate periodic meetings between all participants

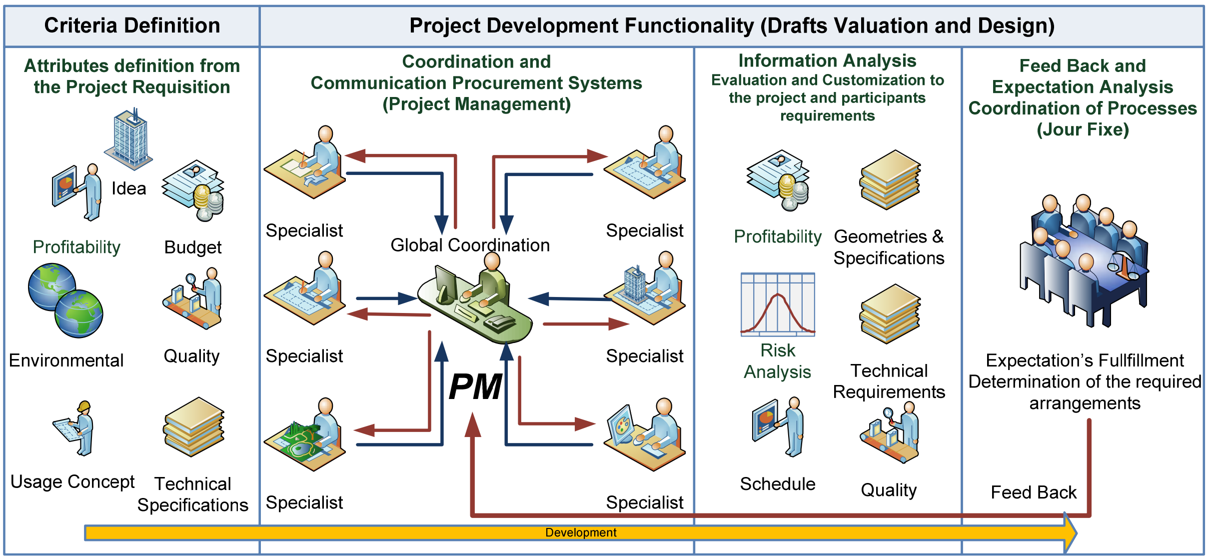


Figure 4-14: Project development - design process

In this form the main goals are defined and after the approval of the project, the project management starts to collect detailed information via the initial studies. For this reason the main criteria must be clearly identified and defined (e.g., cost qualities, schedule and deadlines, responsibilities and management organization, etc.).

In this form the project management breaks down the project into different tasks for its analysis and constant evaluation; these evaluations are performed by several specialists in the different tasks and fields. After the results evaluation performed by the specialists, the evaluations are communicated to the PMs and they coordinate and make a global evaluation of the state of the current project and compare it to expectations.

It is imperative to evaluate the interactions of the different solutions proposed by the different specialists. In this form the necessary improvements are proposed and sent to the corresponding specialist. This process will be repeated until the expectations are met.

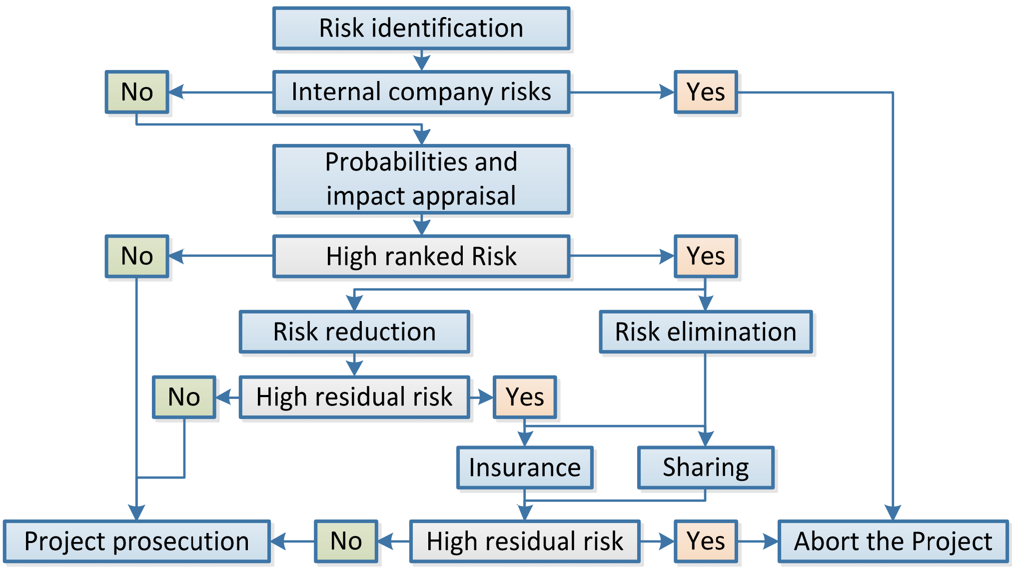


Figure 4-15: Flow-Chart for K.O. criteria (Kaiser, 2011)

Another main task is the definition of the criteria, that in the case that they take place, it means the abortion of the project and consequently not prosecuted (K.O. Criteria). These criteria are normally defined via risk analysis (see Figure 4-15). Every decision leads to a risk treatment and the result (residual risk) must be evaluated and managed.

It is for this reason that the draft's valuation or project conception process can be described as a dynamic and cyclic process in which the evolution path can be followed as a decision tree, when clear rules and systematic are established as specified procedure (see Figure 4-13) the decision can be reproduced and conflicts avoided. Therefore the importance of organizing the information and evaluation procedures for an efficient functionality of the decision analysis methods.

One example of how the technical information can be organized is the German DIN 276, in which the object is disassembled in its several parts for better understanding and management. The German project management nowadays utilizes this kind of information procedure or in other words, based on the functionality of how the construction projects are managed in practice. Several participants (stakeholders) are in charge of different assignments in the project (e.g.: foundations, excavation, air conditioning system, etc.), they are selected according to their capabilities in different fields and they develop their corresponding assignments as specialists.

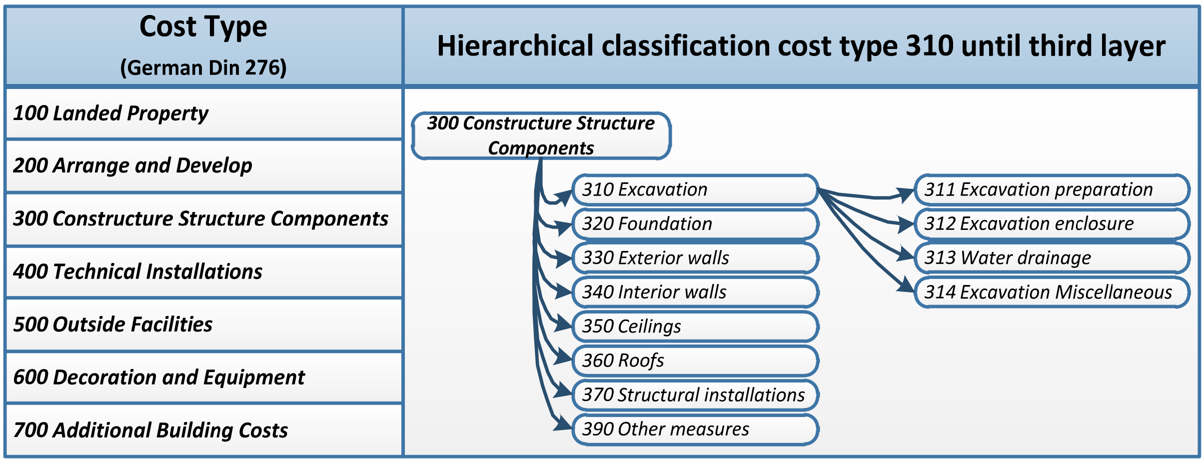


Figure 4-16: Hierarchical classification DIN 276 and example of cost type 300

The German DIN 276 permits one to subclassify the elements of an construction project into single elements, which allows a better overview and control in the project. This classification procedure is performed in a hierarchical form and according to the necessary degree of details it can be utilized until a third level or layer. Normally the cost types 300 and 400 contain the most information and complexity, due to the fact that installations for any construction project represent the main challenge.

This DIN 276 is just one possibility to handle the technical information; however there are many other types of information that also require classification and allocation inside the project.

For an adequate development of the project management there is not just one simple system that permits one to classify all kind of projects in a single procedure, however a general procedure can support the project management but it’s recommendable to customize it for the corresponding project. In this form the general procedure should make it possible to abstract the different criteria and procedures about how the decisions are made inside the project management and also by the different participants in the project.

The PMI delivered in Figure 4-3 one general form how to enhance the criteria and required information. In addition to this the “General Decision Analysis Problem” presented in Figure 2-2 (see section 2.4) is a general procedure from the decision analysis that permits one to identify, classify and evaluate the project’s information and criteria. It’s important to remark that normally the required information can be hierarchically represented which enables the use of the MCDA in the criteria evaluation in a project.

4.4.3 Project and risk management functional requirements

As already mentioned in the previous chapter, there are several types of information in construction projects, also typical for these kinds of projects is the high amount of them. The most important task for project managers is to classify this information according to the project requirements.

In a general form, the construction projects have similar types of information, the difference is given by the type of project, For example for a highway project the technical installations don’t represent a complicated task as for an airport and roofs are not even required. Therefore the relevance of each criterion is only given by the type and the specifically requirements of the project. Table 4-4 shows some of the most important information types in construction projects, from a documentary sight.

Request for information	**Materials Management**	**Equipment Management**	**Cost Management**	**Submittals**	**Safety**	**QC/QA**	**Interpersonal**	**Schedule means and methods**	**Jobsite record keeping**	**Future Trends**
Design intent and clarification	Access to material management	Equipment location	Budget	Test results	Accident reporting	Initiate inspections	Emails	Schedule	Recording timesheets	Positioning data
Subcontractor information	Material location	Fuel monitoring	Material cost accounting	Revisions to submittals	Reporting violations	Report QC/QA problems	Voice Mails	Schedule updates	Progress reporting	Sensory data
Contract specifications	Material order status		Equipment cost accounting	Physical Artifacts	Safety Plans	Reporting inspections results	Meeting Minutes	Delay recordings	Exception reporting	
Contract drawings	Request materials to site		Personnel cost accounting	CAD Models		Test Artifacts		As-built records	Visitor's log	
Work package information	Place material orders		Purchase Orders			Test Plans		Productivity information	Daily Construction Reports	
Means and methods	Material Specifications					QC/QA Plans			Images / Photos	
Implementation problems										

Table 4-4: Typical documents of a construction project, by type (Latimer IV, 2003)

Some of the variety of information in construction projects is presented in the Table 4-4 (see also Figure 4-3), this table was created to show the information generated in a construction project for a document management system.

Another important fact is the development of risk management systems in the construction industry. The newest developments have established the enterprise risk management, in which different risk analysis methods are linked to each other. Risk management involves the application of measures to conduct risk in opportunities and avoid hazards, based in the application of risk analysis. However even when risk management is nowadays a requirement (mostly in developed countries), there is not a standard procedure for its implementation (see section 3.11); is for this reason that exist many forms of risk management and especially of risk analysis in the practice.

According to the company's awareness towards risks, risk analysis can be performed with high details and complexity levels from which the results derived can be attached to specific criteria, or just a very simple checklist to assign a total risk to the whole project. In the praxis is normally the second method the standard procedure and detailed risk analysis are rare. Along the development of a construction project and consequently the resulting object, there are many processes and information analysis required for a functional object's life cycle (technical life, see 4.3).

Risks can be also classified in several forms, the easiest form is in two different risk categories: "projects risks" and in "external risks". Another way to classify them is as project risks, legal risks, branch risks, finance risks, procurement risks, personnel risks, etc.; some of the most important risks types are presented in the section 3.2 presented. Here is important to mention that risk management enclosures the decision making process around risk criteria, this means how risk are treated and the analysis of these measures.

Risk managers are responsible for delivering risks analysis in a simple form that permits to identify critical criteria for the project managers, and in this way support their decision making process. As result, the collection of criteria in data banks makes possible for future projects to establish a systematic procedure and high light the most important criteria.

Risk analysis should permit to analyse the results of the decisions made by the project managers, decision such as price agreement of materials, personnel trainings, currency appreciations, liquidity risks, etc.; their effect to the projects and in this form recommend appropriate measurements.

The use of quantitative risk analysis methodologies permits to evaluate the effectiveness of chosen measures (from data banks), and consequently the risk management process makes possible to analyse the measures and provide scenarios of possible results.

4.5 Selection of the required project management requirements

This chapter presented the main principles, functions and requirements that enable and support the proper functionality of any PM system together with considerations of life cycle and sustainability in construction projects. There are several ways to organize these systems and criteria, nevertheless an adequate decision analysis system must represent the systematic and procedures performed by the corresponding PM, consequently is not possible to select a single procedure or system for the application of the here elaborated decision analysis system (see sections 5 and 6).

Risk and Project management are created and performed according to the requirements of the project and the capabilities of the Managers, consequently decision analysis is aimed to support their functions and as result they have to abstract the functionality of the system and represent it as a decision analysis system.

For the present work this possibilities are evaluated in sections 5 and 6. A general system is presented in section 5, it permits to sort the criteria in defined modules, in the cases on which no systematic is available. In cases on which a systematic is available the most important activity for decision analysis is to abstract the methodology and represented it in a mathematical procedure, consequently the analysis can be performed. This last procedure is also important to trace back a decision. These tests were implemented in section 6.

4.6 Conclusions

This Chapter presented a general overview of PM and its functionality, it is clear that the main task of PM consists in separating the project in several tasks with their own goals, but each of them in concordance with the main projects goals. The project management must select the corresponding management organization system, and the appropriate evaluation method for the different criteria.

Inside of construction projects, quality, costs and times are the most important pillars by the development of the project; consequently the estimation, scheduling and the evaluation from the several experts for the proposed solution represent the main criteria to be evaluated. However in the planning process, the evaluation is based on relations and considerations about the expectatives of the project. In the recent time life cycle considerations must also be analysed and considered, which increased the quantity of criteria. Nevertheless the core of the PM is the coordination, transfer and evaluation of the several criteria and information inside the project.

Construction projects contain high amount of criteria, therefore an efficient information management system offers a chance to improve the PM itself. Subsequently the planning will delivered a project that can be applied for its construction and reduce the problem known as the "separation of the execution from the planning"[171],

[171] (Manoliadis, 2006)

therefore the clear definition of goals, criteria, targets and organization together with the system presented in this work permit to reduce this problematic and support main goal of PM to “built as planned”.

Risk management in the practice should be performed in a quantitative form and oriented according to the before defined projects goals. The system and risk analysis procedure proposed in this work permit the selection of different measures and through this, the elaboration of possible scenarios delivered from a quantitive basis. In this way the benefits of risk analysis can be exploited. However risk criteria are normally just one part of the total criteria inside a project. There are many other criteria that are independent of risk. The simultaneous evaluation of risk independent criteria with risk evaluation methods in the practice is performed separate until today and the general overview can be easily lost. The decision risk analysis system presented in this work is based in decision analysis methods and makes possible a general evaluation in a single process.

5 Development of the risk analysis based decision making system

5.1 Introduction

The previous chapters presented the current state of art in decision analysis, risk management and project management. They represent the basis for the development of the system. Current construction projects require systematic and transparency for an adequate control and functionality for all the participants[172], thus the developed risk analysis systems supports the project development in these topics, by delivering a systematic in the criteria assessment.

The topic of the present work is the project development in the narrower sense[173], thus project management (PM) delineates the basis for the systematic's procedure and the decision analysis permits to elaborate the required mathematical model for an objective assessment of alternatives.

The proposed system delivered in this work is composed by a system and a decision analysis model, arranged in defined modules. Through this system and model, the decisions made by choosing the best alternative, can be reproduced and verified. It permits also to see the relevance of each criterion and their influence in the decision.

5.2 The Decision / Risk Analysis System

5.2.1 Definition

The decision / risk analysis system presented in this chapter is a methodology for the evaluation of alternatives (drafts) in the project development of construction projects. It can be considered as an abstraction and representation of the decision analysis procedure by defining and fulfilling the expectations of a required civil object.

This system integrates all the required and selected criteria in a decision analysis model, which enables a complete criteria evaluation with objectivity, transparency and incorporating all necessary evaluation methods. This system allows the integration of quantitative risk analysis as one of the evaluation methods in the criteria valuation. The decision / risk analysis system provides the project management support by delivering an assessment tool, which enables to choose the best alternative between different drafts, under the consideration of the main and sub objectives in a single evaluation process.

The Figure 5-1 presents a simple representation of the system's functionality, once the PM is established the main target must be defined; this means the desired result have to be clearly defined. Consequently the main goals have to be defined; this

[172] (Whelton, 2001)
[173] See section 4.3, definition according to (Diederichs, 1999)

means that the sub goals (requirements) can be set as the desired m³, kW, costs, time and qualities. At this stage life cycle considerations can be utilized in the system. In this form the planners will elaborate their corresponding alternatives. When these alternatives are presented an evaluation takes place in which all criteria is evaluated and permit to decide which alternative is the one closest to the expectations. This cycle will be repeated until all expectations are reached, besides this systems incorporates risk analysis as criteria.

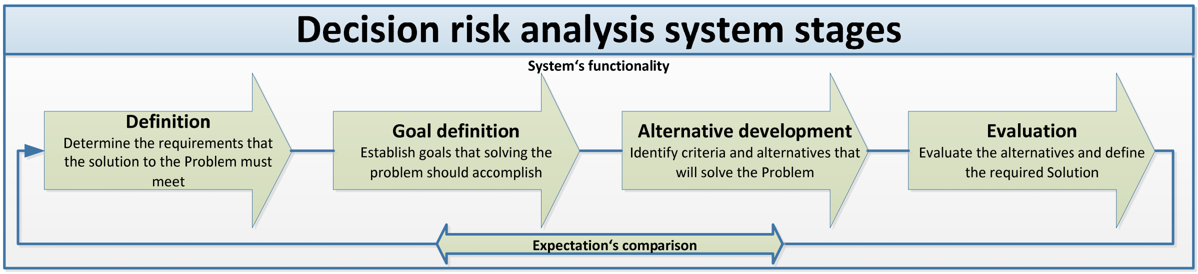


Figure 5-1: System's functionality

5.2.2 Decision / Risk Analysis System Objectives

The main objective is to support the project management and participants during the evaluation of the drafts in the project development, via an integral criteria assessment procedure. The included decision analysis model is developed in AHP.

AHP (see section 2.6) makes possible to array the information in hierarchies and according to this arrangement, to evaluate all criteria from each alternative in a single assessment procedure. Through the utilization of risk analysis from stochastic methods, the conception of projects in the project development can be performed with more certainty. However the use of simple risk analysis methods (not stochastic methodologies) is at the same time possible.

The main goals for this system can be listed as follows:

- ***Systematic identification of the project's main criteria (main expectations)***: The PM and participants have to define the main goals, for the project and for their corresponding tasks.
- ***Support of the PM tasks through a graphic representation of the decision and of the used evaluations methods:*** The decision must be exemplified in a hierarchical representation including all the required criteria in the defined modules.
- ***Clear quantitive definition of the expectations:*** Once the criteria are identified, it is important to define their corresponding goals (e.g. required m², m³, schedule, energy requirements like kW/hr, costs, etc.) in order to perform the evaluation of each alternative's criterion. The relevance of each criterion to another has to be defined also.
- ***Traceability and justification of the PM decisions:*** Through the utilization of AHP and the defined expectations (requirements), the selection of any alternative can be verified and controlled.

- ***Integration of quantitative risk analysis, especially from stochastic evaluations:*** Risk analysis from methods like the Monte Carlo Simulation (MCS) and Artificial Neuronal Networks (ANNs) can easily be integrated in the project development process and permits also the use of simple methodologies like check lists.
- ***Dispersion reduction in the risk analysis through the utilization of artificial neuronal networks:*** The use of ANNs in the treatment of the inputs in the risk analysis process permits to increase the certainty and consequently to reduce the dispersion of the risk analysis results (see section 5.4.2).

The high amount of information in development of construction projects leads normally to overlook besides forget considerations or information that might be important in another point of time; therefore it is always important to include them into the final analysis. Many of these information are evaluated and considered by selecting the best alternative, however many of them are not collected or documented and finally represented in the decision analysis process or in a single graphic illustration. As result the selection's traceability is very often not possible after a period of time.

The decision / risk analysis system enables the verification of the selection and to accelerate the decision analysis process. The use of weights in the analytic hierarchic process (AHP) model makes also possible to evaluate the decision if the expectations changed, due the expectations are in the weights represented. Thus is critical for the project to properly define these expectations into the weights. Consequently the velocity and certainty of the project development will be increased and the communication improved.

5.2.3 Decision / Risk Analysis System Description

In the project management the communication represent one of the most important tasks for a successful completion of any project (see section 4). Thus the proposed system permits to improve the communication process through the utilization of decision analysis methods, in this case AHP. As mentioned in section 2.10 this method has a compensatory basis and permits a hierarchical representation of the decision plus consistency verification.

The decision analysis model is represented in Figure 5-2, this illustration permits one to distinguish the functionality of the model. The criteria for the evaluation of alternatives are divided here in seven modules. These modules represent nothing else than the main criteria and they are located in the first level of the model, in the second level are the sub criteria organized in the corresponding modules. In this figure, four of the modules are organized according to the German DIN 276. The alternatives are located in the very last level, in this level where the criteria evaluation takes place. The number of levels can be increased according to the required number of sub criteria.

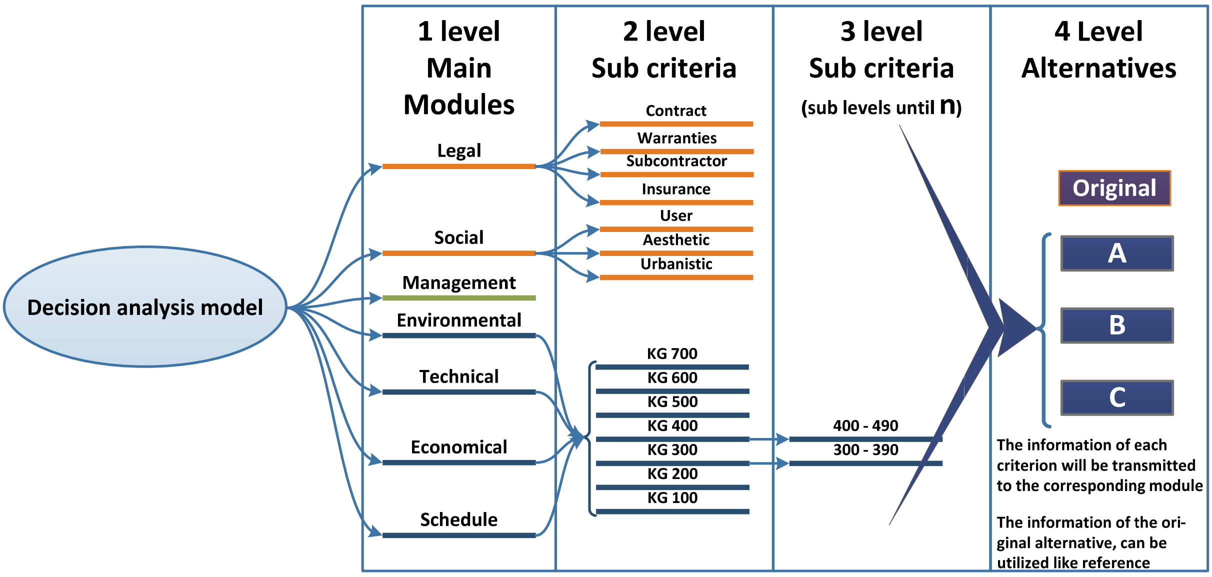


Figure 5-2: AHP decision risk analysis model (example)

The main modules are:

- ***Legal:*** all legal considerations that have an influence in the project (like contracts, legislations, etc.)
- ***Social:*** array that groups criteria aimed to evaluate the project interactions with humans (owners, users, etc.)
- ***Management:*** collection of criteria related with the organization and administration of the project and its resources
- ***Environmental:*** criteria that evaluate the interaction and impacts of the project with the environment and surroundings
- ***Technical:*** collection of criteria that evaluates the technical requirements of the project
- ***Economical:*** ensemble of criteria that appraise the costs and economical sustainability of the project
- **Schedule:** array of criteria that estimate the times and required schedules of the project.

Under these modules different sub criteria can be grouped and organized, however this is just one possible way to array the different criteria. Accordingly, the same type of criteria should be located in the corresponding module. It is recommended for any constructor, to establish their own hierarchical organisation. The here proposed main modules represent a general from to organize criteria, when there is no other available. Nevertheless the flexibility of the AHP allows to utilization of any hierarchical representation for the development of the decision model.

The decision model makes possible the utilization of a high quantity of criteria and their corresponding evaluation methods, for example the DIN 276, DGNB or LEED profiles, etc., can be used as utility function (see section 2.7) and through the representation of their relevance to each other using the weights, the expectations are reflected in the alternatives selection process.

5.2.4 Decision / Risk Analysis System Working-plan

The decision analysis model takes place for the alternative selection, however before using it, a systematically approach to the decision is required for the appropriate development of the model. Consequently the decision / risk analysis system permits to abstract the decision and as result, to represent it in the elaboration of the model.

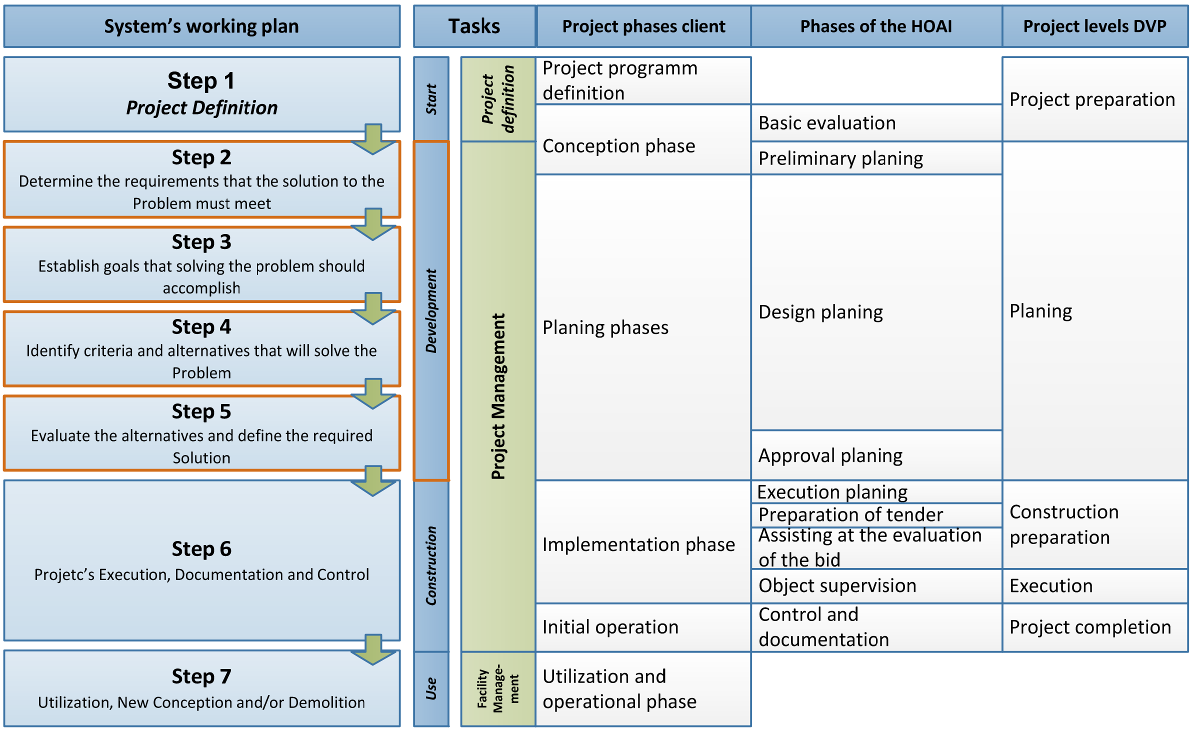


Figure 5-3: Systems working plan and their corresponding project phases

Figure 5-3 presents an introduction of the system tasks sequence and their relationship with the different project phases. The decision risk analysis system sequence corresponds to the DVP project planning stages/phases. In consequence the steps two to five represent the implementation of the system.

As the very first task, is vital to provide a correct description of the requirements that the project must achieve (step one). Subsequently the main objectives (e. g.: net cubic meters, costs and dates) and the sub goals (e. g.: energy consumption, CO_2 emissions, areas relationships, colors, technical equipment, etc.) must be defined (step two and three).

Consequently drafts are prepared and coordinated by the PM in step four. Finally, the alternatives are evaluated and compared to expectations (which were already defined in step two and three) to define their fulfillment (step five).

These five steps represent the most important tasks by the development of the system, however each of these steps comprehend several procedures and subtasks for a successful systems development.

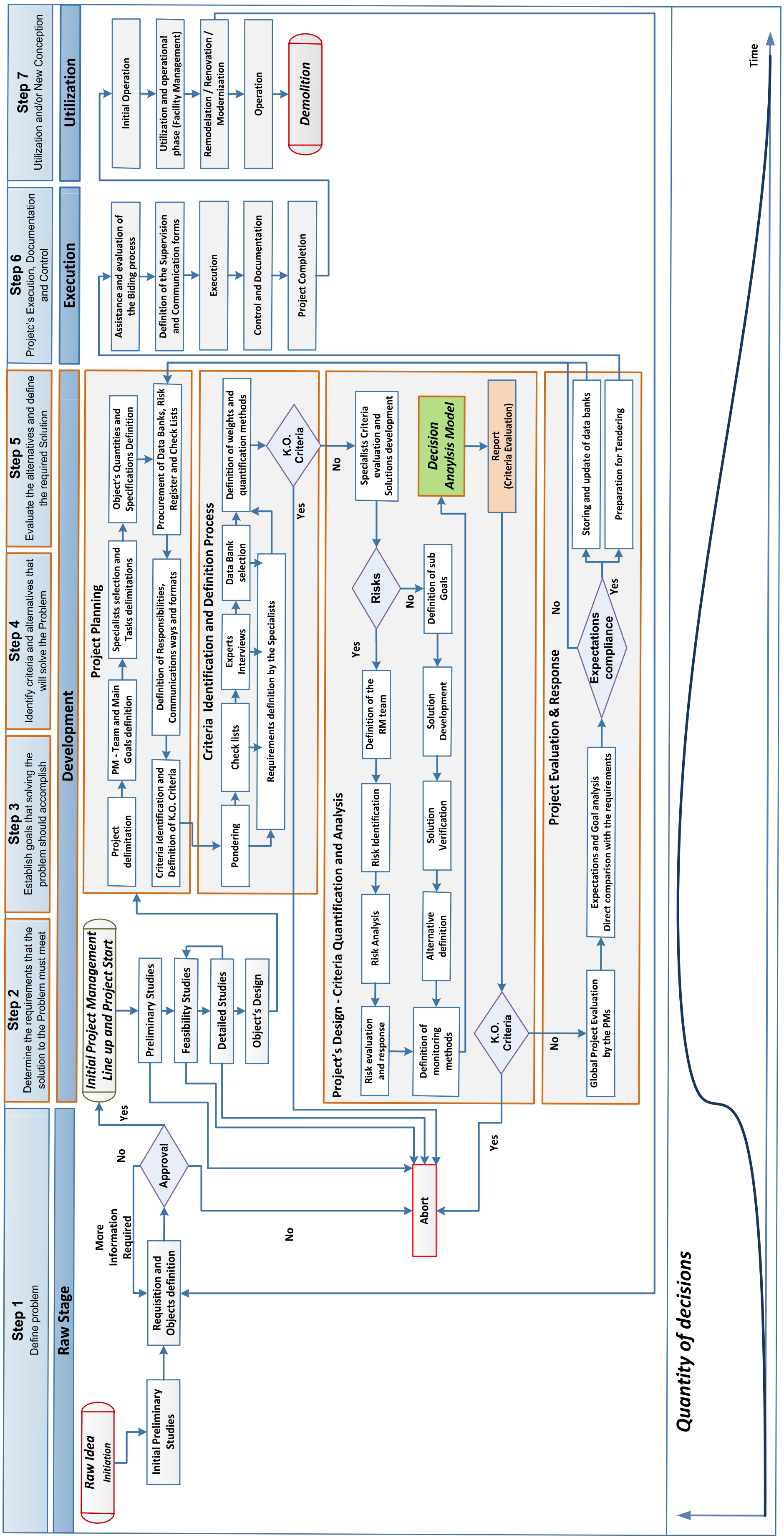


Figure 5-4: General decision risk analysis system working plan

The Figure 5-4 shows a detailed description of the system including all required measures and steps, all the system is presented within the completely life cycle (see section 4.3) from the raw idea and conception until its demolition. The main core of the system is based in four different tasks:

a) "**Project planning**":
It is conduced to define the project expectations as well as the PM team, specialists and project participants; together with their responsibilities, communication channels and formats. This task defines the initial considerations about the necessary input information and use of possible databases.

b) **“Criteria identification and definition process”**:
It focuses on the identification, procurement, design and management of input information (alternative solutions or draft proposals), as well as on their relationship between themselves (weights). Risk analysis can and should also be considered and accordingly planed.

c) **“Project’s design – criteria quantification and analysis”**:
It is responsible for developing the analytical model and the treatment of input information (risk-based and risk-independent in utility functions) concerning to their proper use in the model; risk analysis takes place in this process. Other important objective is to evaluate the results from the analysis process.

d) **“Project evaluation and response”**:
As a result of the calculation model, the selected alternative (draft) is presented. All expectations will be compared and if the expectations are fulfilled, the tender process begins. Otherwise the unfulfilled expectations will be forwarded to the respective experts for their improvement and the process is repeated.

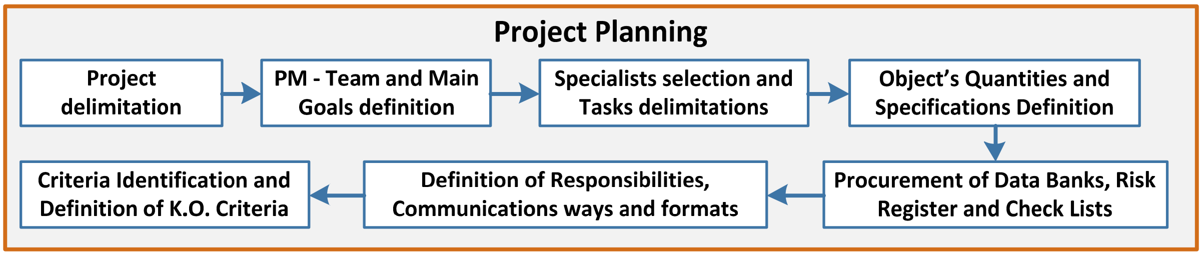


Figure 5-5: Project planning

a) **Project planning**
This process includes seven sub processes (see Figure 32), which are closely associated with the organizational tasks of the PM. For the implementation of the calculation system, it is relevant to perform these sub processes under the considerations of the decision analysis model.

1. **Project delimitation**: The most important project’s attributes and /or expectations should be in this process largely explained. Attributes such as function, cost, area, dates, architectural details, etc., are the bases for the project and should be explained to all participants. In this form the main criteria are defined and the first expectations are delineated. The function of this process is to support the definition of the project’s main objectives and to support the management through clear objectives.

2. **PM – team and main goal definition**: After the determination of the projects requirements, the PM-team will be determined. The PM-team has as first task, the definition of the main objectives with their corresponding requirements and expectations.
3. **Specialist selection and tasks delimitations**: A further task is the selection of experts. Normally the specialists are responsible for different tasks (activities) of the project; consequently their work area and responsibilities are defined. The most used structure to organize these tasks in Germany is given by the DIN 276.
4. **Object's quantities and specifications definition**: This process allows a detailed definition of sub goals for the different tasks in the project by the specialists. Consequently, there will be more accurate considerations according to their requirements and expectations reflected into their evaluation methods.
5. **Procurement of data banks, risk register and check lists**: For a quantitative treatment of the criteria, it is vital a constant development and update of the input information. This concept is not new, due to the reason that performance factors are constantly used to prepare realistic approximations and bids in the cost estimation of the construction projects.
   The decision analysis model permits the application and development of databases. The system is a cyclical process; therefore it is relevant to integrate all the gathered information earned from different projects, in databases and to constantly update and develop them under the consideration also of risk analysis.
6. **Definition of responsibilities, communications ways and formats**: This process aids to an effective functionality of the PM. The development and definition of organizational charts with the different functions between all the project participants, takes place here. This process, together with the definition of communication tools and formats represent the main tasks. The PM has the responsibility of define these instruments and to provide them to the project participants. All this is done according to the demands and peculiarities of the project.
7. **Criteria identification and definition of K.O. criteria**: this process helps to identify the required criteria for an effective project achievement. Some of the criteria may affect the project in a critical negative way; these criteria are called K.O. criteria. An essential part of this process is to identify the main attributes given by the specialists, their properties and establishing the criteria and their characteristics, specially the criteria that represent the end for the project (see Figure 4-15).

The project planning process supports the organizational tasks for a better functionality of the PM and the system. This process is the most important to secure the success of the system. Therefore all these steps should be carried out thoroughly.

b) **Criteria identification and definition process**

Once the organization, main goals, general requirements and working groups were established, the main tasks are the treatment, acquisition and development of solutions with more detailed information. For this target the process offers several possibilities for the identification and definition of criteria.

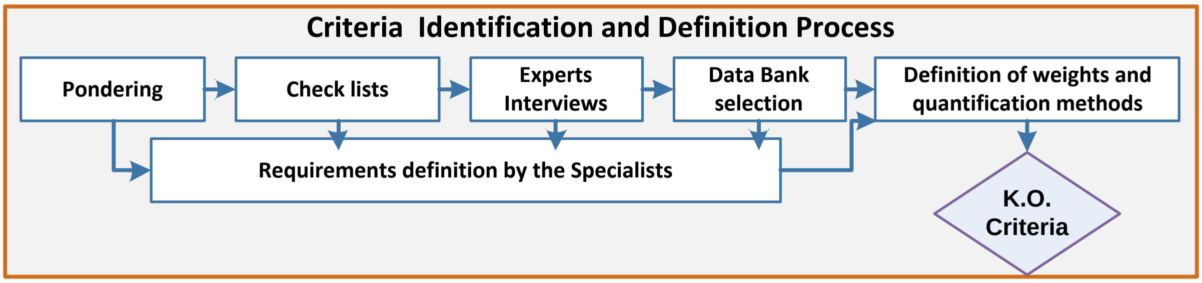


Figure 5-6: Criteria identification and definition process

There are two alternatives for defining the criteria, if the definition is developed by professional planners (typical activity) or if information or criteria must be examined to determine the ultimate goals of subtasks (new challenge or complicated activity). In the first case the alternatives are developed based in requirements and norms, relationships, etc. on the second situation is when the required criteria do not exist or is not available, but is indispensable for project development, therefore appraisals are prepared.

Typical examples of this situation are the projects that take place for the first time. In these cases estimations are considered, in this situation a similar procedure like in the risk identification can be used (see section 3.5.3 and Figure 3-10).

As a result of this process the main requirements are set and the certainty of the input information is increased by the utilization of databases and also due the mechanisms for information acquisition, which are systematically planned. Finally K.O. criteria are redefined and compared. Risk-based information and other criteria must be identified in this process.

c) **Project's design – criteria quantification and analysis**

The alternatives design is the core process of project development, for this part of the project solutions are developed, based in the identified requirements. Therefore the different objectives, targets, requirements and expectations are combined, so that the solutions fulfill these expectations. Consequently the information produced in their evaluation is introduced in the decision analysis model for the selection of the best draft; finally the results of the decision analysis are presented in a report.

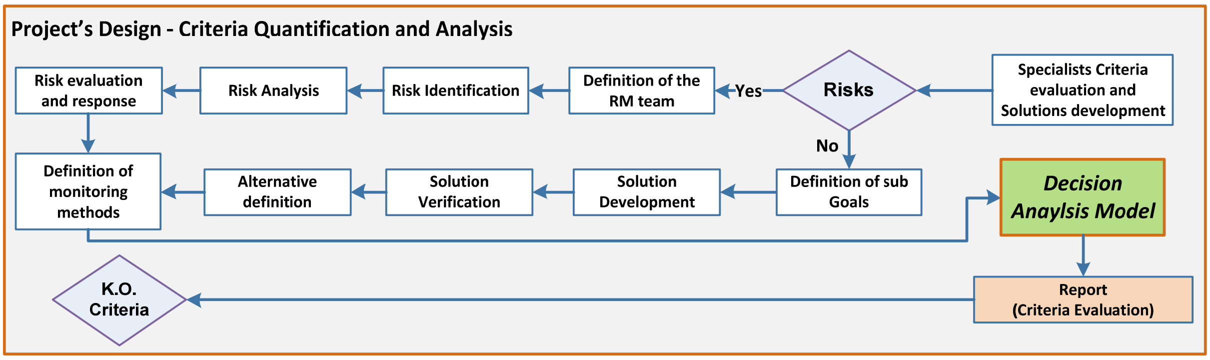


Figure 5-7: Project's design – criteria quantification and analysis

As crucial step inside this process, is the necessity of distinguish between the risk-based and risk-independent criteria (see Figure 5-7). Many of the risk-independent criteria are identified and defined in the previous process, so that the development of alternatives or sub tasks only requires to review the final results and can be directly utilized into the decision analysis model (e.g.: Net Areas, Kw/h, etc.). On the other hand, there are criteria or characteristics that are risk dependent. These criteria can be processed and assessed using risk analysis methods.

In the implementation of the current risk analysis, there are various methods available (see here section 3.7 and 3.8). Depending on the project and its conditions, different methods might be used. With the aim of integrate stochastic risk analysis to this process, a new risk analysis approach was developed. This approach is explained further in section 5.4.2.

All the gained information is loaded in the decision analysis model and in this form the selection of the best alternative is performed. The alternative with the higher rating is consequently the best alternative. These results are finally presented in a report and the K.O. criteria controlled. Finally the results can be compared and evaluated with their expectations. These results should include measures for the monitoring of the sub goals.

d) **Project evaluation and response**

As a final step the results of the decision analysis model are presented to all participants. If the expectations are still not reached, new goals or sub goals will be defined and prepared for its further processing. The PM has the responsibility of coordinate the participants and conduct the verification of weights and in this form to reflect the new expectations. The PM must also conduct the new objectives, targets and/or requirements back to the “criteria identification and definition process” and in this form; the system starts from this point, and the procedure will be repeated until the expectations are reached or the K.O. criteria leads to the abortion of the project.

In this way an iterative procedure is carried out. If expectations are reached, the process “preparation for the tendering” takes place. Accordingly the system is terminated and the information obtained will be used in the continuous improvement of the data bases.

5.3 The Decision / Risk Analysis Model

The decision risk analysis model was developed with the consideration of seven main modules, in which the main criteria can be assigned. These modules are: legal, social, management, environmental, economical, technical and schedule. These seven modules represent in a general form the typical type of criteria present in every construction project. Within these modules all main and sub criteria can be assigned and depending on the project requirements, further subdivided. The Figure 5-8 presents the decision risk analysis model.

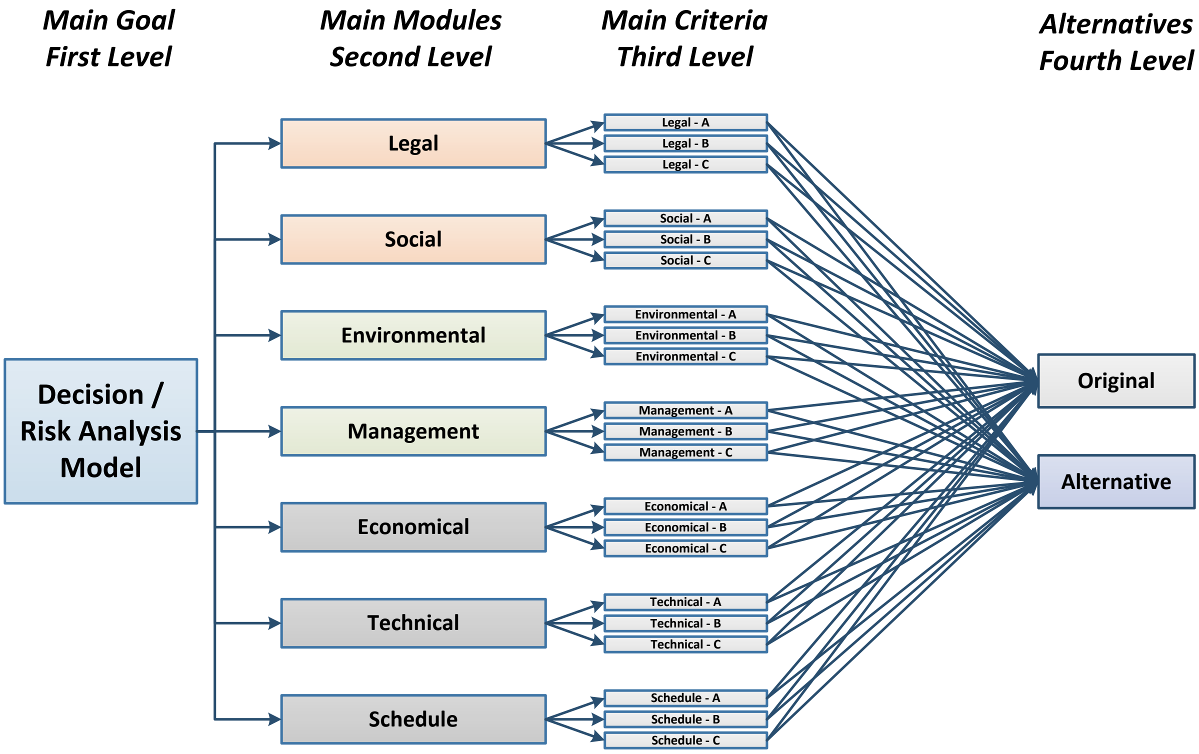


Figure 5-8: The decision risk analysis model

The model in Figure 5-8 shows two alternatives and 21 criteria (in array of three criteria per module). The description of the decision as a hierarchical representation permits easily to recognize the criteria and their relationship to each other. Risks are not shown in this figure; however they can be easily integrated into the model.

There are two different ways to integrate the risk analysis in the model, the integration dependents directly on the degree of risk awareness of the participant or of the project. In the practice there are two typical procedures from which the estimation of risk is performed in construction projects (see Figure 5-9):

- **Overall risk determination of the project**: For this procedure a single risk analysis is prepared for the determination of a single risk measure, typical for companies with low risk awareness. This is usually called risk or contingency. In this case, risk can be considered as a module.
- **Determination of the different risks of partial tasks of the project**: This procedure integrates different risk analysis for the consideration of the overall risk in the project, used in companies with high risk awareness. The individual risks are evaluated with their corresponding risk analysis method. Finally the total overall risk or risk ratio is determined, in this case risks must be considered as criteria.

The first procedure is commonly used in construction projects and is mostly based on qualitative risk analysis. Contractors, who have higher risk awareness, make use of the second procedure, which rarely occurs in construction projects. In this form risk assessment can be combined with other not risk based criteria evaluations methods, for the overall evaluation of the project alternatives.

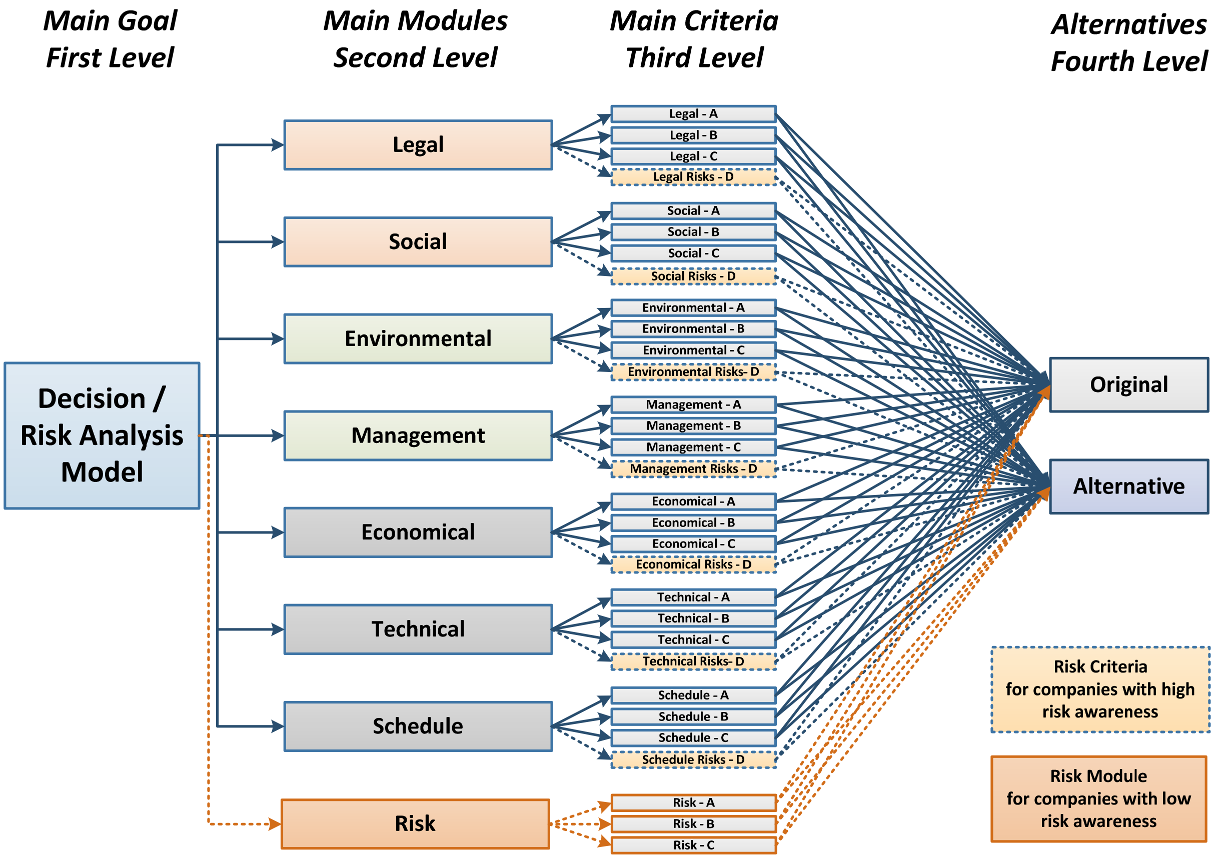


Figure 5-9: Risk analysis integration in the decision risk analysis model

5.4 Development and adaptation of the decision analysis model

The main modules given in the decision analysis model provide a possible basis for the criteria allocation. However these modules can be adapted according to the requirements of the PM and of the project itself. The presented hierarchy of Figure 5-8 and Figure 5-9 provide just a way for the assignment of criteria, and it is recommended if is there no system is available.

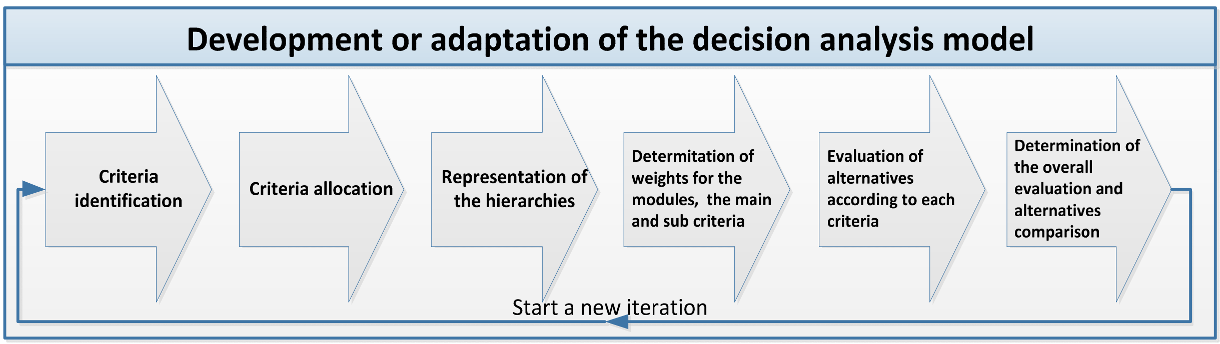


Figure 5-10: Development and adaptation of the decision analysis model

For the development or adaptation of the decision analysis model, there are six necessary steps (see Figure 5-10):

- **Criteria identification:** The criteria required for alternatives evaluation, were previously identified by the PM, experts and stakeholders and will be prepared for the model. This means that utility functions and quantitative scales will be elaborated for this objective.

- **Criteria allocation:** The criteria will be assigned to the corresponding modules. Main and sub criteria will be established in this form in the corresponding hierarchical categories.
- **Representation of Hierarchies:** The identified and assigned main and sub-criteria are finally presented in a hierarchical diagram. This chart allows the decision's review as well as the control of their weightings and evaluations.
- **Determination of weights:** The relevance of the main modules, criteria and sub criteria is defined by their weights settled and agreed by the PM, experts and participants. Important for this step, is to distinguish between weights and evaluations. Weights are required to represent the relevance of the criteria and modules to each other, while evaluations reflect partial rankings for each appraised criterion.
  The evaluation establish how appropriate each criterion is, while the weights reflect the relevance of each individual criterion to the decision (see Figure 5-11).

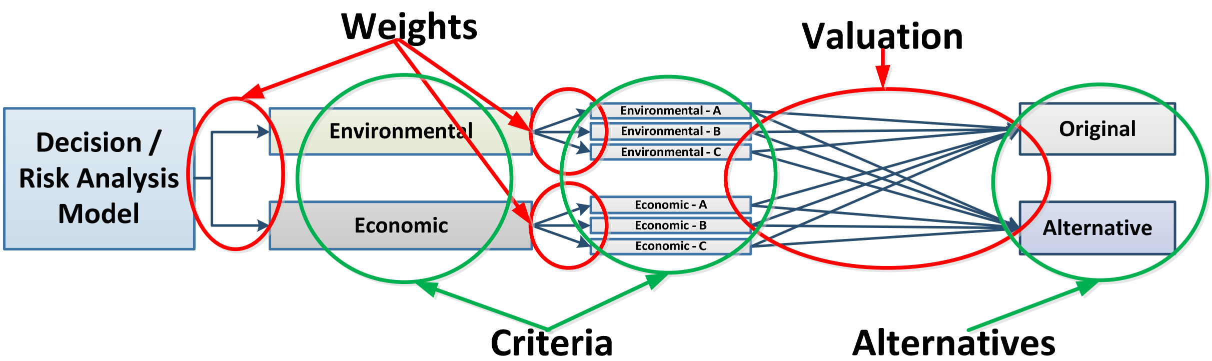


Figure 5-11: Weights and valuations

- **Alternatives evaluation:** for the further model's processing, the criteria evaluations are required. These evaluations are elaborated by the corresponding specialists and delivered to the PM. Consequently the evaluations are loaded in the decision analysis model (like inputs and utility function). Essential part in this step is the definition of the formats in which the information exchanges should be made.
- **Alternatives comparison:** With the results of the decision analysis model, each criterion will be compared with its expectation and goals and finally the alternatives compared. The model makes possible a graphical criteria representation for the decision analysis, and for the scrutiny of each criterion.

When the cycle is executed and the expectations were still not reached, the process will start again and the changes in the criteria, weightings and ratings will be updated for the new cycle. This process is performed repeatedly until the expectations will be fulfilled. Is for this reason that the project development can be understood as a decision tree (see Figure 4-13 and Figure 4-12).

5.4.1 The Analytic Hierarchical Process (AHP) decision analysis model

The application of the decision analysis model is performed in MS-Excel; the mathematical basis is the application of the AHP method developed by Saaty. This method makes possible a consistency and traceability check of the decision and criteria. AHP is a quantitative assessment procedure that permits the selection of the best alternative with the utilization of paired comparisons between alternatives based on the criteria performance[174].

One of the most typical problems of the AHP methodology is the utilization of the Saaty scale; he proposed for qualitative criteria the use of a limited scale from one to nine and their reciprocal value. This scale is often not enough for the criteria comparison[175], besides the manually comparison of each single criterion to each other, when a high amount of criteria is gathered, turns to be a complicated and demanding task. Another problem is the possibility of a rank reversal[176] when new data is introduced.

For the elimination of the scale problem, a new systematic is proposed in this system. Hence a quantitative procedure is proposed, which consists in the defining quantitative scales based in 100% total for the criteria weighting. In this way the relevance of each criterion is given as a percentage, and the sum of the weights in a module or criteria level should always result 100%.

For example when we have three different criteria, but all three of them have the same relevance, their weights in the decision analysis model will be represented as 33.33% for each of them and their sum 100 %. In this way the paired comparisons will be automatic quantitative calculated, and the AHP procedure simplified. Another advantage is that due the use of quantified weights, the decision can be easily controlled and review (see Figure 5-12).

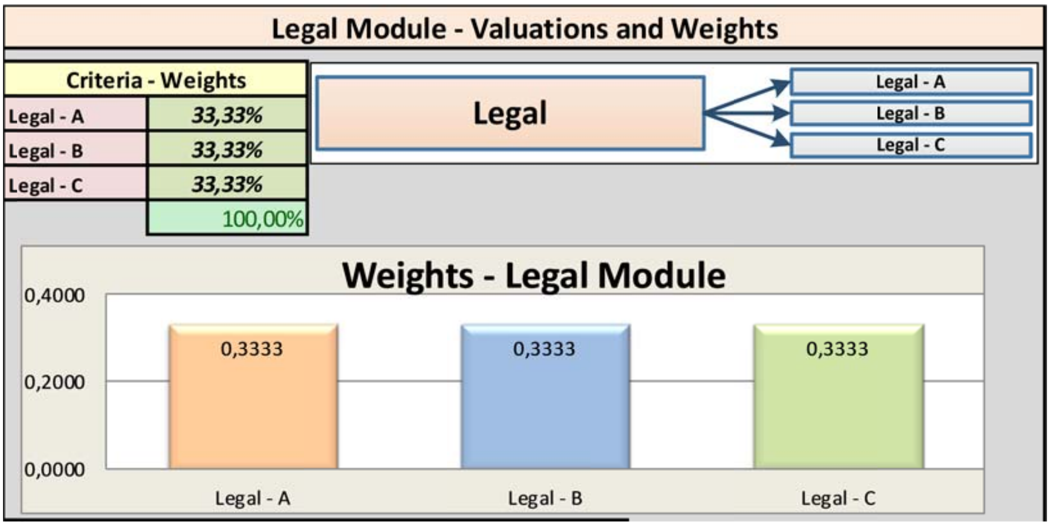


Figure 5-12: Example of the quantified criteria weights

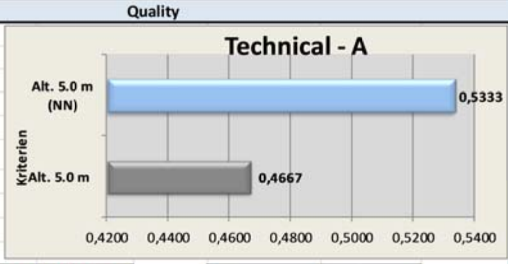
174 (Baker, 2002)
175 (Izhisaka, 2004)
176 (Belton, 1983); (Pérez, 2002)

Regarding the rank reversal, this problem can be easily solved, by the performance of the "criteria identification and definition process" (see section 5.2.4). This process enables to declare and set the most important criteria for the definition of the AHP model. The proposed systematic makes possible the collection of all required criteria and in this way to reduce the possibility of a later criteria adding to the decision analysis model. However when a new criterion is indispensable for the model, the inputs and weights should be deleted and then the model modified.

However AHP presents another complication, by the evaluation of alternatives it is essential to define in the mathematical procedure, if the criterion should be maximize or minimize for its considerations. For example; the higher quality with the minimal costs, for this cases AHP presents complications, because it just permits to utilize the same criterion in the evaluation in every array, which means that all evaluations in the array are set for minimize or maximize, the combination is not possible. To solve this problematic a modification in the weights determination was elaborated (see Appendix I: AHP Methodology).

This modification is a rank correction; the first calculated weights are recalculated by calculating first the inverse value of the weight and finally each criterion is divided by the sum of the new recalculated weights. Thus the new weights are normalized and recalculated again. The new weights reflect the desired selection, "the selection of the minimal value" (see Figure 5-13).

Quality

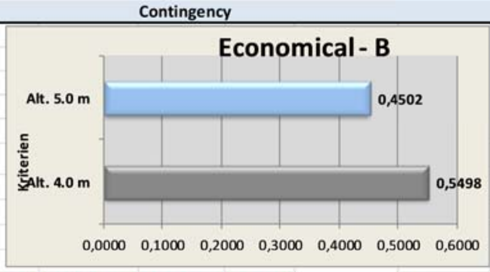


Quality		
Alternative	Alt. 5.0 m	Alt. 5.0 m (NN)
Alt. 5.0 m	1,00	0,88
Alt. 5.0 m (NN)	1,14	1,00
Sum	2,14	1,88

Alternative	Alt. 5.0 m	Alt. 5.0 m (NN)	Cumulated	Weight	(1/n)*we
Alt. 5.0 m	0,467	0,467	0,933	0,4667	1,000
Alt. 5.0 m (NN)	0,533	0,533	1,067	0,5333	1,000
Sum	1,000	1,000	2,000	1,0000	2,000

Alternative	Performance
Alt. 5.0 m	7
Alt. 5.0 m (NN)	8

Contingency



Contingency		
Alternative	Alt. 4.0 m	Alt. 5.0 m
Alt. 4.0 m	1,00	0,82
Alt. 5.0 m	1,22	1,00
Sum	2,22	1,82

Alternative	Alt. 4.0 m	Alt. 5.0 m	Cumulated	Weight	(1/n)*we	Correction	Weights
Alt. 4.0 m	0,450	0,450	0,900	0,4502	1,000	2,221	0,5498
Alt. 5.0 m	0,550	0,550	1,100	0,5498	1,000	1,819	0,4502
Sum	1,000	1,000	2,000	1,0000	2,000	4,040	1,000

Alternative	Performance
Alt. 4.0 m	5.302,84 €
Alt. 5.0 m	6.474,97 €

Figure 5-13: Rank correction for different criteria sub objectives

5.4.2 Risk analysis Artificial Neuronal Networks (ANNs) + Monte Carlo Simulation (MCS)

For the processing of risk criteria, a new methodology was conceived which permits to reduce the input's data dispersion for risk analysis. One of the most accepted stochastic risk analysis methods is the MCS, this method permits to simulate possible scenarios for a determine problem (see section 3.8.9). However the liability of the results depends completely of the quality of the collected inputs.

The ANNs is another methodology that permits to propose possible predictions based in a learning process, from previous elaborated data banks (see section 3.8.12). Nevertheless the ANNs methodology does not permit to elaborate simulations of possible scenarios. The combination of these two methodologies permits the simulation and determinations of possible scenarios, from more suitable inputs previously treated with ANNs. As end result the MCS is more accurate, due the dispersion reduction given by the learning process of the ANNs.

Nowadays there are several computer programs that permit to perform risks analysis in simple MS-Excel tables and in the recent time, new developments in the computer science make also possible the use of ANNs in similar programs based in MS-Excel. Thus the utilization of ANNs combined with MCS is possible, for any risk analysis.

The most challenging field by using this procedure (ANNs + MCS) is given only by the development of the required data banks. This procedure permits to emulate the systematic of SVM (see section 3.8.13), which is a methodology with high potentiality within the risk analysis methods, but still not available as commercial software.

The certainty of risk analysis improves trough to utilization of ANNs and their data banks and as result the dispersion is reduced. Therefore the adequate development of the data bases under the requirements of the PM, is extremely relevant.

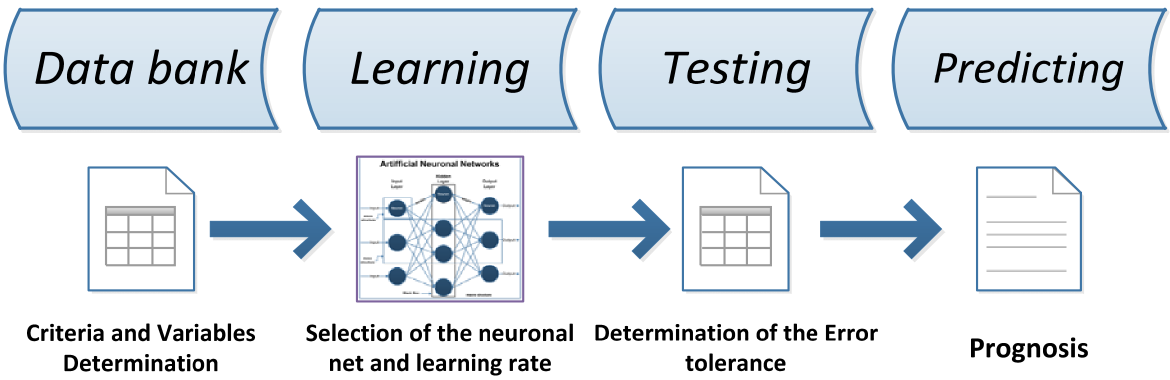


Figure 5-14: ANNs working plan (Sandoval-Wong, 2011)

The application of ANNs includes four essential steps (see Figure 5-14):

1. **Data banks development**: a large collection of values and factors that in the result impact are here gathered for its processing, and in ANNs in MS-Excel tables listed.

2. **Learning process**: the ANNs learn from previously prepared data banks, the learning rate and net configuration are for this task selected. Ultimately this turns into a trained neural network.
3. **Testing process**: the trained neural network is verified and evaluate, to control how precise the trained neural net the real results reproduce. For this reason make use of the data contained in the data bank for the control.
4. **Prediction**: when in test phase no large deviations between the calculated prediction and the real results are found, the trained neuronal network makes a predicting for the required criterion.

The methodology has as "*main advantage of ANNs is that the whole process (training and testing) mimics the human's brain reasoning. In other words, it learns by the experience: Once a good database is developed the chances to obtain reliable predictions with ANNs are very feasible*"[177]. When a prediction is required the estimator makes an analysis of the available data and his own experience, and in this form delivers his estimation.

The next step for this procedure is MCS, with the prognosis delivered from the trained ANNs. The MCS is performed with a low dispersion aimed to determine the corresponding probabilities and correlations between all the criteria (see Figure 5-15).

A drawback for the application of ANNs is the need for databases. According to investigations only with lots from 500 data, reliable predictions can be performed. Another disadvantage is the trained artificial neural network cannot be verified[178]; on the other hand the results delivered by the ANNs are reliable and furthermore, its application has proven to be useful and promises great potential for risk analysis.

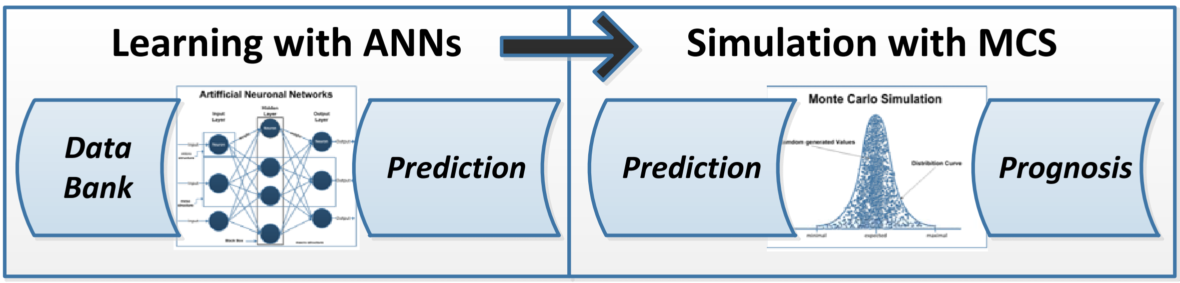


Figure 5-15: ANNs + MCS (Sandoval-Wong, 2011)

The use of ANNs allows a safer and more reliable risk analysis. A major advantage of this approach is that uncertainty influences are in the prediction integrated. The ANNs require no formula for the predictions, due the artificial neuronal network learns from the data, how to emulate the results. Therefore the uncertainty effects that influence the results are learned by the ANNs and taken into account in the forecast.

177 (Sandoval-Wong, 2011)

178 It presents a black box effect, which means that there is no chance to verify the trained neuronal network. "*The model obtained with neural network is not understandable in terms of physical parameters*" (Johannet, 2007)

Thus more accurate results in the reality can be achieved. *"Another relevant issue of this new methodology is the interface while transporting the ANNs results into inputs for the MCS simulation. Nowadays, it is possible to use both, ANNs and MCS with user friendly software. This fact is a plus for any risk manager because it provides confidence while basing the analysis in a very well-known system"*[179]. Besides ANNs allows the simultaneous use of text and numbers as input, for the elaboration of required predictions.

For this dissertation the development of the decision analysis model, the software "Neuronal tools" of Palisade was employed. This tool works on the basis of MS-Excel, which allows its use in the practice. The accuracy of the results of the ANNs was high (see section 6.2.3). The variation of the predictions (prediction) with the expected values (targets) was normally not higher than 2.0%. However this methodology is not recommended, when there is not data available for the prediction. In this case methodologies like Delphi offer an opportunity for the development of stochastic risk analysis, but with higher dispersion rates.

5.5 The AHP Decision Analysis Model

The decision analysis model is shown in Figure 5-16. This figure presents the total value, the weighting of the main criteria (four modules) and sub criteria, the evaluation of the criteria and the presentation of the criteria hierarchy, in the general overview.

The MS-Excel model is divided into several sheets that contain each of the seven modules, together with a general overview, plus a sheet for information input and a sheet for calculating the weights of the main criteria (modules).

In the overall view all results and evaluations will be summarized and presented. All information of the alternatives, criteria, weightings and the entire alternative evaluations are considered here in a graphic form.

Figure 5-16 presents the modules and general alternatives evaluation, in this case the alternatives have the same valuations, and thus both are valuated with 0.50. The graphical representation permits to verify the decision, weights and inputs data. In the green cells the PM can type the weights and evaluations; in this case all criteria have the same relevance and evaluation.

With the finality of testing the reliability and applicability of the decision analysis model and consequently of the decision risk analysis system, different tests were performed. Therefore information was collected from the practice and processed with the decision model and system. These tests and their results are presented in the following chapter 6.

[179] (Sandoval-Wong, 2011)

Figure 5-16: MS Excel AHP decision analysis Model (general overview)

5.6 Conclusions

The current chapter presented the decision risk analysis system and the decision analysis model. The system permits the project managers to introduce a systematic evaluation of alternatives (different project drafts) and to conduct the project through its evaluation process during the project development.

Before the utilization of the decision analysis model, the system permits to identify and collect the most important criteria for the alternative comparison, together with their corresponding assessment system. Finally they have to be integrated in the model with the corresponding weights. The weights should always be determined before elaborating the also required criteria evaluations; nevertheless they can be modified to verify different expectations.

Risk analysis is just one type of criteria in the evaluation process; however for increasing the certainty in the project development, a new method is here presented the “ANNs + MCS”.

One of the weaknesses of every risk analysis procedure is the quality and liability of the input data for each criterion. Therefore the collection of these inputs is the most relevant task for increasing the liability of any risk management process. ANNs and MCS are normally used as separate methods. This work makes use of both methods, ANNs to obtain the initial inputs and MCS for the simulation of risk scenarios (see section 6.2.3).

This method increases the certainty and reduces the dispersion in the risk analysis process; nevertheless data banks are required for its utilization. The use of commercial software for these methods (ANNs & MCS) permits its applicability in practice, and its applicability in the MS-Excel decision model. The opportunities for the proposed system will be evaluated in the following chapter.

6 The risk based decision making system implementation

6.1 Introduction

This chapter presents the results of the testing phase of the proposed system. Therefore different tests were performed to test the reliability and applicability of system. With this objective information was collected from the practice and processed with the decision risk analysis system.

For the system's verification it was important to evaluate the information focused in the quality of the collected documentation, during the project development, together with criteria evaluation methods and the utilization of risk analysis. However the most important task is to evaluate the systems used while decision is made in the practice.

Consequently two validation tests were carried out. The first test makes use of the decision analysis process utilized in a state agency in the USA. For this test their decision analysis process was abstracted and represented in an analytic hierarchical process (AHP) model aimed to verify and pursue their selection process in the project development. The second test is based in the same procedure with the application of the system developed in this dissertation.

A third test is included in section 6.2.3, this test permits to appreciate the opportunities and possibilities offered by the decision analysis model. All the tests included in this section are collected and saved in digital form in the annexed CD.

6.2 Evaluation case "DAR-Project"

The project utilized for the tests is a highway project located between the communities of Mira Mesa and Scripps Ranch in San Diego, California. The project is a "direct access ramp" (DAR), with estimated costs about $ 58 million dollars. The project will be completed in December 2011 for the tender procedure (see Appendix B).

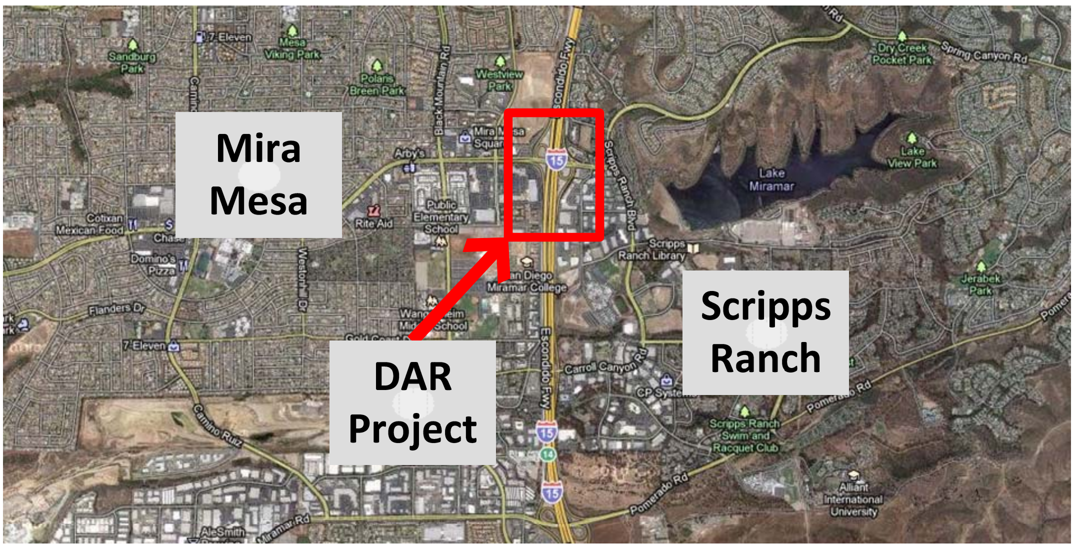


Figure 6-1: D-11 I-15 Mira mesa/Scripps ranch direct access ramp (Google maps)

For the evaluation of the system, it is important to analyse the possibilities offered by the system, this means to check and valuate the decisions taken by the PM along with the project development. Thus the documentation and assessment process was evaluated with the developed system and the selected alternatives verified.

During the project development of the DAR project, were three different stages or situations verified (situations 1 to 3) and one last stage evaluated considering risk analysis (situation 4, see Figure 6-2). The project is conducted by the California Department of Transportation (Caltrans), in cooperation with the Federal Highway Administration (FHWA) in USA. Accordingly, to verify the applicability of the system in the practice, the first test was conducted making use of the decision analysis procedure carry out by Caltrans.

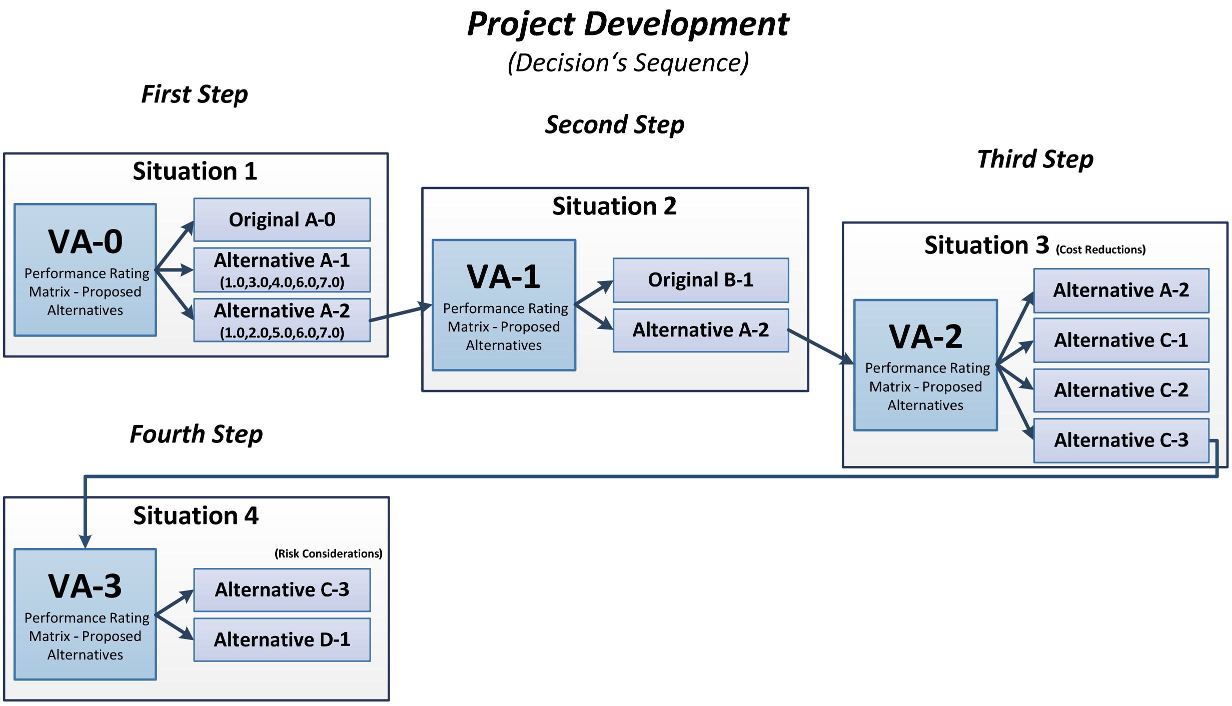


Figure 6-2: DAR project development

Figure 6-2 presents the alternative's development in the DAR project; from the figure it is easy to appreciate the four different situations. In the *situation 1* there were three alternatives available, from which the alternatives A-1 and A-2 represent variations of the original concept A-0, in the *situation 2* there are two alternatives and four in the *situation 3*. The last situation presents just two alternatives, the selected alternative from the *situation 3* and its corresponding risk analysis D-1. Caltrans performs a process called "Value Analysis Methodology" (VA) for the alternative's development, evaluation and finally selection; this method is utilized as a standard procedure and supports the quantification and project documentation[180].

[180] In the Appendix C the "Caltrans Value Analysis Activity Chart" is presented, this chart represents the working plan of the decision analysis by Caltrans.

This methodology was applied for the alternative's selection in the two first situations; the third situation was purely based in the costs due a cost reduction. Finally the fourth situation was analysed under the considerations of a stochastic risk evaluation (via MCS). Risk analysis was performed at this moment for the first time; therefore it was required the utilization of appropriate systems for the definition of its metrics (see 6.2.3).

The VA methodology makes use of a "Performance Rating Matrix" for the alternative's evaluation in the *situation 1* and *situation 2* (see Figure 6-2). In this matrix the alternative's performances are represented in a quantitative form and permit also the use of weights for the inclusion of projects expectations in the evaluation. This matrix is complemented with an "Overall Performance Rating", from which the decision is made (see Figure 6-3).

Value Matrix

Proposed Alternatives (Preliminary)

Attribute	Attribute Weight	Concept	Performance Rating										Total Performance
			1	2	3	4	5	6	7	8	9	10	
Mainline Operations	21	Baseline Concept					5						105
		VA Strategy 1					5						105
Local Operations	29	Baseline Concept					5						145
		VA Strategy 1					5						145
Maintainability	14	Baseline Concept					5						70
		VA Strategy 1					5						70
Environmental Impacts	21	Baseline Concept					5						105
		VA Strategy 1				4							84
Construction Impacts	5	Baseline Concept					5						25
		VA Strategy 1						6					30
Project Schedule	10	Baseline Concept					5						50
		VA Strategy 1							7				70

Note: Figures have been rounded.

OVERALL PERFORMANCE	Total Performance	% Performance Improvement	Total Cost ($M)	Value Index (Performance/ Cost)	% Value Improvement
Baseline Concept	500		58.0	8.62	
VA Strategy 1	504	1%	55.2	9.13	6%

Figure 6-3: Performance rating matrix and overall performance rating, alternative A-1 (Strategies, Value Management, 05. Feb.2010)

In the performance rating matrix and overall performance rating are the most important criteria presented and evaluated in order to facilitate the selection of an alternative in a determined moment. For making the decision, just the results of the overall performance are considered. The criteria located in the performance rating matrix are just sub criteria for the calculation of the total performance.

This decision analysis methodology showed the following pros and contras:

- This methodology provides a systematic approach to the evaluation of alternatives (designs) in project development.
- This methodology creates possibilities for quantifying the criteria for their evaluation.

- This methodology identifies and defines goals as well as sub goals besides their expectations.
- The performance rating matrix doesn't provide a direct overall evaluation of alternatives
- Many criteria are not directly used for comparison and just a fraction of them are used for the evaluations.
- Criteria such as % Performance and % Value Improvement are just a repetition of other criteria.
- The methodology allows only a partial direct comparison of alternatives.
- Utilization of criteria weights in the analysis of overall performance is not possible.
- The concertation of the performance ratings is a demanding and large process product of long meetings.

In conclusion this methodology permits a quantitative approach to the alternatives evaluation, however is limited for just a small amount of criteria for its evaluation, in addition to this risk analysis is not considered in these evaluations. The use of AHP and defined formats for the criteria evaluation should permits a detailed decision analysis.

Three different tests were conducted aimed to evaluate the possibilities offered by the system proposed in this work. Test 1 was conducted using the criteria and structure used for the state agency in the USA, thus the collected information and evaluation process and stages were reproduced with the AHP procedure.Consequently three different stages were tested, to evaluate how adequate represent the decision analysis method, in this case AHP, the evaluations and decision systems from practice, in this case the location of criteria and evaluations procedures of a real example were in detail evaluated in Test 1.

As second step, the proposed hierarchy in section 5 (see Figure 5-9) was tested in order to evaluate how adequate is this hierarchy for the practice and to evaluate the possibilities of the model making use of the criteria and evaluation methodologies. In this tests more documented criteria, that was not utilized in the VA evaluation was considered and included in the test. Accordingly Test 2 was conducted with more criteria identified in the projects records and included in the hierarchy and evaluation process, which permitted a more detailed decision analysis.

The Test 3 is conducted to demonstrate the possibilities offered making a systematical use of risk analysis, for this goal an empirical example was created aimed to display the opportunities opened by the model. This example was necessary due the lack of information regarding risk analysis as well as many other criteria that was no more available for the example used in tests 1 and 2. After the conclusion of the two first tests was clear that the most of the information was not collected in the documentation of the project and even the decision analysis process was not reflected in the documents.

6.2.1 Test 1 - Systems Validity Check DAR-Project VA-AHP application

The abstraction and verification of the decisions made by the PMs in the *situations 1* to *3* was considered as the first test for the validation of the system. The *situation 4* represented an evaluation, which at the moment of the test was been conducted, accordingly its applicability for supporting the PM was evaluated.

For this test, the steps of the working plan presented in the section 5.2.4 were followed. Accordingly the documentation was evaluated and the results of the first process "project planning" are here presented (see also Appendix B):

1. **Project Definition**: Direct access ramp, costs $ 58,000,000.00 and ready to list in December 2011, projects implementation 2012.
2. **PM – team and main goal definition**: Different teams in Caltrans were prepared for the project development. The VA is of high relevance for the development of alternatives and criteria selection, which is determined by the preliminary investigations. Thus the criteria identified in the VA are considered as the main criteria and valuated through an attributes performance ranking; these criteria are called "performance attributes", in this case:
   - Mainline Operations
   - Local Operations
   - Maintainability
   - Environmental Impacts
   - Construction Impacts
   - Project Schedule
   - Total Performance
   - %Performance improvement
   - Total Cost
   - Value Index
   - %Value Improvement
3. **Specialist selection and tasks delimitations**: For the processing and development of solutions experts were selected who have accompanied the project development and the alternatives (drafts) defined.
4. **Object's quantities and specifications definition**: Different alternatives were developed and quantified by the correspondent participant, aimed for meeting the expectations (see Figure 6-2).
5. **Procurement of data banks, risk register and check lists**: This step is not integrated in the process followed by the PMs; therefore it was not possible to trace this information in the project's documents.
6. **Definition of responsibilities, communications ways and formats**: For this procedure the performance rating matrix represents the basis; thus the evaluation of the sub criteria is collected by the PM and the overall performance is calculated and evaluated in determined meetings.
7. **Criteria identification and definition of K.O. criteria**: For this step the critical criteria was identified in the steps one and two. Therefore the costs and schedules of the step one represent the K.O. criteria.

After the project definition on the project planning, the project's "criteria identification and definition process" and the "project's design – criteria quantification and analysis process" take place. However at the time as the current tests took place, the decision were already made, therefore it was important for this test the verification and tracking of the *situations 1, 2* and *3*. Consequently these two processes were performed as one, due the limited information available. Then a decision analysis model (based in AHP) was determined using the criteria and valuation methods used by the PMs.

The criteria considered is presented in the overall performance table in the Figure 6-4, all the weights have the same relevance.

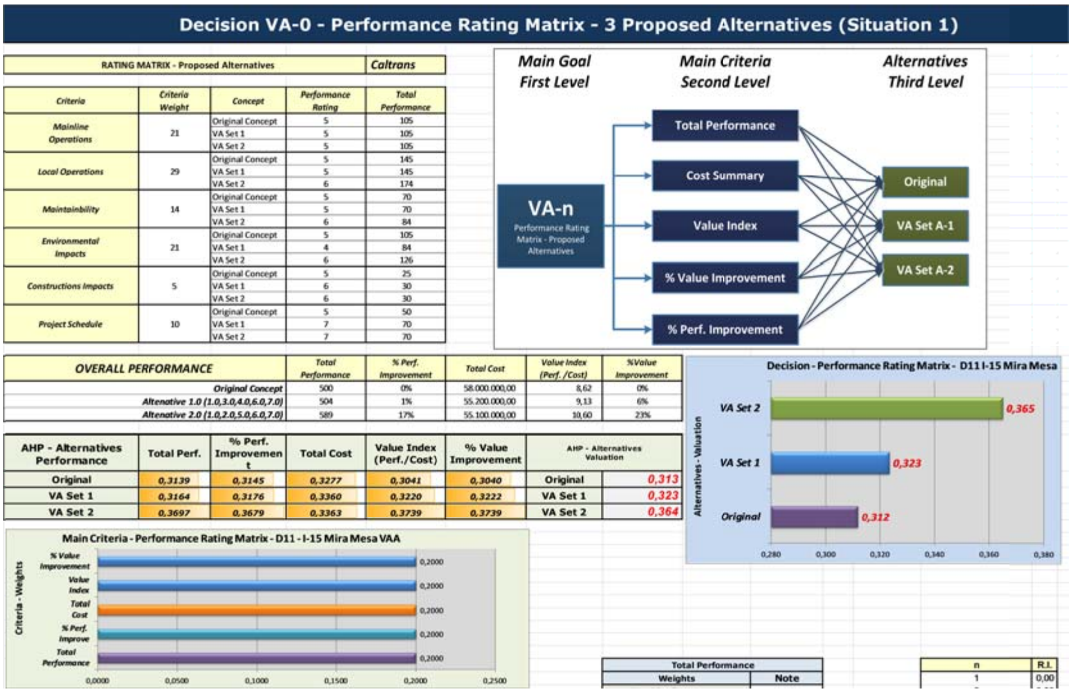


Figure 6-4: AHP decision analysis model *situation 1*

For the *situation 1*, the best alternative is the alternative VA Set A-2 (see Figure 6-4), this results corroborate the decision made by the PMs. Nevertheless is important to remark that three of the five criteria used, are just relationships between the total performance and total cost, thus the criteria to consider should be only the total performance and total cost.

As consequence of the *situation 1*, the alternative A-1 was discarded and the original improved (this will be clarified in the following test 2). However the expectations were still not achieved at this point and the project required more processing for the fulfillment of the expectations. Therefore a new iteration started from the criteria identification and definition process and from the project's design – criteria quantification and analysis, for a further alternative evolution (see Figure 5-4).

For the *situation 2* a detailed analysis between the original alternative A-0 with some modifications (renamed as B-1) and the alternative A-2 was prepared. Thus a new AHP decision analysis model was elaborated.

Figure 6-5 presents the overview of the alternative selection in the *situation 2*. There it is easy to appreciate that the alternative A-2 represented again the best alternative. For the alternative evaluation a performance rating matrix for each of the five measures proposed was elaborated (each in extra a sheet). Finally the decision was made with the overall performance of each measure as criteria, all of them with the same relevance.

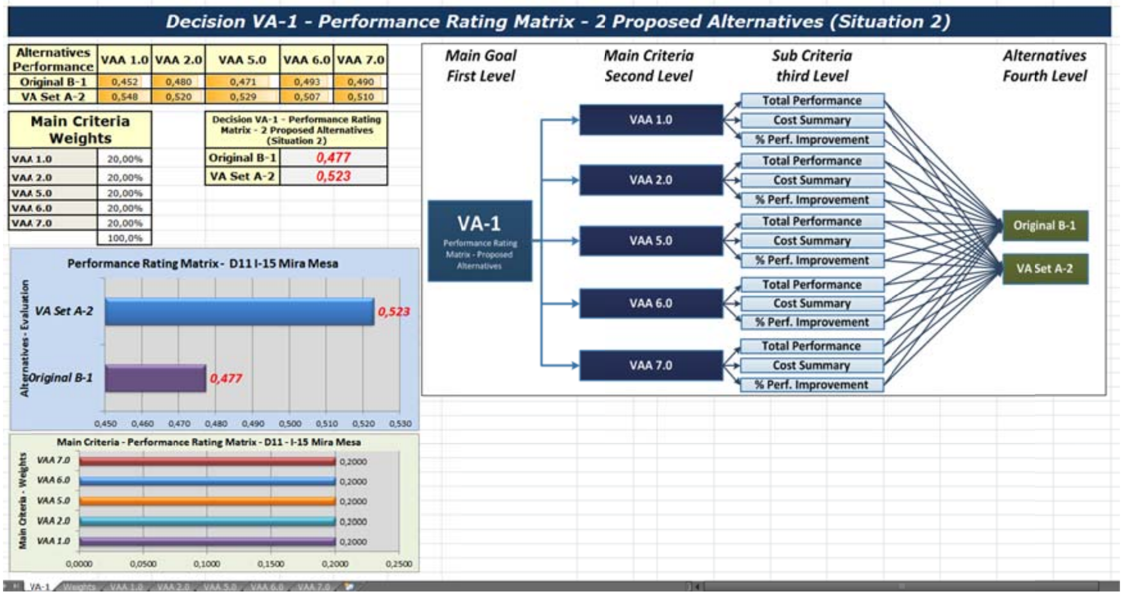


Figure 6-5: AHP decision analysis model *situation 2*

For the *situation 3* in Figure 6-6 the performance rating matrix, was employed for the analysis. Here is important to remark that even when the PM didn't perform any performance attributes evaluation, the decision was based on costs, and all other criteria had the same performance rating because no changes were performed. However for this test the VA format was utilized and the relevance between all criteria was considered equal. As result the alternative C-3 was selected, because it represented the most cost effective one.

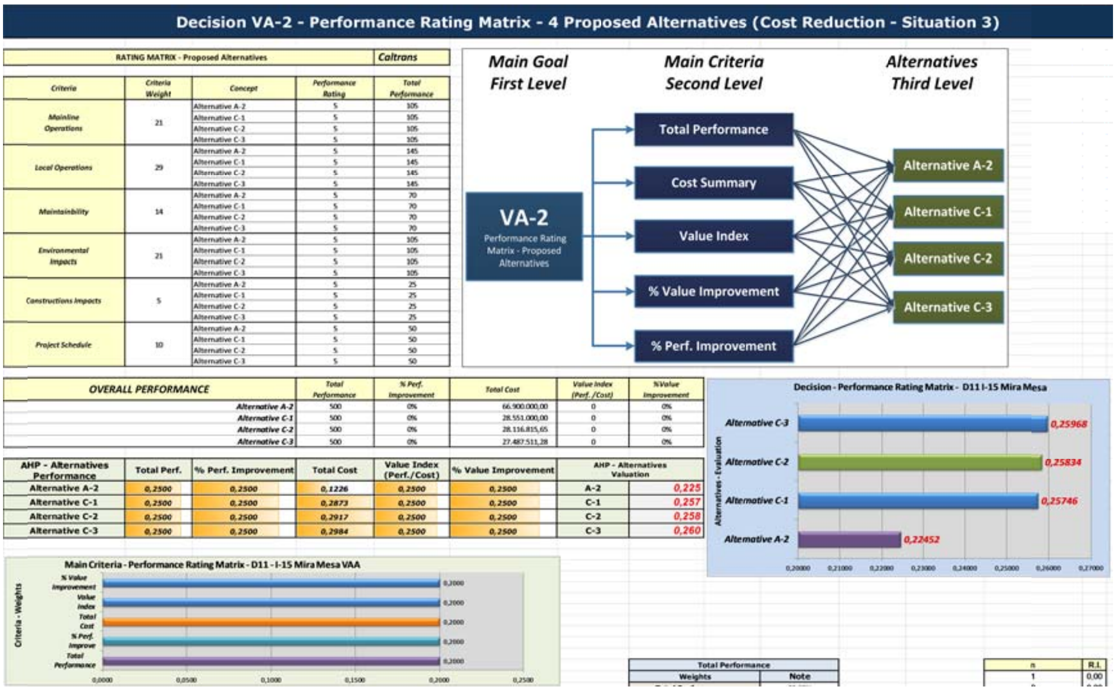


Figure 6-6: decision analysis model situation 3

As last test the *situation 4* presented the opportunity of supporting the decision making use of risk analysis, thus the risk manager prepared a stochastic risk analysis, aimed to provide certainty to the selected alternative and define the corresponding risk costs. Accordingly a risk management procedure was developed from which a risk analysis was elaborated (see Appendix D). In this situation were two alternatives analysed, the alternative C-3 selected in the *situation 3* and a new alternative with considerations of risk analysis (alternative D-1).

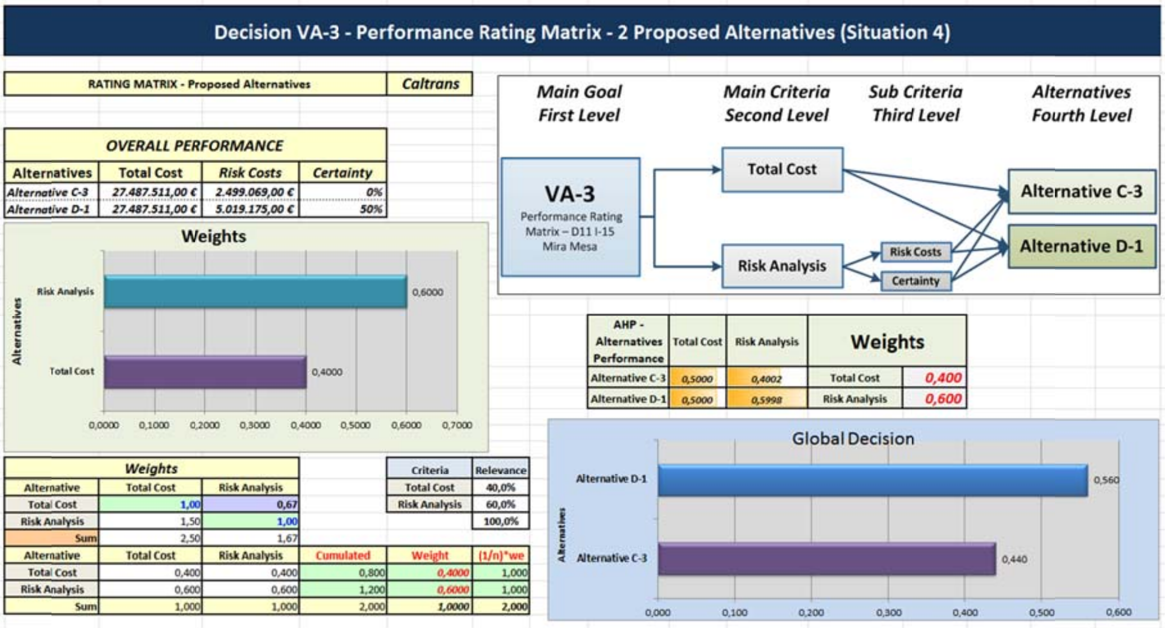
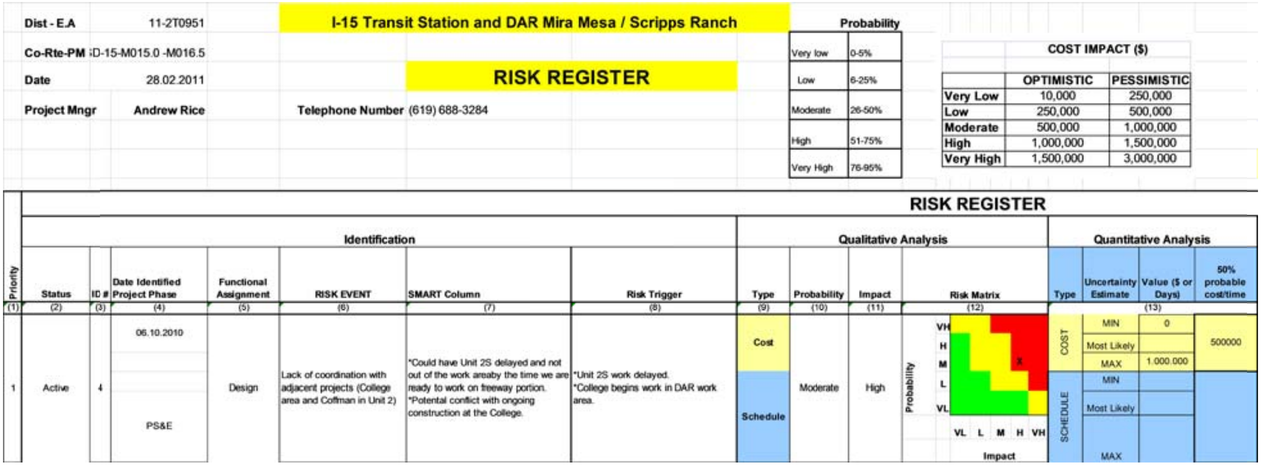


Figure 6-7: Decision analysis model *situation 4* with risk analysis

For this situation it was possible to define weights directly from the risk manager, due that at that moment, the decision was being performed. For the main criteria the relevance of risk analysis was set in 60% and the total cost with 40%. In the second level, the relevance of risk cost is represented with 20% and 80% for the certainty.

For this *situation 4* the criteria “Certainty” was introduced as an instrument to reflect the level of liability. This means that possible dangers and opportunities were considered and analyzed in a risk report (see Appendix D). For the measure of the certainty, the confidence interval utilized in the risk analysis was employed, in this case 50%; consequently 0% certainty represents no risk analysis.

From the results showed in the Figure 6-7 it is easy to appreciate that the project costs were calculated as $ 27,487,511.00, accordingly the risk costs for the alternative C-3 are $ 2,499,069.00 and for the alternative D-1 $5,019,175.00. However even when the alternative D-1 has higher risk costs (twice so expensive than C-3), it was recommended to select it, due its certainty (50% to 0%). This means that the alternative C-3 with less risk cost does not provide any guarantee of not to exceeding the projected costs ($ 29,986,580.00), while the risk analysis in the alternative D-1 assures with 50% of probabilities, that the price will not exceed the total amount of $ 32,506,686.00. As conclusion, the alternative with the highest certainty represents the best choice.



Dist - E.A	11-2T0951	I-15 Transit Station and DAR Mira Mesa / Scripps Ranch
Co-Rte-PM	;D-15-M015.0 -M016.5	
Date	28.02.2011	RISK REGISTER
Project Mngr	Andrew Rice	Telephone Number (619) 688-3284

Probability	
Very low	0-5%
Low	6-25%
Moderate	26-50%
High	51-75%
Very High	76-95%

COST IMPACT ($)	OPTIMISTIC	PESSIMISTIC
Very Low	10,000	250,000
Low	250,000	500,000
Moderate	500,000	1,000,000
High	1,000,000	1,500,000
Very High	1,500,000	3,000,000

RISK REGISTER

Priority (1)	Status (2)	ID # (3)	Date Identified / Project Phase (4)	Functional Assignment (5)	RISK EVENT (6)	SMART Column (7)	Risk Trigger (8)
1	Active	4	06.10.2010 / PS&E	Design	Lack of coordination with adjacent projects (College area and Coffman in Unit 2)	*Could have Unit 2S delayed and not out of the work areaby the time we are ready to work on freeway portion. *Potental conflict with ongoing construction at the College.	*Unit 2S work delayed. *College begins work in DAR work area.

Type (9)	Probability (10)	Impact (11)	Risk Matrix (12)
Cost / Schedule	Moderate	High	Probability: VH, H, M, L, VL; Impact: VL, L, M, H, VH; X

Type	Uncertainty Estimate	Value ($ or Days) (13)	50% probable cost/time
COST	MIN	0	500000
	Most Likely		
	MAX	1.000.000	
SCHEDULE	MIN		
	Most Likely		
	MAX		

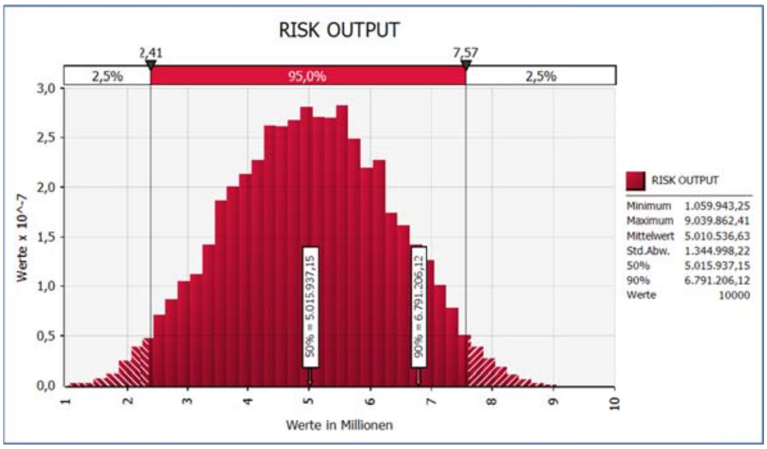


Figure 6-8: Risk register (Maria-Sanchez, 2011) and risk analysis DAR-project

Test's conclusions

The utilization of the decision analysis model using AHP has proven to be useful and adequate for the practice, through its use it was possible to review the decision made by the PMs besides to verify which criteria was employed for alternative's selection and their relevance in each situation. Hereafter a list of advantages and disadvantages is presented:

- The model allows a total evaluation of the alternatives in direct comparison in a single procedure.
- The relevance of the main criteria (overall performance) can be modified using the weighting.
- Weights must be first determined, but can be easily changed as required.
- The alternative evaluation and the decision analysis structure allow a simple re-view of the decision.
- The decision (evaluation) can be easily checked via its graphical representation in the decision's hierarchy and utility functions.
- The inclusion of utility functions permits to increase quantification, certainty and transparency to the decision analysis process
- The decision analysis model requires AHP skills for its implementation.
- The VA-methodology can be easily introduced to the AHP-model.

The procedure applied by the PMs represented no complication for the elaboration of the AHP model; this means the application of the formats and decision analysis methods (VA-methodology), the model permitted to verify the decisions and to check the evaluations made by the PM. It is important to point out, that the decision analysis model enables to include a higher number of criteria, which was not included in the original VA-analysis. The application of the AHP decision analysis model not only permitted to reproduce and verify the decisions made by the PM, but also to integrate risk analysis as criteria in the decision analysis process. The inclusion of more criteria is possible when these are required.

The proposed scale in the determination of weights (with base in 100%), simplified the problematic of performing manually the criteria comparison. It permitted also a faster model's operation and easier weights verification (faster determination of the pair-wise comparison). Therefore the utilization of the system and finally of the model permitted a more objective, extended, flexible and quantified decision analysis besides transparency with a determined systematic.

6.2.2 Test 2 - Application of the proposed decision analysis model to the DAR-Project

The first test permitted to affirm that the decision risk analysis system permits to conduct the project through the project development, making use of decision analysis systems from the practice, though its flexibility was also possible to verify the evolution of the project. On the other hand, the analysis of the documentation permitted to appreciate, that many information was considered in the project development but not utilized in the alternatives evaluation in quantitative form, mainly because the PM was focused in the evaluated attributes and relations given by the performance rating matrix, consequently many of this not included but considered information was not even documented.

RATING MATRIX - Proposed Alternatives				Caltrans
Criteria	Criteria Weight	Concept	Performance Rating	Total Performance
Mainline Operations	21	Original A-0	5	105
		VA Set A-1	5	105
		VA Set A-2	5	105
Local Operations	29	Original A-0	5	145
		VA Set A-1	5	145
		VA Set A-2	6	174
Maintainbility	14	Original A-0	5	70
		VA Set A-1	5	70
		VA Set A-2	6	84
Environmental Impacts	21	Original A-0	5	105
		VA Set A-1	4	84
		VA Set A-2	6	126
Construction Impacts	5	Original A-0	5	25
		VA Set A-1	6	30
		VA Set A-2	6	30
Project Schedule	10	Original A-0	5	50
		VA Set A-1	7	70
		VA Set A-2	7	70

Criteria not included (in quantitive form)				
Module	Alternative	Concept	Description	Total Performance
Legal		Original Concept		0%
		VA Set 1		0%
	2.0	VA Set 2	Has to be a Construction Change Order (CCO) to the Unit #2 contract	-15%
Social		Original Concept		0%
		VA Set 1		0%
	5.0	VA Set 2	Several Improvements for Traffic and Safety for pedestrians and bikes	20%
Environmental		Original Concept		
		VA Set 1		
		VA Set 2		
Management		Original Concept		
		VA Set 1		
		VA Set 2		
Economical		Original Concept		
		VA Set 1		
		VA Set 2		
Technical		Original Concept		0%
	3.0 & 4.0	VA Set 1	Adds construction of a hinge	-100%
		VA Set 2		0%
Schedule		Original Concept		
		VA Set 3		
		VA Set 4		

OVERALL PERFORMANCE	Total Performance	% Perf. Improvement	Total Cost	Value Index (Perf. /Cost)	%Value Improvement
Original Concept A-0	500	0%	58.000.000,00	8,62	0%
Altenative A-1 (1.0,3.0,4.0,6.0,7.0)	504	1%	55.200.000,00	9,13	6%
Altenative A-2 (1.0,2.0,5.0,6.0,7.0)	589	17%	55.100.000,00	10,60	23%

Figure 6-9: Input information of *situation 1* in the general AHP model

The proposed system and the AHP methodology enable to group a high number of criteria and alternatives besides to their corresponding assessment methodologies. However with the main objective of testing the AHP model proposed in section 5.3, the following test was developed, this test is aimed to verify its applicability and adaptability. Thus more criteria were identified in the documentation of the project and were included to the analysis (see Figure 6-9 and also Appendix B).

Accordingly the decisions of three different situations were tested with the general model (see Figure 6-2). The *situation 2* was not considered because it only represents a detailed analysis of the two alternatives A-0, which after a little modification was renamed as B-1 and the A-2, both from the *situation 1*.

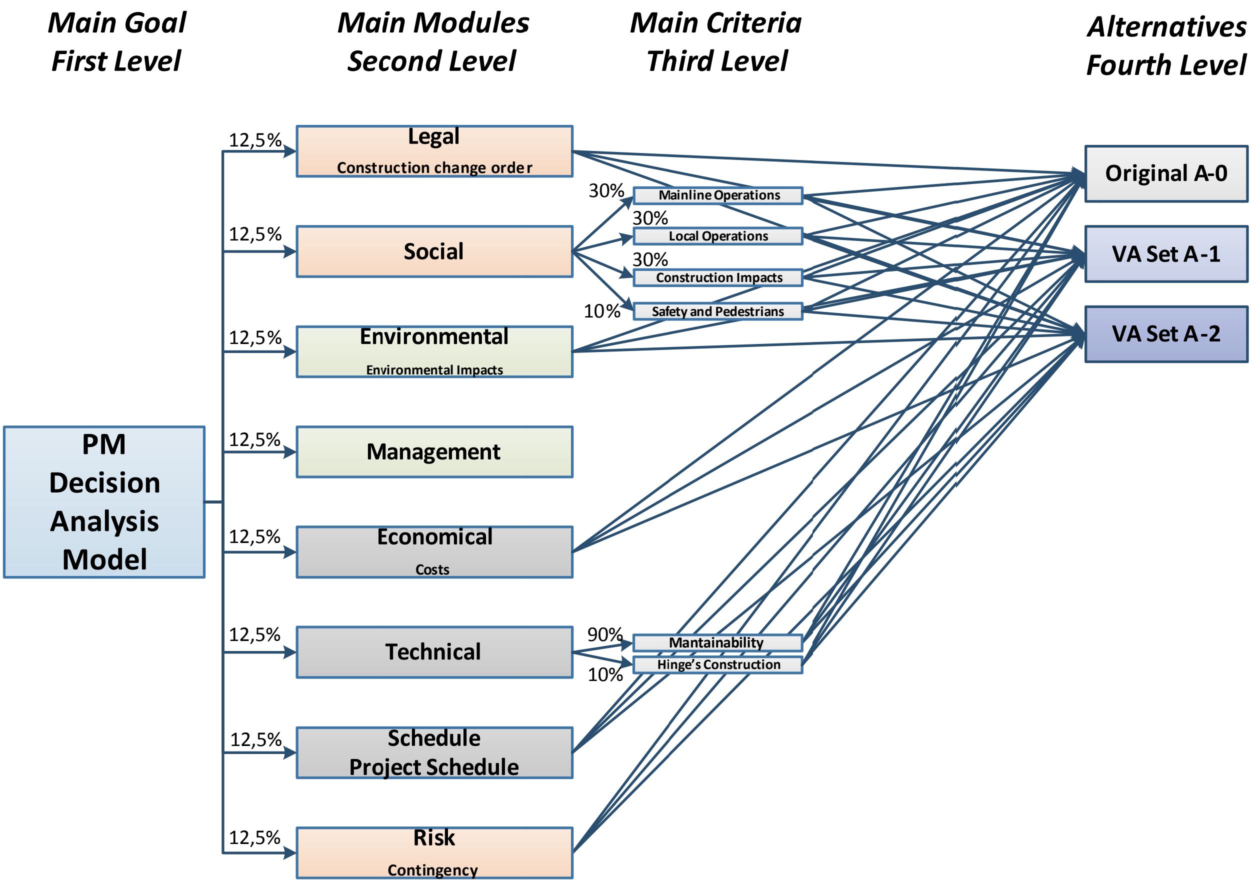
As a first step in this test, the already identified criteria of test 1 together with new criteria was assigned to the correspondent module (legal, social, management, etc.), all of them from the VA analysis. As a second step, the decision was represented in a hierarchical structure. Subsequently, the ratings were loaded into the general AHP model and the weights defined and checked.

For a better design in the MS excel model and to facilitate an adequate information exchange, an extra MS excel sheet was inserted for the input of information, which uses the format of Caltrans (see Figure 6-9), together with information that was not used in the alternative evaluation.

At the same time quantitative evaluation was made for the criteria not included in the VA-methodology utilized by the project managers (PMs). This evaluation was elaborated under a subjective basis, considering the information delivered by the documentation provided in the VA-Report. Thus the utility function prepared is the sum of 100% plus the presented evaluation of the Figure 6-9. For example in alternative A-2 social module, the new identified criteria improve the benefits of the alternative in 20%.

The graphic representation of the decision and the alternative selection are presented in the following Figure 6-10. The corresponding weights are also in this figure included.

The results of the *situation 1* permitted to confirm, that the alternative A-2 represented the best alternative. For this test all modules were weighted with the same relevance, however the sub criteria were weighted according to the projects requirements, therefore it is now easier to appreciate the reason because the Alternative A-1 was discarded for the *situation 2*. This was not possible in the test 1, because all the weights had the same relevance, thus we can now appreciate why the original alternative was considered in the *situation 2* as the alternative B-1 (see valuation in Figure 6-10).



Alternative	Legal	Social	Environmental	Management	Economical	Technical	Schedule	Risk
Original A-0	0,3509	0,3132	0,3333	0,3333	0,3222	0,9000	0,2632	0,3333
VA Set A-1	0,3509	0,3309	0,2667	0,3333	0,3386	0,1000	0,3684	0,3333
VA Set A-2	0,2982	0,3559	0,4000	0,3333	0,3392	1,0000	0,3684	0,3333

Valuation	
Original A-0	0,3937
VA Set A-1	0,3028
VA Set A-2	0,4286

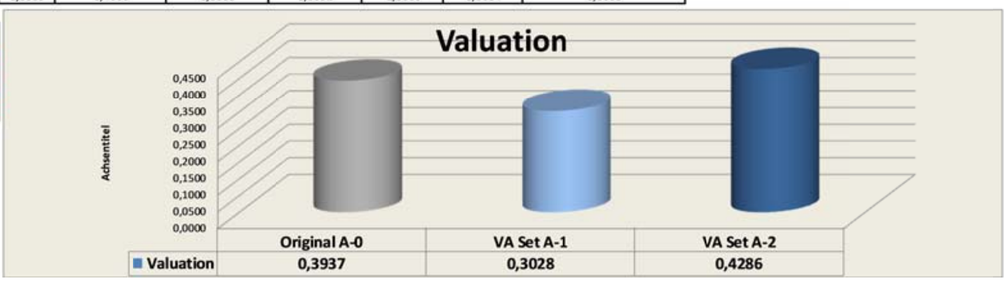
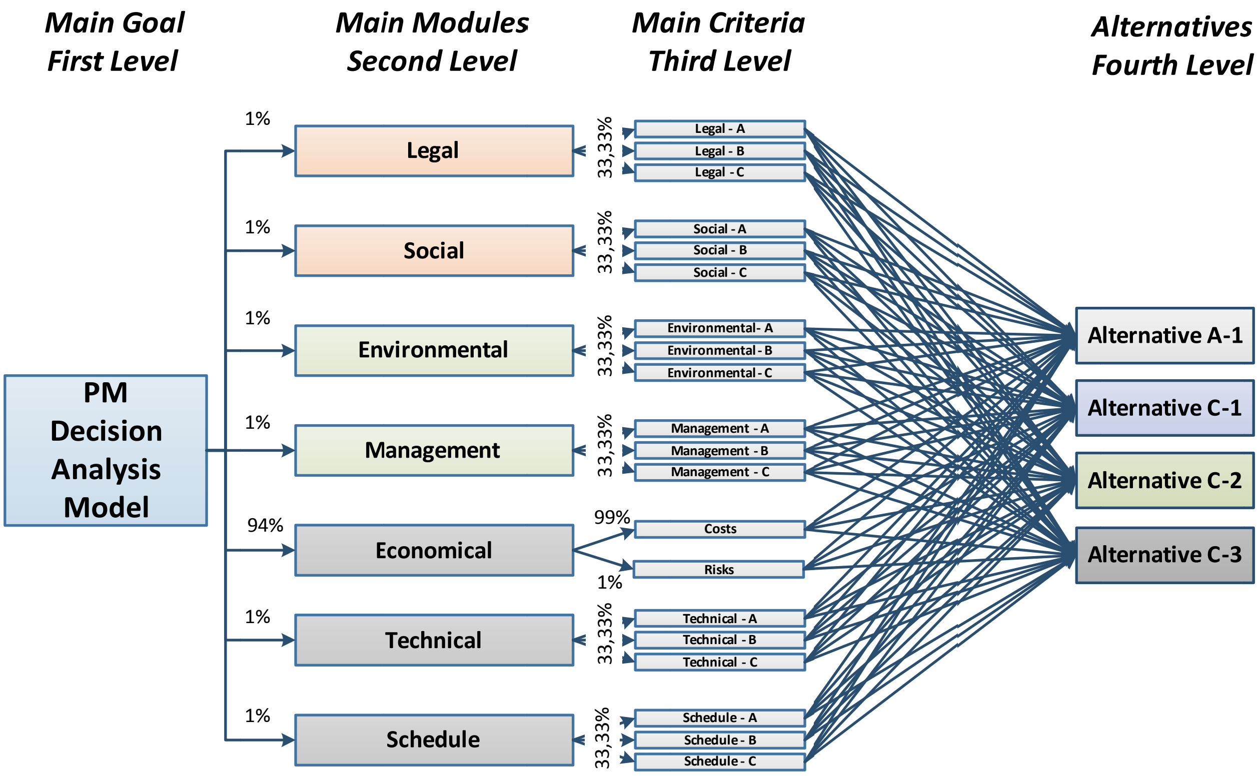


Figure 6-10: General AHP model *situation 1*

For the *situation 3* there was no VA-Report elaborated, the decision was made under a purely consideration of costs. Nevertheless for the AHP model it represented not complication and just the module economical was considered, therefore all other weights for other modules as well as sub criteria and alternative's evaluation have the same value, as presented in the Figure 6-11.

The decision represents the expected result, because the most cost effective alternative is the C-3 with \$ 27,487,511.28, then the C-2 with \$ 28,116,815.65, then the C-1 with \$ 28,551,000.00 and finally the A-1 with \$ 66,900,00.00; all other criteria evaluations have the same value and in this form, do not influence the selection. The selected weights permitted to concentrate the decision in the cost considerations; they can be easily tracked in the Figure 6-11.



Alternative	Legal	Social	Environmental	Management	Economical	Technical	Schedule
Alternative A-1	0,2500	0,2500	0,2500	0,2500	0,1239	0,2500	0,2500
Alternative C-1	0,2500	0,2500	0,2500	0,2500	0,2869	0,2500	0,2500
Alternative C-2	0,2500	0,2500	0,2500	0,2500	0,2913	0,2500	0,2500
Alternative C-3	0,2500	0,2500	0,2500	0,2500	0,2979	0,2500	0,2500

Valuation	
Alternative A-1	0,1314
Alternative C-1	0,2847
Alternative C-2	0,2888
Alternative C-3	0,2950

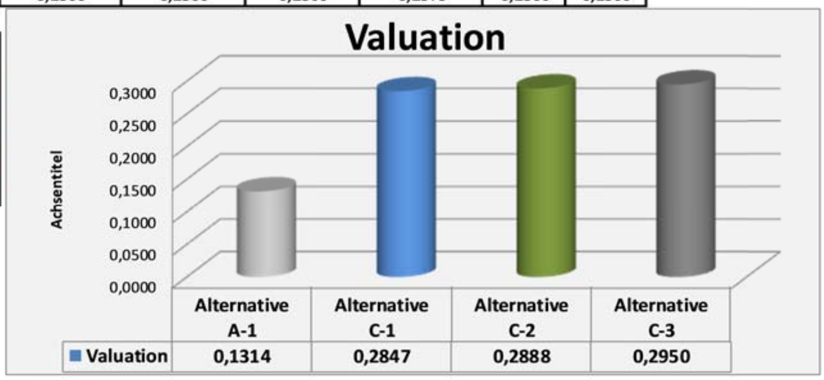
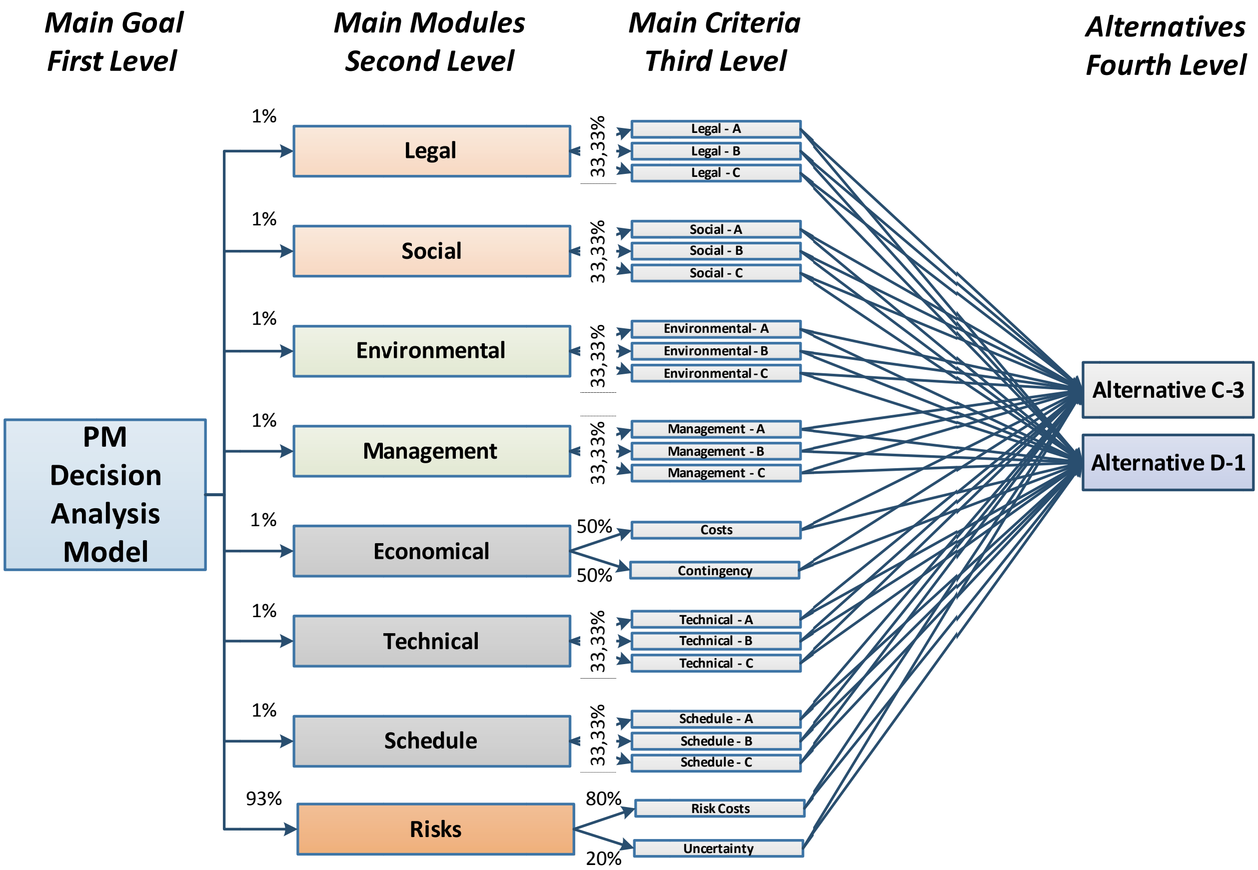


Figure 6-11: General AHP model *situation 3*

The *situation 4* it was also a situation in which the decision is based just in few criteria; the risk analysis and consequently the certainty of each alternative. For this situation the risk analysis was utilized, however there was also no VA-Report elaborated, just a risk analysis report (see Appendix D). Nevertheless the general model permitted to organize the criteria and the risk analysis was considered as a module.

Figure 6-12 presents the general decision's overview with the representation of the considered weights and the alternatives evaluation.

Again the result confirms the selection of the D-1, which is the most liable alternative, because of its certainty. The risk costs are higher in the C-3 but there is no certainty in the results, therefore D-1 is the best alternative.



Alternative	Legal	Social	Environmental	Management	Economical	Technical	Schedule	Risk
Alternative C-3	0,5000	0,5000	0,5000	0,5000	0,5000	0,5000	0,5000	0,3865
Alternative D-1	0,5000	0,5000	0,5000	0,5000	0,5000	0,5000	0,5000	0,6135

Valuation	
Alternative C-3	0,3944
Alternative D-1	0,6056

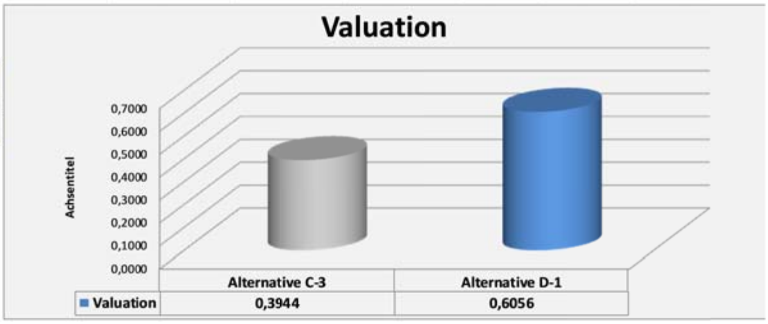


Figure 6-12: General AHP model Situation 4

Test's conclusions

The proposed modules of the AHP model permitted to reaffirm the PM's alternatives selection and a more defined allocation of criteria, thus the models flexibility and readiness for the practice was proved in this test. In the *situation 1* (test 1), the alternative A-1 was discarded; however it was not easy to appreciate why only the alternatives A-0 and A-2 were used for a further development. The main reason is that the criteria "hinge's construction" was not included in the original PM's decisions analysis (see Figure 6-10), it was just described inside of the VA report, along with many other criteria.

This reflects the mentioned problematic of losing vital information, that the decision constitutes; many information are not stored and can be lost in the progression of the project. Mainly due the large number of factors and criteria; together with the high pressure on the project participants.

The use of utility functions permits the inclusion of more criteria with a quantitative basis, nevertheless it is important to define the measure criterion for it quantification. The utility functions are commonly used on the MCDAM (see section 2.3), consequently through their use, the flexibility and level of detail in the analysis is increased by using new identified criteria.

The utilization of the proposed decision analysis system and model, permit their utilization in the practice and permit also to include much more criteria for their analysis. However for their application the definition, quantification and transfer procedures besides their formats are vital. The use of AHP and MS Excel enable its applicability in the practice as decision analysis model. Consequently their use allows a simple decision's processing and review, nonetheless, a good knowledge of the AHP process is needed. The flexibility and readiness of the proposed decision analysis model permits its application in the practice.

6.2.3 Test 3 – Empirical system's test in a sound protecting wall

The results of tests 1 and 2 have shown that the functionality of the system and model are suitable for the practice. They allow the evaluation of project designs during the project development and at the same time; they enable the introduction of a systematic procedure together with transparency in the decision analysis process. The use of weights makes possible the adequate representation of the project's expectations and consequently an easier decisions monitoring.

Risk management especially its sub process risk analysis, is another important criterion that can be inserted in the decision analysis. A typical problem in the construction industry is the reduced application of risk analysis. Although numerous companies claim to have suitable risk analysis systems, many of them are not business-related and often not even stochastic. Therefore for a large number of contractors, the countless benefits of risk management are completely unknown and consequently RM is considered as an extra burden.

Risk analysis is considered in the proposed decision analysis model as an additional module or criterion, in this way the integration of risk management can succeed in a simple manner in the project development. Ultimately the model allows the use of MS Excel for a simple processing and review of decisions. Nevertheless, a good knowledge of AHP and risk analysis methods is needed.

During the development of the tests 1 and 2 was clear that much of the information utilized for the development of the DAR project were no longer available, therefore many of the possibilities offered by the proposed system and model, couldn't be verified in these two tests. Hence with the objective of checking the opportunities and possibilities offered by the system, especially of the decision analysis model, the test three was prepared. In this form, detailed risk analysis, selection of the criteria to evaluate, use of databases and functionality of the decision model were analyzed.

For the present test a sound protecting wall is projected; here is important to point out that in the development of any construction project, normally simple relationships of different criteria are utilized. For example, for a building the relation of areas and costs are some of the most important designing criteria. For this test, more detailed project estimations were applied decision analysis model. The main reason is to demonstrate that even with more complicated methodologies than the commonly used in the project development; the system provides an appropriate and reliable alternative analysis. Accordingly, cost estimation, scheduling, quality and other criteria were used for this example with a higher level of detail than simple relations.

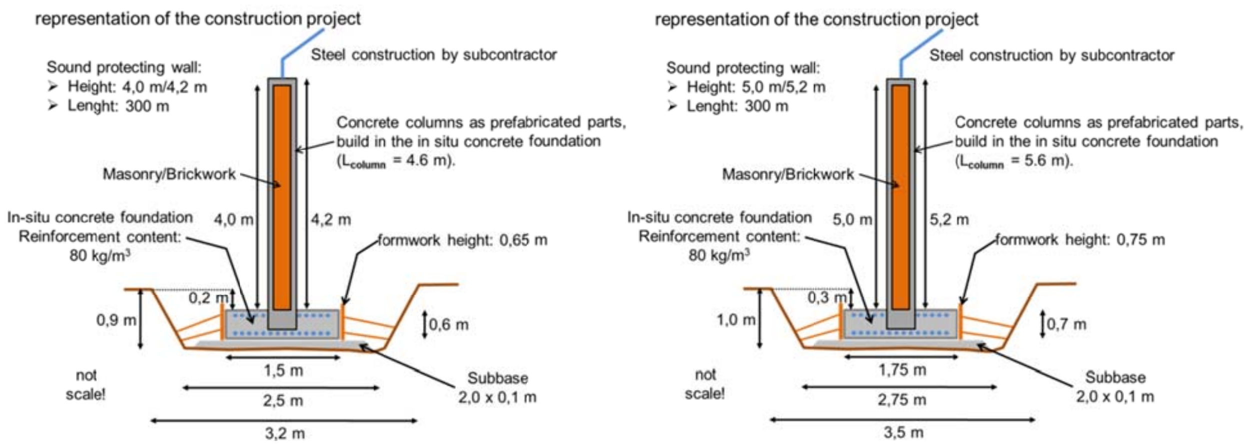
1. *Criteria definition*

The project is defined as the construction of a 300m long sound protecting wall for a determined street. All the activities for the construction of the wall should be considered but the steel construction and the columns; they will be performed by a subcontractor. The concrete columns will be as prefabricated elements delivered to the site.

For a sound protecting wall project, two different alternatives were created for its analysis (see Figure 6-13). The alternative A was developed for a wall height of 4.0m and the alternative B was created for a height of 5.0m. The complete project description is presented in the Appendix E.

The liability of the system was evaluated in tests one and two, thus this test is aimed for the decision analysis model and risk analysis. For this project the main objectives are defined as follows:

- Budget: € 360,000.00
- Maximum duration 31 days
- Quality of sound insulation & public acceptance



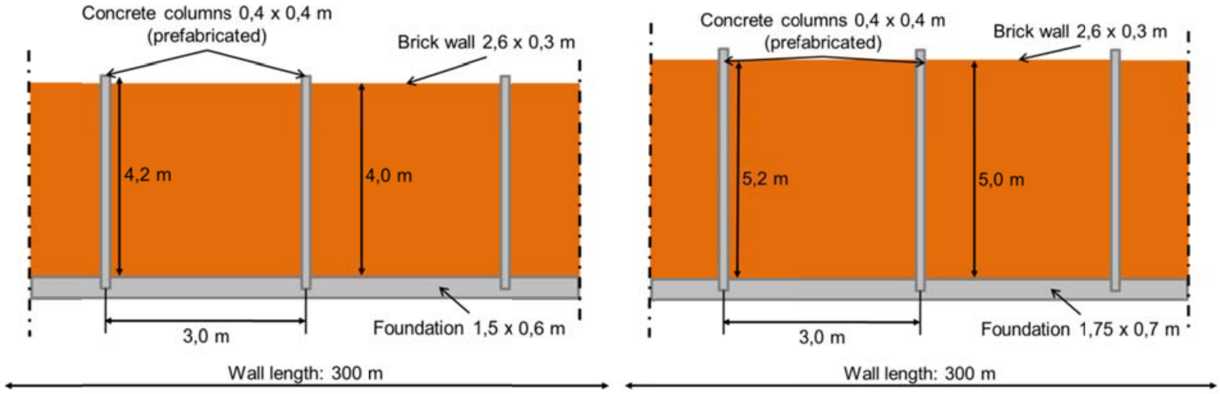


Figure 6-13: Alternatives for the sound protecting wall

The main goals reflect the expectations of the project, the most important of them are the budget and the maximum duration. If any of these are exceeded the project can be aborted, consequently they represent the K.O. criteria.

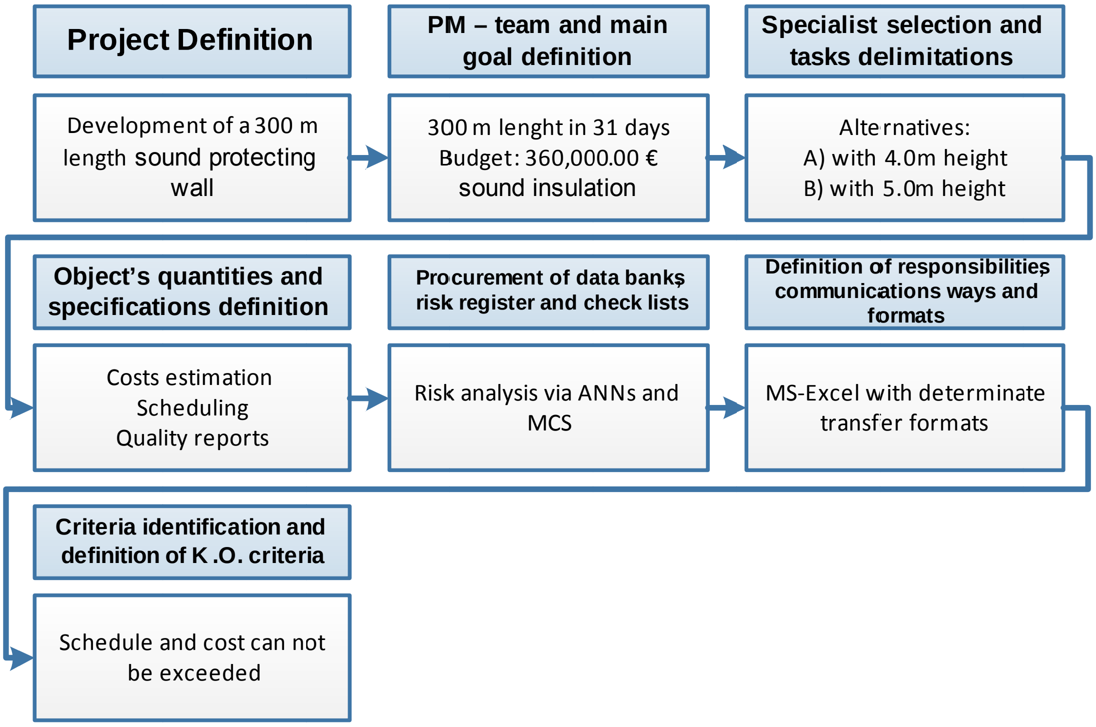


Figure 6-14: System's project planning, sound protecting wall project

For the realization of the project the seven phases of the system's project planning have been carried out and their results can be seen in Figure 6-14.

2. ***Alternatives development***

The criteria definition permitted to propose two feasible different alternatives, now for their analysis it was important to elaborate their corresponding cost estimation, scheduling and evaluate their quality. It is important to note that the cost estimation and scheduling for this project are performed in a more detailed form, than in a common project development, in which simple relations are considered.

However for the cost estimation and scheduling the most important inputs required are costs and performance factors. Thus it is vital to treat this factors based in the project and constructor characteristics.

This dissertation proposes a new methodology that makes use of ANNs as first step, before performing any risk analysis, when data banks are available. The utilization of the ANNs permits a more precise approach to the required performance factors. In consequence the most important criteria that have an influence in the project and for the risk analysis will be identified and more adequate treated for the cost and the scheduling estimation.

For the determination of the required inputs for the risk analysis, data bases were generated and treated making use of the ANNs. These databanks were elaborated using a formula, which consists in the multiplication of different influences with the performance factor value ("factor", see Figure 6-15), aimed to determine the expected value for each required criterion ("result").

Blinding - Subbase

Crew	Cement	Conditions	Weather	Factor	Result
normal	F5-F6	very bad	good	0,09	
good	F1-F4	good	very bad	0,08	
normal	F1-F4	very bad	very bad	0,07	0,20
bad	F5-F6	bad	bad	0,09	0,17
normal	F5-F6	very bad	good	0,08	0,12
bad	F5-F6	very bad	good	0,09	0,14
good	F5-F6	good	bad	0,07	0,07
bad	F1-F4	bad	very bad	0,07	0,16
good	F5-F6	very bad	good	0,08	0,09
good	F1-F4	good	good	0,08	0,05
normal	F1-F4	good	very bad	0,10	0,14
bad	F5-F6	very bad	good	0,08	0,12
normal	F5-F6	good	good	0,07	0,05
bad	F5-F6	good	bad	0,08	0,10
normal	F5-F6	bad	bad	0,09	0,15
bad	F1-F4	good	bad	0,08	0,11
normal	F1-F4	good	bad	0,08	0,10
good	F5-F6	bad	bad	0,09	0,13

Prediction Report: "Net

Tag Used	Prediction
predict	0,1244
predict	0,0980

Target	Variation
0,1239	0,38%
0,0979	0,04%

Crew	
good	0,85
normal	1
bad	1,1
Cement	
F1-F4	1
F5-F6	0,9
Conditions	
good	0,9
bad	1,3
very bad	1,7
Weather	
good	0,9
bad	1,4
very bad	1,6

Figure 6-15: Data bank Blinding – Subbase (calculated with Neuronal Tools)

The databanks have about 1500 entries of different factors with their corresponding end result. Finally two different situations were given and the corresponding results represent the expected performance value (prediction).

Figure 6-15 presents the data bank "blinding – subbase", this figure permits to appreciate the results calculated by the ANNs (prediction). For this part of the test it was important to evaluate how reliable the results offered by the ANNs are (see section 5.4.2). Thus the utilization of the formula permitted to calculate the corresponding real results (Target in the figure) and compare it against the result offered by the ANNs (prediction in pink, Figure 6-15 and Figure 6-16), the variation presents the deviation from the ANNs to the expected value.

The predictions delivered by the ANNs permitted to assure that this methodology makes possible to perform a more precise prediction; just in three cases the variation was bigger than 5% than the real value, most of them presented a deviation of less than a 1.0 % (see Figure 6-16).

Data bank	Tag Used	Prediction	Target	Variation
Excavation Numeric	predict	0,233	0,2317	0,63%
	predict	0,321	0,3242	-1,07%
Excavation Text	predict	0,2986	0,2317	28,91%
	predict	0,3059	0,3242	-5,62%
Blinding Numeric	predict	0,1243	0,1239	0,28%
	predict	0,0989	0,0979	1,04%
Blinding Text	predict	0,1244	0,1239	0,38%
	predict	0,0980	0,0979	0,04%
Reinforced Concrete Numeric	predict	0,6678	0,6683	-0,07%
	predict	1,5901	1,5900	0,01%
Reinforced Concrete Text	predict	0,6675	0,6683	-0,12%
	predict	1,5638	1,5900	-1,65%
Masonry Numeric	predict	1,0214	1,0296	-0,80%
	predict	0,6699	0,6669	0,46%
Masonry Text	predict	1,0266	1,0296	-0,30%
	predict	0,6029	0,6669	-9,60%
Backfill Numeric	predict	0,1028	0,1010	1,79%
	predict	0,1548	0,1559	-0,73%
Backfill Text	predict	0,1028	0,1010	1,78%
	predict	0,1547	0,1559	-0,77%

Figure 6-16: Overview over the different data banks (calculated with Neuronal Tools)

In this form the identified performance factors required for the cost estimation and scheduling were predicted using ANNs (see Appendix F), this factors are:

- Excavation
- Blinding – Subbase
- Reinforced concrete
- Masonry – brick working
- Backfill

The cost estimation and scheduling make use of the calculated factors via ANNs; however for the development of the project four stages were evaluated based in the cost estimation and the schedule respectively (see Figure 6-22). Therefore, for a more adequate further progress (evolution, see Figure 4-13) of the project's alternatives, MCS was utilized for their optimization. MCS permits to improve this tasks and though its examination with the sensitivity analysis of each alternative. Consequently the cost estimation and scheduling represented the basis for the MCS model. Thus the predicted performance factors delivered by the ANNs represented the expected values for the risk analysis. As initial stage for the alternative's development a crew of two men was considered for each activity (see also Figure 6-22).

For the performance factors a variation of 2% was utilized for minimum and maximum values for the MCS but not for the concrete columns, for the reason that no data bank was available, in this case the maximum and minimum values were proposed. The variation of 2% in the predictions delivered by the ANNs was defined due the certainty that provided after the analysis of the results of the ANNs procedure (see Figure 6-16).

Subsequently for all risk criteria the Pert distribution in the MCS was employed; the main reason is that maximum and minimum values are finite and defined besides the data behavior is expected to describe this form (see Figure 6-17).

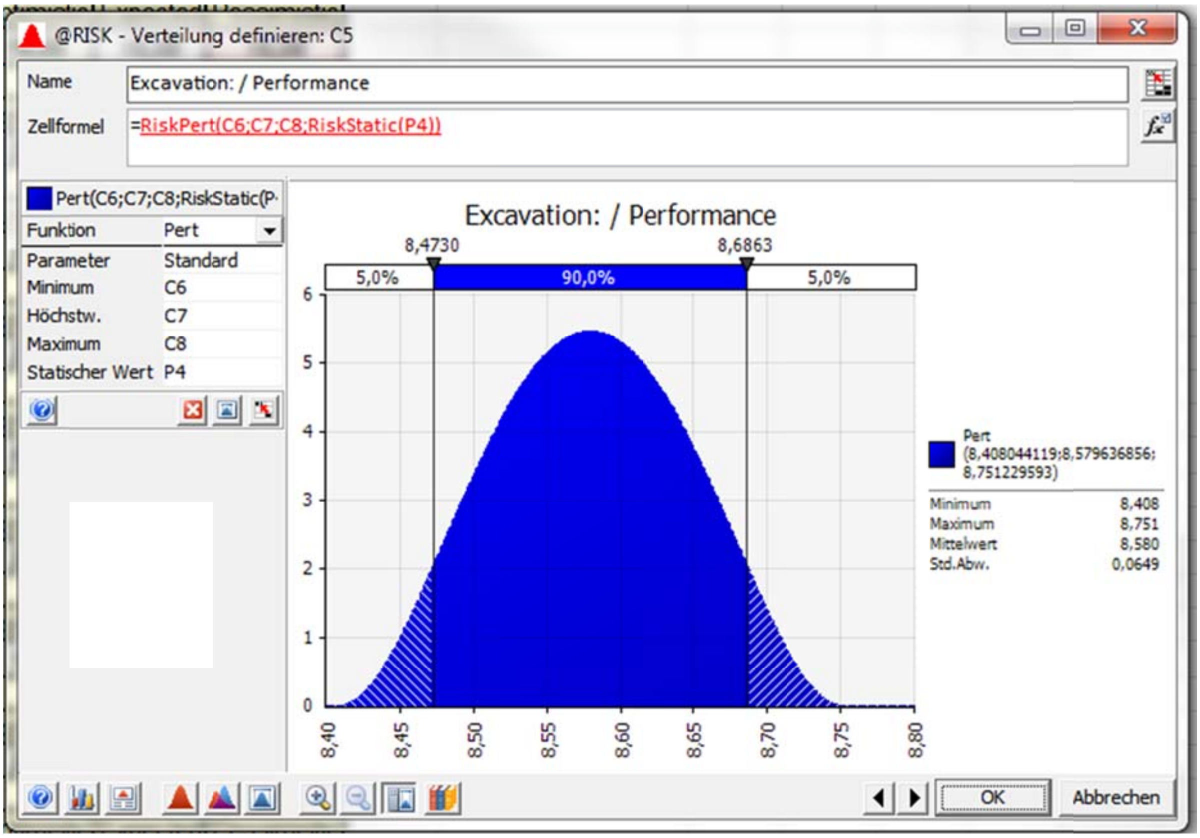


Figure 6-17: Performance factors - cost estimation inputs (@Risk)

Not only the performance factors were utilized as risk criteria, many other like, costs, machines, crews, etc., they were treated also with a Pert distribution, nevertheless minimum and maximum values were assigned without using ANNs[181].

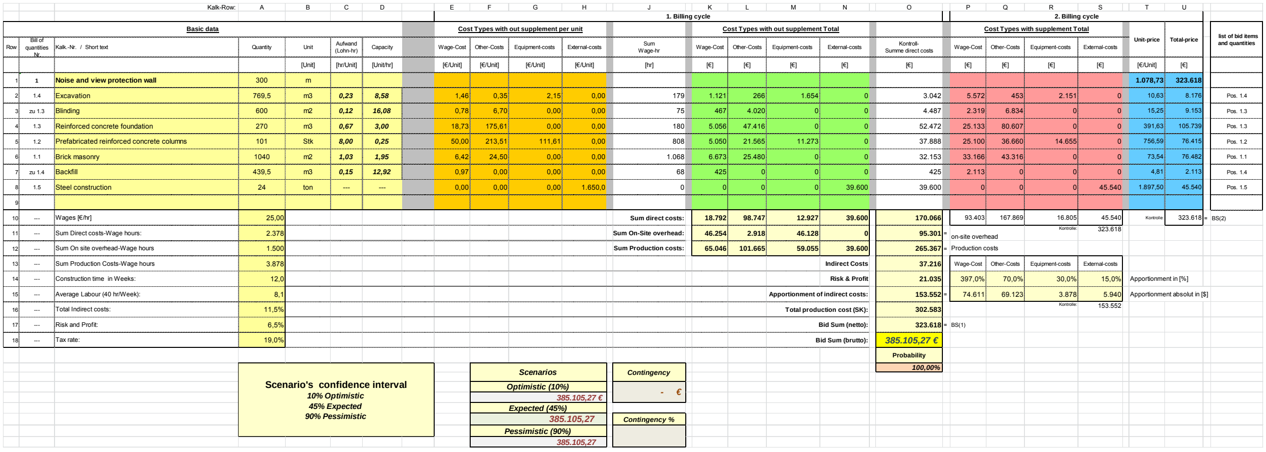
The cost estimation and scheduling showed the following costs and duration for the alternative (4.0m) in comparison to the original objectives:

- € 385.105.27 > € 360.00,00
- 58 days > 31 Days

Therefore it was necessary to improve this alternative; accordingly a more detailed analysis risk analysis was performed. Risk analysis permits to evaluate the probabilities of the calculated results, plus a sensibility analysis of the criteria. Through the utilization of the confidence intervals, different scenarios can be formulated[182].

[181] For a better overview of the risk criteria, the calculation is included as MS Excel file in this dissertation; all red marked entries are risk criteria. All MCS evaluations were performed with @Risk.

[182]The results delivered from the calculation and scheduling are deterministic results, MCS enables the stochastic analysis of the results.



		Kalk-Row:	A	B	C	D	E	F	G	H	J	K	L	M	N	O	P	Q	R	S	T	U	
											1. Billing cycle						2. Billing cycle						
Basic data							Cost Types with out supplement per unit					Cost Types with out supplement Total					Cost Types with supplement Total						
Row	Bill of quantities Nr.	Kalk.-Nr. / Short text	Quantity	Unit	Aufwand (Lohn-hr)	Capacity	Wage-Cost	Other-Costs	Equipment-costs	External-costs	Sum Wage-hr	Wage-Cost	Other-Costs	Equipment-costs	External-costs	Kontroll-Summe direct costs	Wage-Cost	Other-Costs	Equipment-costs	External-costs	Unit-price	Total-price	list of bid items and quantities
				[Unit]	[hr/Unit]	[Unit/hr]	[€/Unit]	[€/Unit]	[€/Unit]	[€/Unit]	[hr]	[€]	[€]	[€]	[€]	[€]	[€]	[€]	[€]	[€]	[€/Unit]	[€]	
1	1	**Noise and view protection wall**	300	m																	1.078,73	323.618	
2	1.4	Excavation	769,5	m3	0,23	8,58	1,46	0,35	2,15	0,00	179	1.121	266	1.654	0	3.042	5.572	453	2.151	0	10,63	8.176	Pos. 1.4
3	zu 1.3	Blinding	600	m2	0,12	16,08	0,78	6,70	0,00	0,00	75	467	4.020	0	0	4.487	2.319	6.834	0	0	15,25	9.153	Pos. 1.3
4	1.3	Reinforced concrete foundation	270	m3	0,67	3,00	18,73	175,61	0,00	0,00	180	5.056	47.416	0	0	52.472	25.133	80.607	0	0	391,63	105.739	Pos. 1.3
5	1.2	Prefabricated reinforced concrete columns	101	Stk	8,00	0,25	50,00	213,51	111,61	0,00	808	5.050	21.565	11.273	0	37.888	25.100	36.660	14.655	0	756,59	76.415	Pos. 1.2
6	1.1	Brick masonry	1040	m2	1,03	1,95	6,42	24,50	0,00	0,00	1.068	6.673	25.480	0	0	32.153	33.166	43.316	0	0	73,54	76.482	Pos. 1.1
7	zu 1.4	Backfill	439,5	m3	0,15	12,92	0,97	0,00	0,00	0,00	68	425	0	0	0	425	2.113	0	0	0	4,81	2.113	Pos. 1.4
8	1.5	Steel construction	24	ton	---	---	0,00	0,00	0,00	1.650,0	0	0	0	0	39.600	39.600	0	0	0	45.540	1.897,50	45.540	Pos. 1.5
9																							
10	---	Wages [€/hr]	25,00								**Sum direct costs:**	**18.792**	**98.747**	**12.927**	**39.600**	**170.066**	93.403	167.869	16.805	45.540	Kontrolle:	323.618	= BS(2)
11	---	Sum Direct costs-Wage hours:	2.378								**Sum On-Site overhead:**	**46.254**	**2.918**	**46.128**	**0**	**95.301** =	on-site overhead		Kontrolle:	323.618			
12	---	Sum On site overhead-Wage hours	1.500								**Sum Production costs:**	**65.046**	**101.665**	**59.055**	**39.600**	**265.367** =	Production costs						
13	---	Sum Production Costs-Wage hours	3.878												**Indirect Costs**	**37.216**	Wage-Cost	Other-Costs	Equipment-costs	External-costs			
14	---	Construction time in Weeks:	12,0												**Risk & Profit**	**21.035**	397,0%	70,0%	30,0%	15,0%	Apportionment in [%]		
15	---	Average Labour (40 hr/Week):	8,1												**Apportionment of indirect costs:**	**153.552** =	74.611	69.123	3.878	5.940	Apportionment absolut in [$]		
16	---	Total Indirect costs:	11,5%												**Total production cost (SK):**	**302.583**			Kontrolle:	153.552			
17	---	Risk and Profit:	6,5%												**Bid Sum (netto):**	**323.618** =	BS(1)						
18	---	Tax rate:	19,0%												**Bid Sum (brutto):**	***385.105,27 €***							
																Probability							
																100,00%							

Scenario's confidence interval
10% Optimistic
45% Expected
90% Pessimistic

Scenarios
Optimistic (10%)
385.105,27 €
Expected (45%)
385.105,27
Pessimistic (90%)
385.105,27

Contingency
- €
Contingency %

Figure 6-18: Cost estimation sound protection wall (alternative 4,0m)[183], see appendix G

For the determination of the correspondent scenarios it is indispensable a historical analysis of different completed projects. They can be sorted in three different groups, the projects that were performed as expected (expected scenarios), the projects that were performed better as expected (optimistic scenarios), and finally the projects with bad performance (pessimistic scenarios).

These analyses must be performed according to the initial risk evaluation; the corresponding confidence intervals of the real costs and the initial expected costs, permits to set the corresponding scenarios (see Figure 6-19). The scenarios represent the quantity of risks and uncertainties that took place in the project with reference to the very first expectations. This methodology permits to elaborate a liable prediction at the very beginning of the project and to determinate the opportunities and hazards for any specific project, even before the execution of the project takes place.

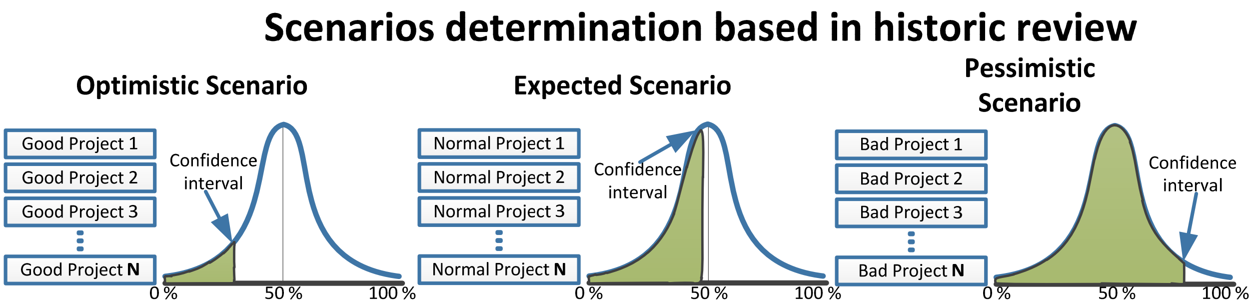


Figure 6-19: Scenarios determination based in historic review

In this form the risk analysis of the project was prepared, the MCS calculated the probabilities of be completed with the estimated costs, plus the three possible scenarios; these results are shown in the following Figure 6-20. Ultimately, the sensitivity analysis allows to identify rapidly which criteria should be improved for the further project development (see Figure 6-21).

[183]The cost estimation is presented in the "Appendix G: MCS Results" at the end of this work.

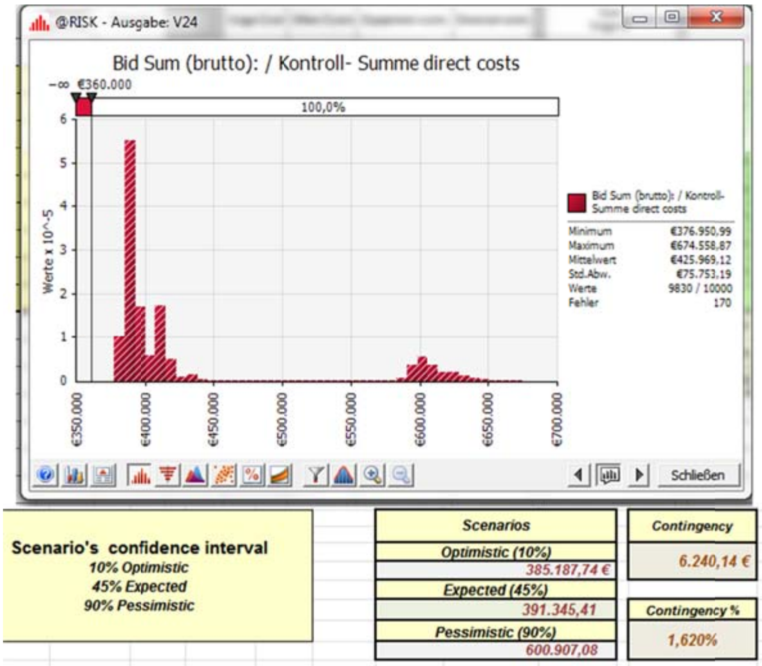


Figure 6-20: Results of the MCS, alternative 4.0m (@Risk), see appendix G

The Figure 6-20 presents the results of the risk analysis for this first alternative with 4.0m. It permits to conclude that the estimated costs are expected to take place just with a probability of 9.67%. This means there is a likelihood of 90.33% of actually exceeding these costs, accordingly under this situation costs of € 391,345.41 are expected (expected scenario) and in a pessimistic scenario about € 600,907.08 and even worse no possibility of reducing the costs to € 360,000.00. Hence it is imperative to improve the alternative; for this objective the sensibility analysis enables an easier criteria selection for the improvement see

Figure 6-21. The coefficient values are presented and they reflect the way in which a criterion impacts the considered value in this case, masonry has higher impact in the result.

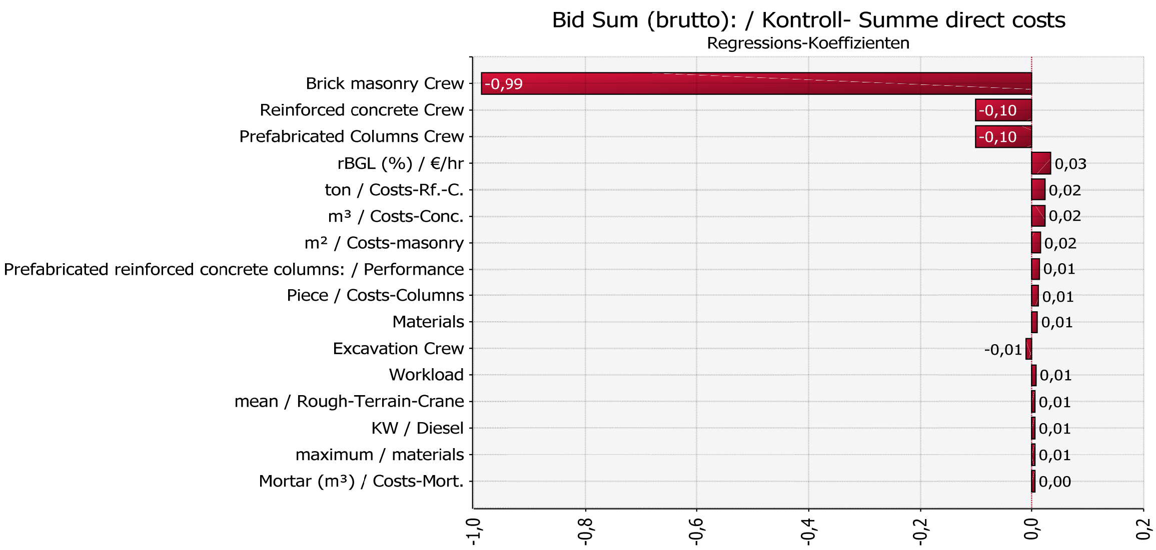


Figure 6-21: Coefficient-Values by the Sensibility analysis alternative 4.0m (@risk)

The methodology proposed in this dissertation permits to define a “contingency” amount. In the cost estimation the risks cost are given as a percentage of the bid sum, however this methodology recommends an amount for preventing losses and is determined as the difference between the proposed bid sum (deterministic value) and the expected scenario.
The sensibility analysis permits directly and in quantitive form to identify the most relevant criteria to improve, from the illustration it can be seen that the masonry crew is the most important criterion to be improved. Therefore, as a further measure four men were provided for this crew.

With this procedure (ANNs + @Risk) the alternatives were improved and according to the sensibility analysis, the alternative’s probabilities are at the same time in different scenarios analyzed, consequently the alternative with higher possibilities of be completed in the expected scenario (bid sum plus contingency) is selected. The development of the two alternatives (alternative’s evolution) is resumed in the Figure 6-22, the MCS was performed with 10,000 iterations for each case.

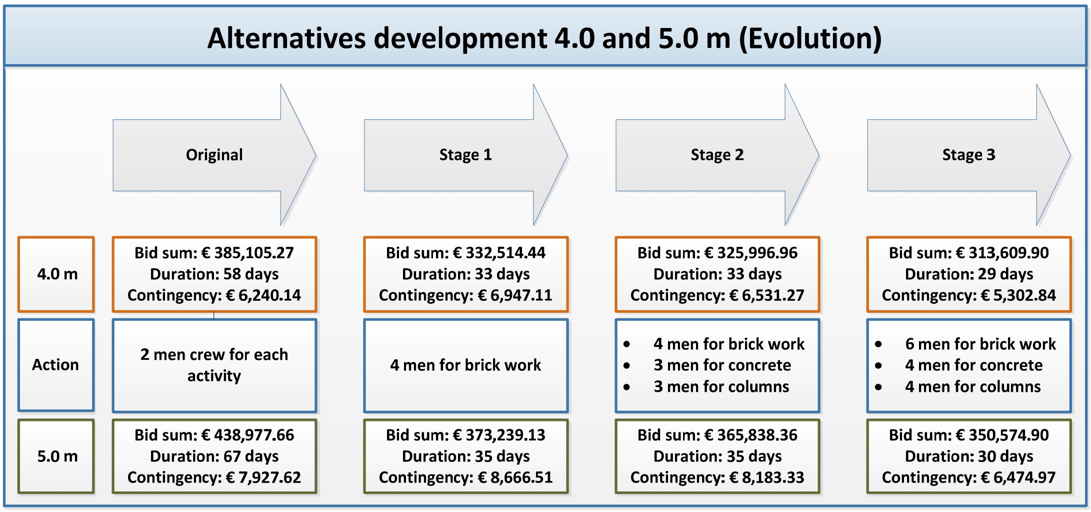


Figure 6-22: Alternatives evolution 4.0 and 5.0 m

The results presented in the Figure 6-22 permits to trace back the evolution of the alternatives. The analysis was performed selecting the bid sum proposed by the expected scenario calculated in the risk analysis; the cost estimation included also the schedule planning (see Appendix G). Consequently for each alternative the expected scenario was compared with the main objectives.

Finally the stage 3 developed for both alternatives were selected for the evaluation (see Figure 6-22). The development procedure based on risk analysis permits to appreciate that risk analysis is nothing else but a decision analysis under the consideration of risk criteria (see section 3.1).

The utilization of the here proposed risk analysis methodology allows the consideration of contingencies; this means that although risk analysis from historical examination was performed, an extra amount for the consideration of contingencies (uncertainties) can be added to increase the certainty of the project. The purpose of the contingency is to cover up any eventuality that might and will be occur in the development of the project, they represent not identified or quantified risks (partial or total uncertainties). The utilization of data banks permits to adjust the predictions to the own profile, characteristics and particularities of the contractor.

3. **The decision analysis model**

The chosen alternatives 4.0 and 5.0 m from the alternative's development (stage 3) are considered the most suitable for the fulfillment of the project expectations. Thus a detailed analysis that includes all expectations for the project is required and not only risk considerations; with this aim the decision analysis model was prepared.

The definition of weights, utility functions and scales for the evaluation of criteria are the most important tasks in the elaboration of the decision analysis model, thus for any project they must be always defined as first step. However for this test, the proposed general decision analysis model is applied and consequently tested, therefore the allocation of the different criteria in the corresponding modules is the main task.

The identified criteria for the alternatives evaluation of the sound protecting wall project are:

- normativity; requirements given by the regulations and permits (legal module),
- aesthetics, compliance with the aesthetic requirements (social module),
- public acceptance, acceptance of the society and according to the landscape (social module),
- noise reduction, reduction of the noise pollution (environmental module),
- environmental effects, environmental impacts of the project (environmental module),
- quality, project requirements from standards, authorities and technic (technical module),
- complexity, level of difficulty for the execution of the project (technical module), and
- Finally for the scheduling and economic criteria the information delivered by the risk analysis was employed.

The graphic representation of the decision analysis model is presented in the Figure 6-23. With the defined criteria allocation, it is vital now to specify the correspondent relevance for each criterion and module, and they should represent the expectations of the project. The weights were determined for the first analysis as follows; legal 4.0%, social 10.0%, environmental 45.0%, management 1.0%, economical 15.0 %, technical 15.0% and schedule 10.0%; all weights including the sub criteria weights are represented in the Figure 6-23.

The configuration of weights represented in the Figure 6-23 permits to see that the project has its priority in the environmental module and subsequently the noise reduction is the most important criteria.

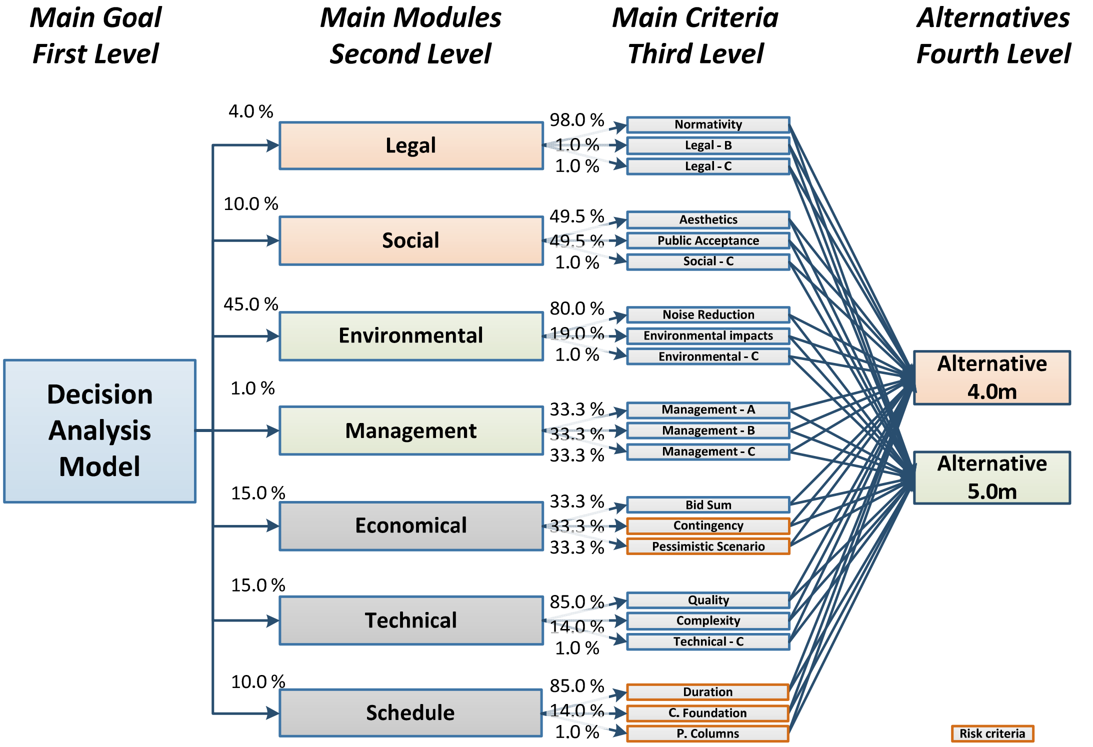


Figure 6-23: Sound protecting wall decision analysis hierarchy

Inputs

Legal Module			
Alternatives	Normativity	Legal - B	Legal - C
Alt. 4.0 m	9	1	1
Alt. 5.0 m	9	1	1

Social Module			
Alternatives	Aesthetic	Public Acceptance	Social - C
Alt. 4.0 m	9	8	1
Alt. 5.0 m	5	4	1

Environmental Module			
Alternatives	Noise Reduction	Env. Impacts	Env. - C
Alt. 4.0 m	5	7	1
Alt. 5.0 m	10	7	1

Management Module			
Alternatives	Management - A	Management - B	Management - C
Alt. 4.0 m	1	1	1
Alt. 5.0 m	1	1	1

Technical Module			
Alternatives	Quality	Complexity	Env. - C
Alt. 4.0 m	8	7	1
Alt. 5.0 m	6	5	1

Alt.- 4.0 m			
Criteria	Duration (d)	Expected (45 %)	Difference
Total Duration	28,71	28,71	0,00
Excavation	5,61	5,61	0,00
Blinding lean concrete	2,33	2,33	0,00
Concrete (Foundation)	12,64	12,67	0,03
Concrete Columns	6,31	6,52	0,20
Brick masonry	3,71	3,71	0,00
Backfill	2,13	2,13	0,00
Costs	Unit	Probability	
Bid Sum (brutto):	313.609,90 €	6,96%	
Contingency (Expected Scenario)	5.302,84 €		
Optimistic Scenario	314.309,76 €		
Expected Scenario	318.912,74 €		
Pessimistic Scenario	325.686,52 €		
Direct Costs	Expected (45%)	Probability	
Excavation	3.126,78 €	24,99%	
Bliding	4.515,28 €	33,28%	
Prefabricated Columns	24.317,23 €	35,41%	
Reinforced Conrete Foundation	51.333,12 €	20,13%	
Brick Masonry	26.251,36 €	43,98%	
Backfilling	425,40 €	42,84%	

Alt.- 5.0 m			
Criteria	Duration (d)	Expected (45 %)	Difference
Total Duration	29,63	29,63	0,00
Excavation	6,83	6,83	0,00
Blinding lean concrete	2,33	2,33	0,00
Concrete (Foundation)	17,21	17,25	0,05
Concrete Columns	6,31	6,52	0,21
Brick masonry	4,63	4,63	0,00
Backfill	2,47	2,47	0,00
Costs	Unit	Probability	
Bid Sum (brutto):	350.574,90 €	8,04%	
Contingency (Expected Scenario)	6.474,97 €		
Optimistic Scenario	351.166,35 €		
Expected Scenario	357.049,87 €		
Pessimistic Scenario	366.029,67 €		
Direct Costs	Expected (45%)	Probability	
Excavation	3.805,85 €	25,13%	
Bliding	4.515,00 €	33,29%	
Prefabricated Columns	24.333,39 €	34,80%	
Reinforced Conrete Foundation	69.152,75 €	20,99%	
Brick Masonry	32.799,14 €	44,25%	
Backfilling	493,67 €	42,63%	

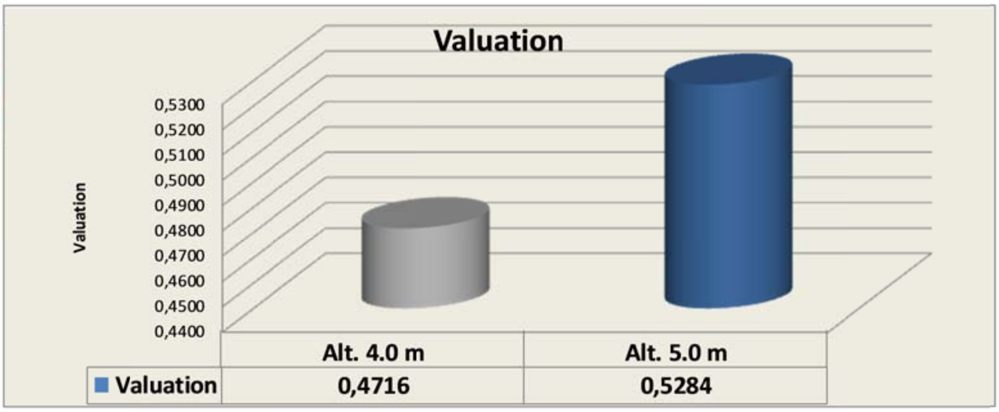
Figure 6-24: Criteria evaluation MS excel input format

For a systematic information transfer a determined input format was defined and added in an extra MS excel sheet inside of the decision analysis model (see Figure 6-24). Through this sheet the evaluations of every criterion were loaded and linked to the corresponding modules for the alternative's evaluation.

The results of the risk analysis with their corresponding formats were used for this step. For the evaluation of criteria like aesthetics, normativity, etc., a scale of one to ten was utilized; in which one represents the worse note and ten the best; MCDA permits the use of scales or utility functions and in this form any kind of data can be applied in the comparisons. The following Figure 6-25 presents the total alternative's evaluation, and overview of the model is in Appendix H.

Alternative	Legal	Social	Environmental	Management	Economical	Technical	Schedule
Alt. 4.0 m	0,5000	0,6532	0,3667	0,5000	0,5356	0,5724	0,5009
Alt. 5.0 m	0,5000	0,3468	0,6333	0,5000	0,4644	0,4276	0,4991

Valuation	
Alt. 4.0 m	0,4716
Alt. 5.0 m	0,5284



Main Modules Relevance	
Legal	4,00%
Social	10,00%
Environmental	45,00%
Management	1,00%
Economical	15,00%
Technical	15,00%
Schedule	10,00%
	100,00%

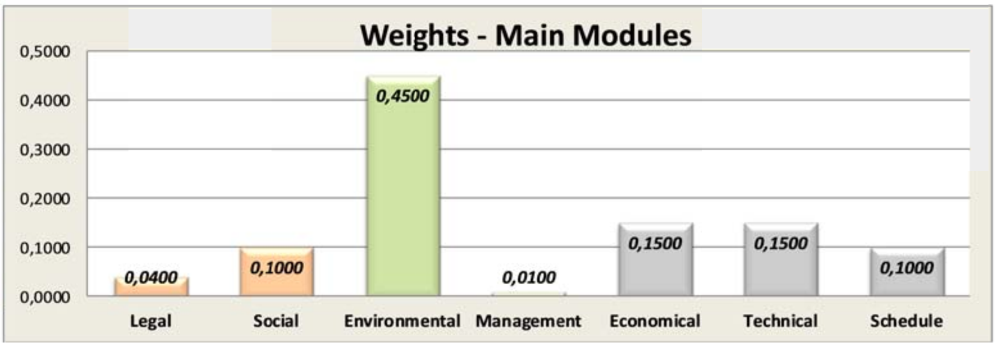


Figure 6-25: Alternative's selection with the original expectations

The total alternatives evaluation (Valuation in Figure 6-25) permits to affirm that the alternative with 5.0m of the stage 3 is the best one for the given weight configuration (expectations). As mentioned before, is easy to appreciate that the environmental criteria was the most important for this conclusion.

A detailed analysis of the alternative performance according to each module is presented in Figure 6-26. It resumes in graphic form the total evaluations for each module, there is easy to appreciate that the 5.0m presented a better performance in the environmental module; however the technical, economical and social modules were better performed by the 4.0m.

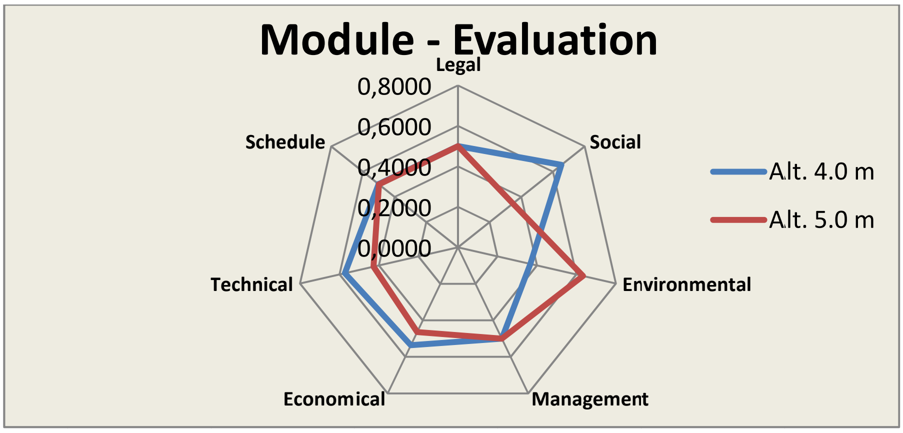
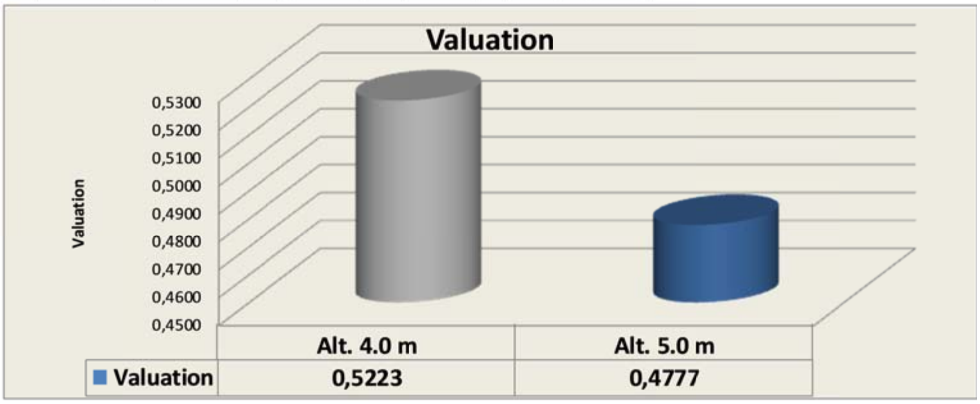


Figure 6-26: Module evaluation alternatives 4.0 and 5.0m

An advantage of the model, is that it permits to evaluate different expectations just changing the weights; for example if we are just considering the costs as most relevant, or in other words, we just care to build the less expensive alternative, we can change the weights as in the following Figure 6-27.

Alternative	Legal	Social	Environmental	Management	Economical	Technical	Schedule
Alt. 4.0m	0,5000	0,6532	0,3667	0,5000	0,5356	0,5724	0,5009
Alt. 5.0m	0,5000	0,3468	0,6333	0,5000	0,4644	0,4276	0,4991

Valuation	
Alt. 4.0m	0,5223
Alt. 5.0m	0,4777



Main Modules Relevance	
Legal	4,00%
Social	10,00%
Environmental	15,00%
Management	1,00%
Economical	45,00%
Technical	15,00%
Schedule	10,00%
	100,00%

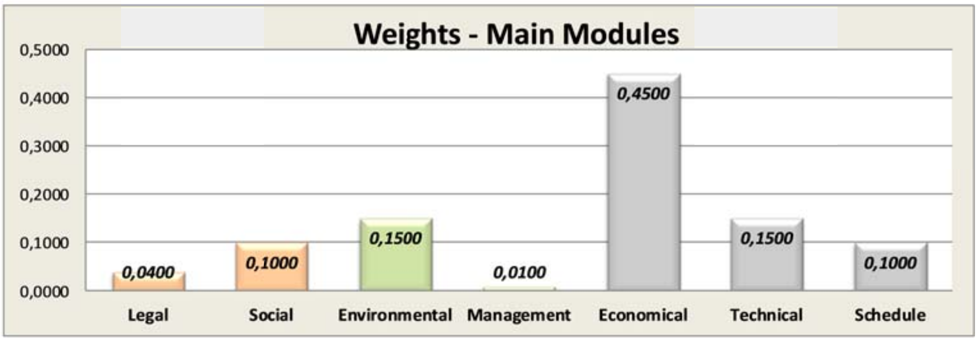


Figure 6-27: alternative selection based on costs

We can see that now that just changing two weights we can chance the selection, in this case environmental with 15 % and economical with 45 %, then the best alternative with 4.0m is the best, mainly because of its performance in the technical, social and economical modules (see Figure 6-26). On the other hand the compensative nature of the AHP methodology prevents or avoids the selection of an alternative, if its evaluation is extreme deficient in the required criterion.

Test's conclusions

This test permits to conclude that the proposed decision analysis model enables a systematic criteria allocation and a detailed overview of the decision, the proposed modules make possible the distribution of the different criteria and together with the graphical hierarchies description and weights, transparency is integrated in the decision analysis process.

The use of risk analysis for the development of the different alternatives opens new possibilities for a quantitative procedure for the project development and enables to associate the corresponding probabilities to each alternative (stochastic analysis).

An important task for any construction project is the determination of the corresponding risk factor for the calculation of the risk costs ("wagnis" in Germany, see section 3.2), because is normally proposed as a percentage of the bid sum, in addition to this the high competitiveness in tendering procedures in the construction industry, makes vital to calculate this percentage in a more accurate and efficient way.

The proposed methodology makes possible to calculate an adequate risk cost aimed to avoid losses in the elaboration of the bid, moreover it permits the consideration of predictions even before the execution take place and in this form to facilitate the decision of participate in the tendering process. Therefore the constantly development and actualization of the data banks represents an essential task, for a reliable evaluation of the confidence intervals.

The inclusion of ANNs for the determination of the inputs for the MCS permitted to reduce the dispersion in the results of the simulation. This can be in the following Figure 6-28 appreciated.

Bid Sum (brutto)	357.727,67 €	Bid Sum ANNs (brutto)	357.727,67 €
Scenarios	Contingency	Scenarios	Contingency
Optimistic (10%)	7.253,70 €	Optimistic (10%)	6.474,97 €
358.102,76 €		351.166,35 €	
Expected (45%)		Expected (45%)	
364.981,38	Contingency %	357.049,87	Contingency %
Pessimistic (90%)	2,028%	Pessimistic (90%)	1,847%
376.192,09		366.029,67	

Figure 6-28: MCS results for the alternatives 5.0m with and without ANNs

The differences between the three scenarios offered by the two simulations, permits to appreciate that the utilization of the ANNs permitted to reduce the range, and accordingly to present a more precise contingency appraisal, from a quantitative stochastic basis. This increases the opportunities in tendering procedures, by reducing the contingency, besides that this amount is developed according to the individual project requirements.

The use of AHP makes possible to configure the decision analysis process according to the expectations of the project. The use of the proposed weights determination based in 100% makes possible a faster and clear approach to the decision analysis and reduces the possibility of making a consistency contradiction (very often mistake with the typical Saaty's methodology). Consequently main modules and criteria can be easily controlled together with their evaluations, due its representation in the AHP model.

Figure 6-29 presents the overview of three modules, with their weights and module evaluation; these graphics show in a simple form the alternatives performance in every module and the corresponding sub criteria relevance of each criterion.

Figure 6-29: Overview of the legal, social and environmental modules, from the AHP model

As last step inside of this test, a comparison was prepared between the alternatives with use of ANNs and without ANNs, see Figure 6-30.

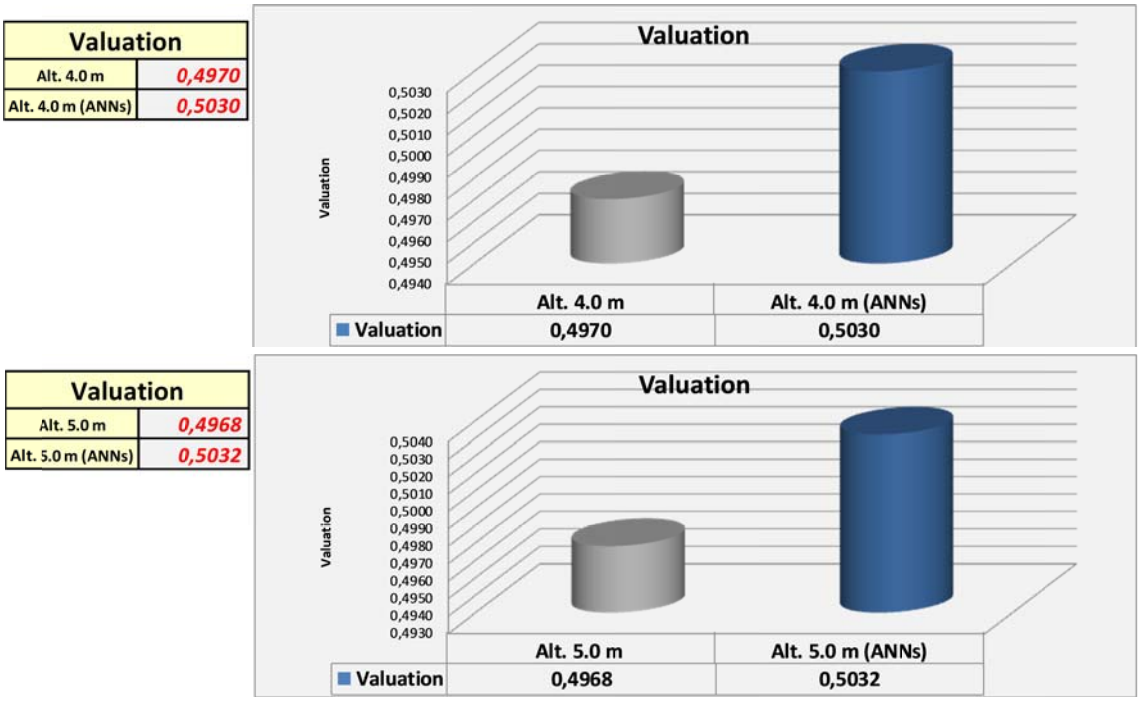


Figure 6-30: Alternatives comparison, with and without ANNs

This last test permitted to appreciate that the alternatives with ANNs represent a better option for their implementation, mainly because the dispersion reduction delivered lower bid sums with higher certainty. Therefore the use of ANNs contributed to a more accurate project determination and consequently the range of the confidence interval calculated from the MCS for the bid sum, was reduced.

6.3 Conclusions

The application of decision analysis methods in the evaluation of drafts for the attendance of construction projects in the project development has proved to be possible and meaningful. The introduction of decision analysis methods incorporates a systematic approach to the decisions within the project management and allows the traceability of the decision itself. At the same time it provides a clear representation of the decision and defines criteria for their evaluation.

Through the application of risk management and particularly through the integration of ANNs in the risk analysis, project development gains in reliability. It reduces uncertainty and examines the risk criteria and their analysis in a more detailed form; this opens new possibilities for project's processing and its further development and consequently for every activity in the project. Hence the constant development and procurement of the data banks represent a vital and relevant procedure for the reliability of this risk analysis.

The integration of the several and different criteria in the decision analysis model (e.g.: m^2, m^3, hr, kW,%, etc.) allows a simultaneous and global evaluation of the project in a single assessment system. AHP enables integrating all these criteria in a single assessment process and provides an overall rating, which reflects the requirements of the project based on the weights used.

The determination of the weights in the typical AHP procedure is an exhausting and complex task. The Saaty's weighting methodology for subjective criteria is complex, this might provoke that the user could easily make mistakes in the comparison process, when a high number of criteria are utilized and for this reason that AHP includes a consistency check. The proposed weighting procedure presented in this dissertation (using 100% as basis) simplifies the work of defining and weighting the criteria and also aids to avoid errors.

The decision risk analysis system has shown high potential, nonetheless it requires more testing in order to improve its applicability in the practice, thus it is important to use this system in other projects in order to investigate its possibilities, opportunities and limitations in detail. For this research the DAR project permitted to appreciate that the system can be applied to projects in practice and showed that it turns out to be important to incorporate such a system as a standard procedure. The modules defined here, can be easily expanded and modified as the projects requires, due to the flexibility of the AHP method, consequently the model can be adapted in terms of objectives and requirements of the project development and management.

Risk management has proven to be highly relevant for supporting the project development. Stochastic risk assessments should be conducted in the planning process for an adequate determination of the risk costs (or contingency), for the consideration of single activities or for the entire project. The use of ANNs helps to reduce the range of the results (of risk analysis) and as result, the elaboration of bids for tendering gains on competitiveness. ANNs permits to reduce the contingency according to the project characteristics and its performed for reducing the possibility of losses due to uncertainties. The results of this work have shown that for achieving reliable results, the elaboration of the data bases is vital, in addition the use of risk analysis and the effects of avoiding risk into other bearers (partners and insurance), it has to be constantly monitored, analyzed and included into the risk analysis. Consequently completed projects should be analyzed and the gained information used to improve the data bases and the risk analysis procedure.

7 Conclusions

7.1 Conclusions

In the construction industry, project development is one of the most determinant procedures in the definition of a construction project, the project managers make use of methodologies based on experience and they are confronted with large quantities of information, however project development is performed under high levels of stress and pressure which propitiates mistakes and misunderstandings and decision analysis aids to prevent this problematic. The decision analysis methods were created to support the decision maker by introducing a systematic procedure and quantification in the decision's evaluation in order to achieve a reliable decision. Accordingly, the decision is performed with subjectivity, thus it permits to clarify and define the different methodologies and/or processes for quantifying and measuring the criteria for all the participants.

This dissertation presents a methodology based on the decision analysis methods aimed to support project development proposing the use of a decision risk analysis system for the alternatives assessment within the project's evolution. Chapter 2 presents a summary of the decision analysis and demonstrates that this field has become a large and important topic for many researchers in different areas around the world, moreover its use combined with computer programs has emerged as a strong and important tool for the evaluation of any decision, when two or more alternatives are available with a high number of complex criteria. Though the use of decision analysis methods is growing and combined with the use of the computer (known like decision supports methods, see section 2.8), opens new possibilities for its instrumentation in construction projects.

Risk management is gaining stand in relevance and especially risk analysis and it's quantification. All of which are included in the risk analysis process. At present time and particularly in construction projects, risk analysis is performed in a strong subjective form and in rare occasions is performed in a quantitative form. Nevertheless the most important problem in this field is the definition of risks and uncertainty. Even though Knight in 1921 defined risk as a quantifiable criterion and uncertainty is denoted for its not quantifiable nature, currently there are several definitions of risk, furthermore in a construction project each of the different participants understands risk in a different way. Which propitiate misunderstandings and obstructs the project development.

Chapter 3 presented a form to define and classify risk and uncertainty together with a resume of the most important risk analysis methods. It is vital to understand that uncertainties must be always considered and included in the risk analysis, in this context a contemplation of uncertainty in the project's bid sum is added in the risk methodology proposed in section 6.2.3, making use of historical analysis and through the application and development of data banks for the artificial neuronal networks (ANNs).

7.2 The developed system

In order to provide a systematic by the procurement and development of any construction project and to overcome the problems mentioned above, this research presented the decision risk analysis system. This system makes use of AHP methodology for the decision analysis and enables the use of different methods for the evaluation of alternatives. In every construction project risk is just one criterion of the project, however normally each of them is considered and evaluated with different procedure, the system proposed in this research makes it possible to assess all the required criteria in a single procedure, with the elaboration of a total score based in the partial ranks elaborated for each of the different criteria.

The collection of criteria is an extreme vast and elaborated task in the project development, the criteria could stem from so many and different fields, like financial, normativity, aesthetics, etc. The section 4.2 presented some of the life cycle and the sustainability considerations. All types of criteria represent the opportunity of been employed as utility functions inside the decision analysis model of the system, which confers more certainty and efficiency to the system.

This system provided also a general model for the allocation of criteria in seven different modules, nevertheless this general model represents just one way to sort the criteria and it can be arrayed as required, though the risk analysis module depends of the risk awareness of the project or contractor. Risk can be included as sub criteria for projects with high levels of risks analysis or be included as a module, when just a single risk analysis is performed for the entire project.

It is important to note that in project development the criteria used for the evaluation are normally single relations and in rare situations a detailed analysis like presented in test three (section 6.2.3) is considered. Nevertheless this test permitted to assure that the proposed system presented no complications to overcome this level of details and can even include more complicated hierarchies and information amounts. Still the utilization of a stochastic risk analysis methodology for the alternative's development permitted to illustrate the opportunities offered by the risk analysis methods. The inclusion of ANNs as first step in the determination of inputs for the Monte Carlo Simulation (MCS) increased the certainty and permitted to achieve more reliable results together with more detailed analysis possibilities via sensibility analysis and the range of the simulated results is reduced.

The utilization of weights makes the composition of the project's requirements possible and enables it to individualize the project according to its specific needs. Therefore the utilization of the proposed scale for the definition of weights based on 100%, simplifies the determination of weights and reduces the effort in the decision analysis model. This procedure represents an advantage against the traditional weighting procedure proposed by Saaty, for the reason that sometimes the scale from 1 to 9 is not enough and the pairwise comparison becomes highly complicated with a high number of criteria.

Another advantage for the project managers (PMs) is the representation of the decision in a hierarchical graphic. Typical for the human being is to perform decision analysis in our own brain, sometimes this procedure is so fast and automated that we don't even perceive how we perform these decisions. Therefore the representation of the decision permits to analyse and visualise all the criteria and evaluation methods implied, for its examination. In this form the transparency and decision' consistency can be verified. Nowadays there are many computer applications for risk analysis and recently also for ANNs, therefore the implementation of stochastic risk analysis should be increased in the construction industry in order to provide more certainty and chances to this and all sectors.

In summary, the following objectives have been achieved through this dissertation:

- Systematization of project development under the conditions of the multi criteria decision analysis (MCDA)
- Application of the analytic hierarchical process (AHP) process in project development
- Introduction of a simplified weighting methodology aimed to streamline the definition of the weights for AHP. Thus the subjective criteria are analyzed in a quantitative form.
- An adjustment in the calculation of the weights in the AHP process that allows the simultaneously use of maximization and minimization goals (e.g.: high quality with less costs), in the criteria evaluation.
- Examination and determination of the opportunities and requirements that are necessary for the application of ANNs in the construction field.
- A clear introduction and representation of a quantitative risk analysis method, for the determination of the overall risk using scenarios from historical analysis.
- A new risk analysis method based on ANNs + MCS, which permits it to enhance the certainty of the project by reducing the scattering of the inputs and accordingly of the risk analysis.
- The application of ANNs enables uncertainties to be taken into account in risk analysis.
- Through the use of scenarios contingencies can be determined individually for the project and added in the bid sum as an amount, this means to include uncertainties to the tender amount. Thus the possibility of losses due to inappropriate risk determination or uncertainties is reduced.
- Integration of risk analysis and its benefits in the project development
- Transparency and simple representation of the decision using AHP
- Verifiability and transparency of the taken decisions and project development process

- Systematization of decisions and development of a single system that simultaneously and reliably rated all criteria of a project.

The utilization of decision analysis proved to provide an important supporting tool to the project development and shows the necessity of including more decision analysis instruments for construction projects. Risk analysis should always be performed and uncertainty should be considered as the not identified or quantifiable criteria that impacts the project.

7.3 Recommendations for further work and research

The system developed in this work is one application of the decision analysis methods in the project development for construction projects. Nevertheless new computer applications are emerging that allow us the use of many other decision analysis methods and develop new instruments in the decision support systems (see section 2.8), therefore several methodologies like for example Outranking can be applied and also deliver adequate results. Nevertheless their utilization represents a challenging task for programmers and software developers. The present work makes use of AHP mainly because of its simplicity and its consistency check, thus it represented for the present research the best alternative.

The proposed modules for the decision analysis model proved to be adequate and provided sufficient support for the alternative's evaluation which can be modified as required. According to the present work a definitive model with fixed modules is not necessary, more important is the flexibility of the system, moreover when a methodology is available (like the VA Analysis), it is vital to abstract it into the decision analysis model, in order to facilitate its comprehension to the participant familiarized with the method.

Risk analysis is integrated to the evaluation process of the system, nonetheless traditional risk analysis like Delphi methodology or Portfolio representations can be also employed, even so the utilization of quantitative risk analysis like the utilization of the new methodologies form the artificial intelligence fields. They are the new target that the current risk analysis pursues, aimed to integrate them in the construction field. A real challenge for the application of quantitative risk analysis is the development of data bases that support the risk analysis.

Robust and defined data bases permit the elaboration of more detailed and reliable risk analysis, whit their corresponding certainty improval. In this field; methodologies like the ANNs and support vector machines (SVM) represent a new horizon for risk analysis, nonetheless they can only work with solid and structured data bases.

Furthermore the utilization of ANNs and SVM enables to include uncertainty considerations in the risk analysis; due these methodologies require just the factors and their result and after the learning process, uncertainty considerations are already integrated.

Therefore the detailed definition of data bases according to the project and/or contractor's goals are of high relevance.

In order to perform a more detailed fine tuning of the proposed system, it is required to implement more applications of the system in different projects and to develop a system's management system that concentrate all earned information and data for its further use. The decision risk analysis system makes use of the AHP methodology for the alternatives evaluation, it is also possible to use of sensibility analysis for the determination of the most relevant criteria and their corresponding weights. This analysis may support the decision maker to have a better understanding of the project and also to recognize the most important criteria for further optimizations. This system was developed for the construction field in attaining the aim of facilitating the use of decision analysis methods and their benefits for construction projects.

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Glossary

A

Acts of God — Events beyond any human control, like natural disasters

Alternative — Alternative also known as "Action" or "Outcome"; is when two or more possible solutions to a problem come in to the selection, each of this solutions enclosures an amount of information to evaluate, they have as main target to fit the expectations.

AS/NZS — "*Standards Australia is an independent, not-for-profit organisation, recognised by the Australian Government as the peak non-government Standards body in Australia*". (Australia)

B

Binary scrutiny — The criteria is ordered and compare in a pair wise comparison also known like binary comparison

Black Box Effect — ANNs presents a black box effect, which means that there is no chance to verify the trained neuronal network. "*The model obtained with neural network is not understandable in terms of physical parameters*" (Johannet, 2007)

C

Ceteris paribus — "which means that when a variable is changed, the rest remains the same; also that only the variable can only be known within a certain range, it is defined by the person who performs the analysis" (Smith, 2006)

Context — This refer to all the external influences (features and rules), that constitute and define the solution's selection.

Compensatory Methods — The principle of the compensatory methods is to verify if the deficiencies of an attribute, criteria or alternative, can be compensated by its benefits and if that's possible.

Criteria — The criteria set the evaluation's measurement; they are the group of rules and characteristics that determinate how to analyze and evaluate decisions. It can be classify in ordinal and cardinal criteria and sometimes in interval, probabilistic or fuzzy criteria:

- **Ordinal Criteria** (qualitative): By the Ordinal Criteria the gap between two values does not have a direct impact in the preferences, the DM will value it according qualitative ranks and / or scales, these scales can be divided in Verbal scale and numerical scale.

- **Cardinal Criteria** (quantitative): By the Cardinal Criteria the DM has to fix a numerical value to the criteria based on his judgments and according the problem's characteristics, this procedure needs normally a justification.

- **Interval, Fuzzy and Probabilistic** criteria: When some vagueness is considered on the measurements, the criteria can be expressed on the three different mentioned forms, to search out for a better accuracy.

D

Decision — Is the end Product of a mental process (mental analysis of factors), by an individual or a group. Decisions can be defined in three different classifications based on its particular point of view, according to Aragonés (Alarcón-Núñez, 2005).

- According to its nature: Certainty, uncertainty and risk
- According to the decision Criteria: Mono criterion or Multi criteria
- According to alternative characteristics: Continue or discrete problems

In the reality problems are normally a combination of them.

Decision analysis (making/aid) — It refers to and structured and approach to the decision making.

For the present research the terms "Decision Making" and "Decision Aid" are integrated in to the "Decision Analysis" to uniformity and adequacy with the newest state of arts.

Decision Analysis Methods — Mathematical methodologies for support the decision analysis process

Decision Maker — Is an individual or a group of them, which carries the responsibility to perform an analysis and find the best possible solution for a given task

Decision Support Systems — DSS are computer-based systems that assist business and organizational in complex decision-making environment. (Marakas, 2003)

Descriptive sampling — "*A Monte Carlo sampling technique based on a deterministic selection of the input values and their random permutation, represents a deep conceptual change on how to carry*

	out a Monte Carlo application" (Saliby, 1997), similar to Latin Hyper Cube Sampling.

E

Enterprise Risk Management	A strategic risk management framework oriented to optimize the risk management functions in an enterprise, by the appropriate classification and finally a more precise utilization of risk methods, risk philosophies and resources, hence to distribute the responsibilities to the correspondent operative management levels and with this to perform the day-by-day interaction with risks in every management level, for an improved global performance towards risks

F

G

General Decision Analysis Problem	Developments of a strategy and/or disciplined methodology with the intention of secure and facilitate the process of making a decision.

H

Hamming Distance	Method elaborated for the computer sciences, for the compare of Intput information as "*The Hamming distance between two strings is defined as the number of characters in which they differ*" (Jarrous, 2009).
Hyper Plane	Supporting vector developed to separate Data in respective dimensions. "*More generally, a hyperplane is any codimension-1 vector subspace of a vector space*" (Weisstein).

I

Information and communication Technology (ICT)	Is synonymous for information technology and it refers to the Integration of communications systems to support a process.

J

Jour Fixe	Term tagged to stipulate periodic meetings in which the participants can discuss about the goals and their accomplishment.

K

K.O. Criteria	Crucial criteria for the acceptation of a project, if this kind of criteria is not granted, the project can be declined.

L

Latin Hypercube	A Monte Carlo Sampling technique that permits to screen

Sampling	the selected data by the Random selection numbers, which permits to perform the same procedure of the Monte Carlo Simulation with less runs and with the same advantages
Leptokurtosis	It refers to the cases on which the data is similar to the bell distribution but is not the same, in extreme cases produce fat tails. This is a typical assumption in Value at Risk and Monte Carlo Simulation.
linguistic aggregation methods	Simple decision analysis methods, these methods work based on a linguistic rule like the "if …, then…"; Like the decision trees.
Life Cycle	The general timeframe of an object, from its creation (construction) until its end (fall down) (Rudloff, 2010).

M

Multi Criteria Decision Analysis (MCDA)	It "*refers to making decisions in the presence of multiple, usually conflicting, criteria*" (Hwang, 1981).

N

Non Compensatory Methods	The tradeoffs between attributes are not permitted; the advantages or disadvantages on every attribute will not be compensating by any another.

O

Outranking Methods	Methods based in the binary scrutiny, also defined as pair wise comparison also known like binary comparison, they are based on the most dominant characteristics of the assessed alternative's criteria

P

Project development	Project development is to combine factors such as, location, project conception and capital in order to create a project that as consequence results competitive and job-creating for the microeconomic and therefore is permanent rentable for macroeconomic, social and environmental matters (Diederichs, 1999).
Project Management	Is *"the application of knowledge, skills, tools, and techniques applied to project activities in order to meet or exceed stakeholder needs and expectations from a project"* (PMI, Project Management Institute, 2000).
Project's Risk	"Combination of probabilities of one specific event and its results concerning to the project's goals" (DIN EC 62128, Deutsches Institut für Normung, 2002)

Q

R

Risk — Is the general term for occurring (identified and quantified) events or factors, from which negative or positive consequences can result; “Risk” can be classified on two different categories: “Danger” or “Opportunity”:

- **Danger**: (also known as Hazard) capability that the deviated outcome from current or predicted happening, to endanger the expected results.
- **Opportunity:** capability that the deviated outcome from current or predicted happening, to support the expected results.

Nevertheless danger and opportunities are normally defined on probabilities and their effects

Risk Appetite — Risk appetite can be understood like the quantity of risk that the enterprise can deal with or accept. Barfield, Richard defined it as “*the quantum of risk that the firm is willing to accept within its overall capacity*” (Barfield, 2008).

Risk Management — “Formal Risk Management is a structured approach to administrate (analyse, evaluate and control) risks” (Maria-Sanchez, 2005). In other words RM is the application of management principles in to the risk evaluation.

Risk management process — Defined cycle result of the interaction of its own sub-processes on which identification, analysis, response and controlling are considerate, this sub-processes are interconnected to each other and permits a better reaction to deviations from the aimed goals.

Rank Reversal — The addition of criteria in an existing AHP can provokes that the ranks will turn up in a reversal in the rank.

S

Support vector machines — *“A new type of learning machine for pattern recognition and regression problems which constructs its solution in terms of a subset of the training data, the Support Vectors”* (Schölkopf)

T

Taguchi Method — Method developed by Genichi Taguchi, “*is an experimental approximation to minimizing the expected value of target* *variance for certain classes of problems*" (Otto, 1991).

Taguchi created an on-line and off-line quality procedures with their corresponding philosophy and a methodology. "*For the process of quality improvement depends on statistical concepts. Especially statistically designed experiments.*

The primary goals of the Taguchi methodology can be described as:

(a) a reduction in the variation of a product or process design to improve quality and lower The loss imparted to the society:

(b) a proper product or process implementation strategy which can further reduce the level of variation" (Cheng, 2001).

Trade off based weights Weighting methods that allows the attribution of values to the criteria and in this form to reflect the preferences of the DM, also know like compensatory methods.

U

Uncertainty Uncertainties come in to being for effects of unknowable factors (unexpectedly unknown and immeasurable events) while risk is evaluated with knowable factors and probabilities (expected identified measurable events) (Knight, 1921), therefore the difference between risk and uncertainty lies according to the nature of the data (risk is measurable – uncertainty immeasurable unknowable factors).

It can be classified in:

Pure Uncertainty: not identified, not quantified

Partial Uncertainty: identified but not quantified

Utility functions Aid functions based on the Utility Theory (Neumann and Morgenstern 1944), the DM's preferences are represented in mathematical formulas for its quantifications and further utilization in the DAM.

V

W

Weight Is the numerical importance or relevance for an alternative or criteria referred to others; in other words how an alternative or criteria is preferred (important or dominant) to another. The assignation of a value can be either directly given, by the elaboration of a weight matrix or a utility function.

X

Y

Z

Appendix A: Implementation of decision analysis methods in the construction industry / projects

Contained in the following collection of works presented in this chapter, are some examples of the applicability to multi criteria decision analysis methods (MCDAM) on the construction industry/projects in civil engineering fields. They represent several types of problems and methods under different considerations.

a. ***"Entwicklung einer Entscheidungshilfe zur Festlegung der Vergabeform"; (Development of a decision aid for the determination of the contract form;*** (Racky, 1997)***.***

Subject of this dissertation:

The main topic of this work is the development of a decision aid for the examination and choice of the most appropriate contract form under the German legal structure, with a special handling of the implied risks. The author carries out extensive research and analysis about the most important factors in the German bidding procedure with a special emphasis on the costs, plan optimisation, guarantees and deadlines; with this goal a decision model to support these tasks, is developed.

Final argumentation:

Criteria selection is an extremely important procedure to the determination of the structure of any decision, the author makes an extensive collection and description of the most important factors for the analysis and decision making on the contract forms problematic, his analysis are based on considerations focussed on deadlines, costs, executive plan optimisation and responsibilities / guarantees with consideration of 20 different construction projects.

For each of the four main criteria (costs, plan optimisation, guarantees and deadlines) the author performs a detailed scrutiny about the legal frame, the bounded risks and a qualitative risk management. The form of his analysis is extensively commented and they contain suitable observations about the most important concepts to consider. Thus this work collects several required pieces of data, as well as very important criteria and considerations towards the contract form selecting process. The decision model is not complicated and is not a mathematical model choice aid based on MCDAM; however, due to the problematic he analyses, complexity arises because of constantly changing legal frame and also because a model representation as a quantitative model is extremely complicated.

Concerning the selection of the decision analysis method, he presents a decision method based on simple decision matrices, nevertheless these matrices are not targeted for matrix calculations, but for a graphic criteria presentation.

The model proposed in this work is a table representation of pros and contras for selected criteria, from the four main criteria expressed in qualitative form where “++++” is the maximum and “+” the minimum. Risk considerations were never determinate in a quantitative form, still the author proposes many ways how to distribute and handle risk, in spite of that the proposals are made on experience.

The use of a MCDAM could provide a better approach with an appropriate treatment and determination of quantitative values and scales as well as the use of risk analysis methods, in this way he could deliver better considerations about costs and certainty, nevertheless at the moment as the work was developed MCDAM were not as developed and accessible as today and it was not the main goal of this work.

But to accomplish a MCDA model for this work it would be necessary to redistribute the criteria collected in this research and sort them in quantitative data for their scrutiny, and consequently to search and establish a definitive model structure.

In conclusion this work presents a very extended analysis, collection and description of the facts around the choice of the contract form in the German legal frame, it delivers a simple decision model on which quantitative data (from qualitative considerations) can be treated depending on the project, the results are extremely qualitative, just as the nature of the problem, mostly because the work is based on the regulations which implies extreme number of actualizations, therefore a linguistic method could offer also good opportunities mixed with other quantitative considerations. The model presents aid to the first considerations by choosing the contract form; on the other hand the problem would acquire a better approach by using MCDAM and not only based on graphical or matrix representation, which means the elaboration of measurement and scales (quantification) for a more efficient analysis.

b. ***“A concerted and multi-criterion approach for helping to choose a Structure- Foundation system of building”;*** (Al Diab, 2003)***.***

Subject of this paper:

This work regardless of the fact that it is a resume of a conference, presents a good introduction to the problematic related to the present work, which is the evaluation of the design process of civil engineering construction.

In this work the authors present a problematic under the approach of the best building design; the goal is to elaborate the basis of a multi criterion approach tool to support the selection of a structure-foundation system considering the different design stages for a common offices building; this approach is under a client/architect point of view. The main purpose of this work is to pursue a better coordination between the projects actors and to unify their different and normally conflicting interests and create a validation based on four different criteria. However it is just an introduction to the problem and the decision analysis model was not presented, together with the fact that no specifically MCDAM were directly mentioned.

Final argumentation:

This paper presents a brief introduction to the problematic of design and project actors' coordination in a very basic form; it also presents an analysis of some of the basic criteria needed for the development of an evaluation process. The principal objective is to analyse the combined structure foundation choice and the validation of these two selections and finally combination. With this goal the evaluation of the alternatives is made under the concernment of technical, economical, environmental and social criteria.

As the basis of this work concerning decision analysis, only "*Roy 85*" and "*Henry 96*", which doesn't specify exactly the chosen decision analysis method but leads to the outranking method "ELECTRE" created by Roy and "GENEFOND" proposed by Henry, however that doesn't provide enough information about the DAM because of the several versions of ELECTRE and no specific method is directly mentioned. On the other hand the authors present a simple representation of a diagram that illustrates how the screening process of their alternatives selection is performed, it is ordered in six different "Tasks" and sub "Tasks", this representation provides a general overview of the structure of the MCDA problem; constrains are also mentioned and the Alternatives are sorted to their respective tasks in order to perform the evaluation.

The method presented here is extremely simplified and is based on a small amount of information besides its representation is based in a table, the tasks are labelled as:

- Task 1-box1: Select feasible alternatives
- Task 2-box2: Select feasible alternatives and eliminate unfeasible
- Task 3-box3: Generate the combinations of structure and foundation
- Task 4-box4: Identify the particular criteria for a project
- Task 5-box5: Evaluation of the combined solution based on the criteria
- Task 6-box6: General evaluation through criteria aggregation

The procedure presents a basic evaluation process based on the concordance and discordance principle (another clue to ELECTRE), the task 3-box 3 "Combination task", might present a problem because the application of outranking methods might lead to exclude criteria that could be important to analyse, here the application of a selection based on aggregation methods might achieve a better valuation of the criteria, for the reason that benefits from both sides (foundation and structure) shouldn't be excluded just because one criterion has a bad result, just when this result is extremely bad, can be rejected or is a vital criterion.

For this reason a model created by a combination of two methods should lead to obtain a better selection, by the Feasibility studies (Task 2) screening method based on the concordance and discordance principle is appropriate, but the Combination task (Task 3) offers a better analysis for this combined selection.

In general the proposed model sketched by this work has a promising structure but when it describes the decision analysis methods (DAM) there is insufficient information and it offers just a basic exploration of the selection-combination of structure and foundation. For a better understanding more information is required about the methods, scales, ordinal and cardinal information and the way the criteria should be assessed. This paper represents (like the authors mentioned) a prototype to the creation of an evaluation model and as a prototype it is a good start for its development and the application with DAM.

For the development of this prototype there is more information required and clear representations of the data sources, as well as better specifications of the implicated risks, for the reason that risks were not considered in this paper.

This work can be considered as an introduction to the problematic of the decision analysis in civil engineering and the potentiality that MCDAM have to resolve design problems in the civil engineering field. It shows the steps and the logic of the construction of a MCDAM aimed to support the decision. The combination of DAM and the use of the corresponding risk analysis will bring more certainty to this problematic.

c. ***"Evaluation of the residual load-bearing capacity of civil structures using fuzzy-logic & decision analysis";*** (Faust, 2002)***.***

Subject of this dissertation:

The principal goal of this work is to present an important aid to the evaluation process for civil structures after natural catastrophes occur, this work's goal is to develop an instrument to support the stakeholders and owners in making a decision about a structure after an extreme event takes place. These kinds of decisions are made under the analysis of several criteria and risks (monetary, personal, material, etc.).

Final argumentation:

This work presents an application of the evaluation process in civil structures; the author defines specifically an approach to the problematic of the Post-incident Investigation with considerations of a general decision arrangement aimed at evaluating the possible rehabilitation, demolition or repair of civil structures.

This investigation is based on a high amount of criteria and considerations enclosure on structural evaluation and especially on the necessary disciplines, which are mainly: fracture mechanics, computational analysis, geometry, material investigation, ductility, energy absorption, risk analysis, cost optimization and risks considerations. About the decision analysis the use of the criteria, an adaptation of "Fault trees" is proposed in combination with Fuzzy logic.

A relevant part of the analysis considered in this work is the analysis of risks. Nevertheless the risk analysis is totally concentrated (in this work as) in the detection of weak areas or structural faults, its risks combination and consequences, which is appropriate for this problem.

An important achievement for this work is the definition and quantification of criteria, a large collection of criteria is widely explained and associated with modern measurement equipment and software applications, thus together with the modern structural analysis techniques provided for the research, permits the development of a suitable definition of quantitative scales and criteria in order to perform the analysis; consequently the consideration of risk becomes an important analysis for its "trustworthiness". The author explains that the insufficient data can be treated by the addition of fuzzy logic.

The multi criteria problem defined by this work intended to elaborate a holistic procedure composed of three consistently performed steps, "specifically screening assessment", "approximate evaluation" and "further investigations". In other words this approach leads to a failure path while analysing each criterion.

The method of fault trees lead to single structure analysis and allows the consideration of separate structure components; however the holistic evaluation is delegated in partial evaluations, the proposed method performs an adequate evaluation of the structure's individual components (e.g. Beams, Slabs, Slab/wall connection, Precast elements, Fundament, Moment frames, non-structural elements, etc.) but might represent complications when performing an appropriate holistic evaluation, the choice of a different MCDAM or a combination of them, like the methods based on the compromising principle would allow a better determination of a global structure evaluation, nevertheless the author proposed the use of the Hamming distance[184] to the determinations, with the goal of reducing problems derivate from errors and to perform better calculations.

A better possibility for determining a holistic evaluation is the use of outranking methods, the use of them shall allow through the binary scrutiny of criteria a better approach based on the fault tree structure proposed by the author. However this work explains the process of creating a multi criteria decision aid for a civil engineering problem, one of the most important achievements of this work is the incorporation of the risk analysis and the utilization of several different quantitative results from, for example, physics. That increases the certainty of the analysis.

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[184] "*The Hamming distance between two strings is defined as the number of characters in which they differ*" (Jarrous, 2009).

Risk analysis showed itself to be an important variable to analyse and to control, therefore a higher analysis in other topics outside of structure weakness represent a substantial improvement to this and any other work.

The wide selection, classification and quantification of the criteria is the most important achievement of this work, the use of the several formulas and physic determination, confer the criteria quantification process a high level of liability applied to the evaluations and aims to ensure its better processing. Is for this reason that this MCDAM procedure offers high potentiality (the application of the several formulas as utility functions).

The use of Fuzzy logic shows also that the right combination of techniques shall lead to ensure the profitability and advantages offered by each of them and through its right application, to perform a better use and improvement of the developed methods.

d. ***"Modelo integrado de valor para estructuras sostenibles (MIVES); Value-Integrated Model for sustainable structures";*** (Alarcón-Núñez, 2005)**.**

Subject of this dissertation:

The author of this work has as her main target to elaborate a methodology that shall result in a tool that determines a "Value index", this value index helps to evaluate the sustainability of industrial buildings during its life cycle processes in the Spanish market. The considerations of this work are grounded on three principal axes: requirements, components and life cycle. MCDAMs are employed at the heart of the analysis and as result an application tool is developed from the selected decision analysis model targeted to procure a functional and coherent design procedure.

Final argumentation:

This work presents the habitual problematic of the continual optimizing procedure of the construction industry within the design process. This work shows that in the life cycles processes there is an enormous amount of criteria and factors which constitute the choosing process of a definitive project alternative, therefore the analysis of the several data shall be consequently structured. As a first step, the author elaborates a research of the state of arts surveys in MCDA and in the sustainability concepts; this research helps to choose of the appropriate MCDAM for the decision model.

Several of the most relevant concepts in the decision analysis are defined and presented; these definitions help readers to understand the reasoning of solving the main task. The author also briefly introduces the most relevant concepts of the sustainable development, consequently emphasizes the three most important concepts for its criteria analysis, according to (Hill, 1997); these criteria are named "Pillars" and they represent the main criteria for scrutinity: the “social pillar”, the “biophysical pillar” and the “technical pillar”.

With these principal pillars the authors performs the determination of the most important analysis criteria for this specific problem, under the consideration of the specific needs related to the decision analysis methods. The MCDAM are presented on this work in a complete and well explained form and the work includes many resources to understand the implied considerations. In conclusion the analytic hierarchical process (AHP) method is selected for the development of the decision analysis In the modelling procedure, the author delivers also a simple classification of the MCDAM in this work, and it’s based on two different points of view with respective sub classifications as follows:

- The evaluation methods according the information about the preferences
  - Techniques of void information about the preferences
  - Techniques of partial information about the decision maker (DM) preferences
  - Techniques where the information is complete and both-way
- The multi criteria methods according the number of alternatives
  - Infinite number of alternatives
  - Discrete number of alternatives
    - Aggregation
    - Outranking

This classification of methods represents an effort towards the complicated task of “the MCDAM classification”, nevertheless this is not performed for all the existing methods, many other methods are not mentioned, thus that wasn’t a target for this work.

The classification is small but sufficient to clarify the author’s selection, but they don’t allow a researcher that is still not properly involved with the MCDAM, to obtain an overview and finally select one of them, the overview of the current MCDAM can be enormous and complicated and it can have the result that a novice in the decision analysis field may possibly not be able to follow the justification about why the AHP is the most appropriate selection for this case.

On the other hand there is a good collection, explanation and classification of the used value functions, for the reason that the main analysis on the developed model is based on the value functions, the author remarks on their importance, which is to confer a scale which enables the DAM to analyse and compare the alternatives with high levels of consistency.

The author presents as well some of the most important software that provide assistance to the decision analysis, software like AIM, ELECTRE, PROMLAC, Expert

Choice, etc., and also for sustainability analysis like, BREEAM, GB Tool, GB Tool Español, LEED, etc. these software are briefly analysed and their possibilities are mentioned.

By the development of the Model the most important criteria is set in six different categories as follows; Environmental, Economical, Social, Esthetical, Safety and Functional, all of them are based on three main considerations; Requirements, Components and Life cycle. From this basis the author realizes a collection process of the respective sub criteria, and its allocation in hierarchical form.

The hierarchy is arranged as follows in the analysis:

- Requirements
- Criteria
- Sub criteria
- Indicators

The model is built in AHP and includes considerations about risks, the considerations about risk are realized with the use of the BETA II method, which considers the use of the optimistic value, the pessimistic value and the most probable value to define a mean value “μ” and the standard deviation “σ” and with this to determine through a statistical analysis the behaviour function and select a final value to analyse.

This consideration is made with the goal of creating a Value function (Indicators), for the different criteria involved in the analysis process; the author proposes the use of the criteria values “+” or “-“ for the associated risk value, it also delivers a simple risk analysis of the method. However for more certainty risk should be more thoroughly analysed with more adequate methods (a better quantification), nowadays there are several methodologies for risk analysis that can be included in this analysis to obtain the highest accuracy.

The important achievement of this work is the creation of the values functions for the different criteria employed in the evaluation process together with a coherent hierarchy and structured functionality, in addition to this the use of the AHP as structure of the decision analysis model confers a satisfactory foundation for the final elaboration of the computer science tool “MIVES”; for the evaluation of the best alternative of industrial buildings.

MIVES as end result of this work allows the elaborate of appropriate comparisons with adequate quantitative considerations of each indicator. Another contribution is the inclusion of a sensibility analysis for the results; the sensibility analysis is made in relationship of the criteria and the two main targets; the Model itself and the alternatives. In this way the contribution of the criteria to the analysis can be evaluated and helps to identify the most crucial and relevant criteria for the alternative selection; in addition a geometric mean analysis is also available.

In conclusion, this work presents a foundational work directed to the creation of a methodology and tool for the analysis of an Industrial building in Spain. This work argues for the need of these kinds of quantitive instruments in the construction industry. The analysis of the MCDAM and the sustainability concept provides an overview of the general problematic, the selection of the AHP is appropriate and the detailed analysis of the several criteria, together with the elaboration of the value functions. As consequence the model propitiate accuracy to the calculation of the Value Index.

This tool provides adequate help in each process of the life cycle considerations of a civil structure (design, execution, utilization and reintegration), it presents a large collection of the required functions and steps for the analysis.

Risk analysis can be improved with the implementation of methods like Monte Carlo simulation, Latin hyper cube, Neuronal-Risk Assessment System (NRAS), etc., on the other hand the model analysis makes use of strong foundations on the materials and life cycle determinations. However cost analysis can be improved though a better determination of the risks and the correspondent representation of costs for their pursuance. Nonetheless this work provides the project managers an important support in the decision analysis process and the accuracy of this design process is itself improved.

e. ***"An Algorithm for Decision-Making at the Front-End in International Project";*** (Kulkarni, 2005)***.***

Subject of this dissertation:

This work has as its principal goal the elaboration of a Decision analysis algorithm to support the analysis of construction projects in an international market. The project analysis within this work is geared mainly to the senior management and also for the different project's stakeholders. The work's main objective is to improve competition and recognize opportunities in international construction markets; the final instrument (an algorithm) is presented as a Microsoft Access computer application. The topic of this work is totally under the project management considerations and the key analysis is based on different management strategies that apply to the front end of the project.

Final argumentation:

This work presents an application of the decision analysis in project management issues and describes all the necessary components for the elaboration of a decision analysis model. Nowadays there is a strong tendency for many constructors to take part in construction projects in an international market, because of their attractiveness and their possibilities[185]; nevertheless some of the constructors that have already try

[185] (Kulkarni, 2005)

this kind of adventure noted the importance of an analysis of their strategies, for the reason that after their previous experiences, they are aware of the enormous possibilities of failure[186]; because of this the use of an instrument to evaluate the strategies is important for all stakeholders. These kinds of instruments offer an enormous support to the project evaluations and with this, to make possible the investments in new and/or different countries.

The author examines the problem with the following approach, on the one hand he proceeds to carry out an important review of many factors that are included in the evaluation of international projects and presents the state of arts in the problematic of International projects; on the other hand the author selects the AHP method from the decision analysis methods for the elaboration of the decision analysis (DA) model, the analysis proposed by the author is based on a scoring principle delivered by the selected indicators (called Triggers by the author), ordered in the respective criteria (called Clusters) according each module (called Domain).

A principal achievement of this work is the analysis of the state of arts about the problematic of the project management on international projects; the author presents an important collection and analysis of several models and considerations from the current practices, according to this he abstracts the main structure of the model and locates the indicators to the respective criteria.

To assure a correct procedure, the author defines the model as a combination of AHP and Taguchi's fractional factorial experiments, founded in the nature of the problem. The analysis is developed in four different domains (modules): Domain I Institutional Environment, Domain II Mode of Operation, Domain III Techno-Managerial Input and the Domain IV Project Specific Aspects.

The input data to start with the analysing procedure demands a risk analysis, however it is based in the inputs from a possible previous risk analysis, this accentuates the necessity of performing a quantitative risk analysis, if such a detailed risk analysis is performed the liability of the algorithm will increase. The most important influences on the model are the determination and diminution of the uncertainties; the author presents different categories of uncertainties and proposes a methodology to handle this problematic based on earlier investigations. The author classifies uncertainties according to their evaluation in:

- Effect Uncertainty:
  How to evaluate the impact of the uncertainty in the project
- Response Uncertainty:

[186] Most of the first undertakings in International market are learning by doing because of the high amount of uncertainties and risks.

How to evaluate the managerial response to the uncertainty

- State uncertainty:

  How to assign evaluations of uncertainty to future projects

The author shows the need to perform a better uncertainties processing (to turn uncertainties into risks in a quantitative form, see chapter 3.2 and 3.3) for better accuracy and certainty in its evaluations, but the problem itself is defined by the author as the strong problematic within the project management. Uncertainties have as their most important characteristic that they are unknown influences or criteria, thus the author proposes a constant surveillance of uncertainties, which is the adequate procedure for the evaluation and he also includes a risk analysis in his considerations.

The Taguchi method together with the AHP method presented in this work represent an appropriate and coherent procedure of strategy analysis, the Taguchi method takes care to evaluate the quality of the strategies and the AHP on the decision analysis, the remaining and most important analysis is the preparation of the indicators and criteria for each module.

The method is evaluated on four diverse projects in different parts of the world, which confers an adequate frame to perform its evaluation. Thus the author presents a very coherent and structured methodology by the implementation of decision analysis in the civil engineering field. This work also presents the importance of completing the decision analysis methods by the combination of other methods from different fields, like here the Taguchi Method. The author agrees that the DM can deal better with the uncertainties according to his experience, project interaction, scenarios and organisation, as the DA describes.

The decision analysis methods adequately assist the project management after an appropriate research of criteria, indicators, risks and appropriate handling of uncertainties. The structuring process represents the gist for the definitive completion and development of a model. The model presented in this work includes a module for the handling of uncertainties and an important integration of risk analysis to the evaluation process. The use of Fuzzy logic could provide an important aid by the identification of uncertainties and also the use of sensitivity analysis shall help to improve the results.

f. ***“TUNNEL_SIM: Decision support tool for planning tunnel-construction using computer simulation”;*** (Marzok, 2008)***.***

Article Summary:

This article presents a computer application to assist contractors by the estimation of costs and time for a determinate tunnel construction project. The main goal is to present the decision support tool “TUNNEL_SIM” for the planning of a tunnel project. This method presents an application of the decision making methods to engineering projects and the advantages of including risk simulations in decision analysis. This article is complemented with an example.

Final argumentation:

This document presents an implementation of decision making methods into a designing/planning procedure; the main task is to support contractors in appraising time and costs required for the achievement of tunnel projects, as result the authors present a decision making tool named; ”*Tunnel_Sim*”. Some of the main considerations in this work are risks and uncertainties, mainly because they have a constant presence in tunnel projects and they must be understood and considered in the project’s appraisals.

The decision making tool is developed for the consideration of two main tasks:

i) Estimating total duration and cost
ii) Selecting the best construction alternative.

In three different modules:

a. Tunnel analyzer module
b. Tunnel simulation module
c. Tunnel decision making module

On the structure of the modules and for the considerations of the main criteria, results easy to observe, this tool offers evaluation and analysis in an operative matter and allows to get a better overview on the project’s key factors that define the projects requirements.

The first two modules are subordinate to the decision making module, this means the analysis and valuation process are considered in the tunnel analyser and simulation modules, therefore the decision making module performs the results valuation and permits the identification of the best choice. There are five different tunnel construction procedures considered in the Tunnel analyser module.

1) cut and cover using diaphragm walls,
2) cut and cover using secant pile walls,
3) cut and cover using soldier piles and lagging,
4) cut and cover using steel sheet pile walls, and
5) segmental tunneling using slurry TBM.

Each of these methods has different procedures, requirements and characteristics, thus the analysis is made in two different stages, with their respective sub criteria:

- Define general data
  - No. of working hours per day
  - No. of working days per week

  - No. of bridge zones
  - Project start date
  - Indirect cost
- Define zone data
  - Construction method
  - Task duration
  - Required tasks' resources
  - Labor and equipment unit cost
  - Material cost

For these criteria simulations are performed at the basis of "STROBOSCOPE" which is a general purpose simulation engine via Visual Basic. These simulations models are performed for the different constructions techniques taking care of their special needs.

The method works as follows, as soon the data is identified it will be loaded in the simulations module directly from the tunnel analyser module; this data describes the constructions method in every different zone[187]. Next, the simulation is triggered through STROBOSCOPE. Through this simulation the costs, resource utilization and project duration are determined. At the end the information is transmitted back to the analyser module for the final determination of the total project duration and cost. The main tasks are project costs, project duration and resource utilization, therefore this information is collected from different experts and according to their experience is bound to a weight factor.

This article presents a tool developed with clear use of the decision making methods in the way of structure of the decision making factors and the required quantifications measurements. The criteria evaluation and identification of risks are considered in different modules and under the decision making module evaluated. This article shows how the MCDAM are earning more attention in the construction industry and through them the main goals can better analysed and achieved. The example shows how such a decision model assists the DM (contractors here) to achieve a decision in more effective way.

g. ***"Decision Support Systems (DSS) in Construction Tendering Processes";*** (Mohemad, 2010)***.***

Article Summary:

The principal aim of this article is to review the current DSS applications on the current tendering procedures worldwide, hereafter it makes a description and analysis

[187] Zones are required according to the ground requirements, many different constructions techniques might be implement by the construction of a tunnel.

about different tendering characteristics in the construction industry. It also presents the background towards DSS plus its implementation in tendering practices and their challenges. A review is included about the Information and Communication Technology (ICT) applied to the tendering process, which makes possible the use of Web-based tools together with DSS.

Final argumentation:

One of the most important questions in the construction industry regarding tendering procedures is the management of the high amount of information and its quantification towards the achievement of the best decision possible. This article makes known that "*the successful execution of a construction project is heavily impacted by making the right decision at the right time*"[188].

The decision makers make their decisions under the typical complications of every tendering situation, these are complexity and uncertainty regarding the coordination tasks, all these together with the fact that DM are always influenced by their intuition, subjective emotion or judgement. Thus to ensure a healthy and transparent decision the DM needs a supporting tool, consequently the DSS assists the DM in making this decision possible.

The application of DSS is gaining in relevance to support the tendering procedures in recent times. With the progress and possibilities offered by computer applications nowadays, the information exchange between the different participators in the tendering process can and is provided by this means. According to Halaris "*Tendering is the list of processes to produce, display and manage tender documents by client or consultant. It also involves action to perform bidding by interested contractors in order to win the contract by responding to tenders with their capabilities and skills formation*"[189].

From this definition it is easy to realise that by tendering procedures the collaboration between the client and the consultants depends on their own capabilities to ensure the goals and through this to structure the information for its processing. A representation and review of the current tendering procedures is presented in this article and the tendering procedures can be subdivided into three different types:

- "*Open Tender*": All interested contractors can prepare a bid to submit
- "*Restricted Tender*": Only invited contractor can submit a bid
- "*Negotiation Tender*": Client consults the chosen contractors and negotiates the term of contract with them.

[188] (Mohemad, 2010)
[189] (Halaris, 2003)

This article also makes an examination of the different tendering particularities in diverse countries in the world as for example Nigeria, Europe, USA, Turkey, Malaysia, etc. along with their problems and typical organization procedures. The process starts as soon as a client initializes the requirement of the project; therefore the client employs consultants who take care of feasibility studies.

From this very beginning the cost, time and procurement procedures has to be estimated. Thus the tender documents have to be formulating with information about:

- instruction to tenderers
- conditions of contract
- technical specifications
- drawings
- bill of quantities
- list of forms to be completed by the contractor.

It is for this reason that multi criteria methods offer an appropriated assessment method for the decision analysis and its quantification of criteria such as:

- bid price,
- time for project completion,
- financial capability,
- work experience,
- technical staff available,
- equipment facilities and
- current list of works

The criteria must be evaluated with the goal of finding the potential contractors able to accomplish the project with the required costs, time and quality. Hence two different assessment stages are put forth, the prequalification phase and the detailed technical evaluation. The prequalification phase is conceived for screening out the contractor who does not fulfill the required profile to accomplish the project. The contractors that have been considered capable of achieving the project, are evaluated on the second phase under the consideration of criteria such as: working experience, current work performance, technical staff, plant and equipment as well as estimated project duration. The contractor with the highest score is normally the one to build the project.

The advent of ICT makes suitable the use of Web-based technology for a better utilization of the DSS, of currently there are many ICT applications in the tendering procedure all over the world, known as “Online Tender Management Systems” and they work using Internet basis, like: ePerolehan, Tender Direct, e-Construction, MERX, e-Procurement, e-Procurement System, etc., however the author assures that these instruments do not include an evaluation based on decision analysis methods.

Web-based technology is meant to reduce printing costs but not to support the DM with decision analysis, the “*lack of computerized evaluation tools in current Web-based tendering applications requires decision maker to manually screening for criteria to be evaluated for each tender documents. It is impractical and time consuming for human to manually process the information*”[190] [sic]. On the other hand “*the adoption of ICT in construction industry remains low and at the same time encourage to the increasing use of large volume of unstructured tender documents*”[191] [sic].

The use of DSS in tendering process can be described as an interface with a data management and a model-based management; this means that data-banks are needed together with a model based on quantitative approach. The utilization of Web-based technology makes it possible that several DM around the world can perform an interactive communication, for the project’s benefit.

One of the most important assertions is that “*most phases in tendering processes involve crucial decisions that need to be made either by client, consultant or contractors*”[192], DAM make possible to make neutral and objective decisions, therefore the utilization of DAM via DSS makes possible to achieve this goal. In the DSS proposed by this article, the tendering procedure is divided in:

- Tender specification preparation
  - Feasibility study and risk evaluation
  - Criteria and weights are identify
- tender submission/tender bidding
  - Go or non-Go question
  - Bid price or mark-up price is defined[193]
- tender assessment
  - Screening and Evaluation of the candidates
- contract monitoring
  - regulatory checks on the performance and progress (Supervision)

Each of these phases are evaluated by the following criteria, some of them are take place in the different phases mentioned above.

- communication-driven (communications tools)
- data-driven (data base)
- document-driven (formats and layouts)
- model-driven and (Modell and Mathematical applications)

[190] (Mohemad, 2010)
[191] Likewise
[192] (Mohemad, 2010)
[193] Bid price or mark-up price is defined as the minimum price that possible to win the tender and could maximize profit at the same time (Egemen, 2008).

- knowledge-driven (supporting Modell and Mathematical applications)

This article shows how the application of the different DAM combined with different computer applications offer an important aid to the decision analysis and to any decision with a high amount of participants, criteria and data. It is important to see that one of the most central considerations is the need of quantitative information and/or data organized in structures, however it is also mentioned that "*decision-making requires comprehensive analysis of large volumes of both structured and unstructured data*"[194].

The development of the DSS makes a better way in its application on the tendering procedure within the construction industry but stills has limitations, one of the main reasons as the author claims "*Traditional tendering processes in construction industry are complex and fragmented*"[195]. Nevertheless the possibilities opened by the DSS have become an important source for solutions; consequently nowadays many researchers are getting involved in this field.

This article asserts that the high amount of unstructured data in every tender procedure need to be analysed, therefore the most complicated step for the DSS is "*to automatically convert unstructured data to structured format data for input in decision-making processes*"[196]. As a consequence the DM is indispensable in every step of every DSS.

[194] (Froelich, 2008)
[195] (Mohemad, 2010)
[196] (Mohemad, 2010)

Appendix B: Value Analysis Study Report DAR Project[197]

Value Analysis Study Report

D-11 I-15 Mira Mesa/Scripps Ranch Direct Access Ramp

EA 2T095X
11-SD-15-PM 15.1/15.9 (KP 24.3/25.6)
Contract No. 53A0132
Task Order No. 743

February 2010

Prepared by
Value Management Strategies, Inc.

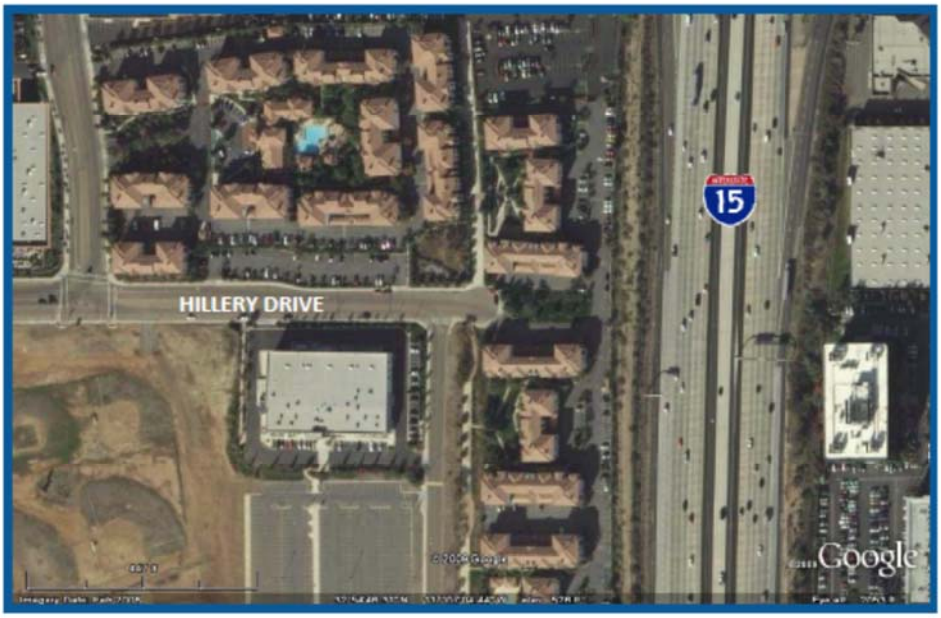
Caltrans

[197] (Strategies, Value Management, 05. Feb.2010)

VA Study Summary Report – Preliminary Findings

D-11 I-15 Mira Mesa/Scripps Ranch Direct Access Ramp

11-SD-15
EA 2T095X
PM 15.1/15.9
(KP 24.3/25.6)



A Value Analysis (VA) study, sponsored by Caltrans District 11 and facilitated by Value Management Strategies, Inc., was conducted for the addition of a Direct Access Ramp (DAR) at the I-15 and Mira Mesa Boulevard Interchange in San Diego County, California. The six-day VA study was conducted in November 2009. This *VA Study Summary Report – Final Results* provides an overview of the project, key findings, and the accepted and rejected alternatives developed by the VA team. ***Detailed documentation and exhibits of the study's analysis are provided in the Final VA Study Report.***

PROJECT DESCRIPTION

Caltrans, in cooperation with the Federal Highway Administration (FHWA), is proposing to construct a DAR to connect the I-15 Managed Lanes facility with the local street system and Transit Center in the Mira Mesa and Scripps Ranch communities of San Diego, California.

The design alternative selected as the baseline is the Hillery Drive location. Total project costs for all elements of this alternative are estimated at a current value, without escalation, and as revised by the VA Team, of $58 million. When escalated to 2012, the estimated project cost is approximately $68 million.

PROJECT PURPOSE AND NEED

The purpose of the proposed project is to provide direct vehicular access to the I-15 Managed Lanes facility for buses, HOVs, and FasTrak users, and to facilitate transit operations along the I-15 corridor and within the Mira Mesa/Scripps Miramar Ranch community. This project will address the need for congestion relief by encouraging mass transit, carpooling, and vanpooling in the project area and by maximizing the integration of land uses and transportation facilities.

VA STUDY TIMING

The VA study was conducted at the 35% design level in the Plans, Specifications, and Estimates Documentation (PS&E) Phase, which is to be completed in August 2011. The project is scheduled for Ready to List (RTL) in December 2011.

VA STUDY OBJECTIVES

The objective of the VA study was to identify opportunities to avoid/reduce impacts (e.g., utilities) and probable risks to enhance the project's value. The team will also assess improvement opportunities derived from project coordination, such as analyzing if time and/or money could be saved by advancing work via Construction Change Order (CCO) to the I-15 construction job. The VA study might also provide recommendations for the Transit Center project, particularly vehicle ingress/egress and other traffic, bike and pedestrian considerations.

KEY PROJECT ISSUES

The items listed below are the key constraints or issues being addressed by the project and considered during this VA study to identify possible improvements.

- Construction of foundations for structures and its coincidence with the managed-lane work on I-15; consider allowing this done as a CCO to the I-15 project.
- Managed lanes will be operable when the project goes to construction in 2012.
- Significant visual aesthetic component currently under review by a separate group.
- Need to coordinate the relationship of the DAR with the proposed Metropolitan Transit Service (MTS) Transit Center.
- The Miramar College Distribution Center will have reduced mobility of trucks from their loading docks; a new loading dock on the north side is being considered (at additional cost to project in the $150K range).

EVALUATION OF ORIGINAL DESIGN

Performance Attributes
Mainline Operations
Local Operations
Maintainability
Environmental Impacts
Construction Impacts
Project Schedule

At the 35% design level, the design concept for the DAR is generally fixed; however, opportunity exists for modifications within this concept to improve operations and structural design elements. These modifications would maintain the rationale associated with the mainline operations while improving local operations and construction impacts. There is also an opportunity to compress the project schedule by beginning project components earlier than currently planned; which also translates into project cost savings. The framework of the Value Metrics process was utilized to evaluate the design alternatives.

The evaluation process considered six attributes that considered key aspects of project performance. (See the table, "Performance Attributes.") The performance scores for each of the design alternatives were then divided by their construction costs to derive a value index. The value indices for each concept were normalized and the results were then expressed as a percent (%) score.

VA STUDY RESULTS

Accepted VA Alternatives	
1.0	Replace MSE Wall with Type 1 Wall for Freeway Ramps
2.0	Coffman to Build Associated DAR Structures
5.0	Modify Access from Transit Center to DAR
6.0	Optimize Width of Streetscape Landscaping at Park-and-Ride
7.0	Initiate Work on Hillery Drive Now

The accepted set of alternatives will accelerate construction by replacing MSE walls with Type 1 walls. Further optimization of the construction schedule may occur by initiating Option B of Alternative 2.0 which would allow construction of the foundations and columns associated with the bridge structures within the Unit #2 Coffman contract as a CCO; and initiating work on Hillery Drive as early as possible. Traffic flow at a local level may be improved by limiting access to the proposed transit center from Hillery Drive. Additionally, aesthetic improvements through maximized landscaping along the Hillery Drive/Park-and-Ride boundary will be achieved. These accepted VA alternatives have the potential to save approximately $2.9 million and reduce the construction schedule by approximately nine months, which will in turn reduce impacts to the traveling public and deliver the project benefits sooner.

The accepted alternatives are discussed on the following pages, along with the alternative number and title, and cost savings and performance that were validated by the Project Development Team (PDT) after the VA study. A sketch is included in instances in which it was helpful to depict modifications made post-study to the VA alternative. The rejected alternatives, and their respective reasons for rejection, can be found following the descriptions of accepted alternatives.

Alternative Number and Title		Initial Cost Savings	Performance Change
1.0	Replace MSE Wall with Type 1 Wall for Freeway Ramps	$1,228,000	+11%

This alternative replaces the MSE walls with Type 1 walls on all four ramps. The Standard Cantilever Type 1 retaining walls begin near the ground level and end up tying into the ramps bridge abutment. One of the many benefits of replacing MSE walls with Type 1 walls for the on- and off- ramps is the elimination of the check for corrosion of the galvanized reinforcement for the MSE walls. Backfill and compaction for MSE walls has been reported as a problem. So the benefit is eliminating the concern for finding suitable backfill material that is not considered to be corrosive. Also, the maintenance of the wire mesh reinforcement would no longer be necessary.

2.0	Coffman to Build Associated Direct Access Ramp Structures	$66,000	+3%

This alternative proposed two options, one of which will be implemented:

Option B: Construct only the foundations and columns associated with the bridge structures for the Unit #5 project with the existing Unit #2 Coffman project.

Moving the construction of the structures to the existing Coffman Unit #2 contract would allow for the construction of the structures to begin prior to the proposed start date (estimated up to a year earlier), and would preclude any potential for two contractors working within the I-15 Express Lanes project limits at the same time.

5.0	Modify Access from Transit Center to DAR	$184,000	+17%

This alternative proposed two options, one of which is feasible:

Option 1: Close the median between eastbound and westbound vehicles on Hillery Drive (from Sta. 22+50 to 23+50). Keep Transit Center to Hillery Drive access open for "right-out" traffic only onto DAR. Buses heading westbound down DAR will turn left, with prioritization, at Westview Parkway/Hillery Drive Intersection to enter the Transit Station from Transit Center Drive.

6.0	Optimize Width of Streetscape Landscaping at Park-and-Ride	$0	+4%

This alternative would modify the parking lot design by changing sixteen (16) 9' x 18'-0" standard parking spaces to sixteen 9'x15' small-car spaces. The driveway width between stalls would remain unchanged. This would increase the planting area width by 2'-7" without decreasing the amount of parking stalls. The increased landscape width would allow for larger-size trees and shrubs to be planted, thereby reducing the visual change resulting from the loss of mature landscaping. The new landscaping would provide better screening of the parking lot from the sidewalk and would buffer views of the DAR walls from the apartments above the parking lot.

Alternative Number and Title	Initial Cost Savings	Performance Change
7.0 Initiate Work on Hillery Drive Now	$1,400,000	+9%

This alternative would begin construction of DAR project as early as September 2011, focusing on the Hillery Drive road work, including utilities. The effort would reduce the schedule by approximately 9 months and would realize substantial savings through reduced escalation cost.

Net Effect of Accepted VA Alternatives

Accepted VA Alternatives	Initial Cost Savings	Present Value Subsequent Cost	Present Value Highway User Cost	Performance Change	Value Change
1.0, 2.0, 5.0, 6.0, 7.0	$2,878,000	$0	$0	+17%	+23%

REJECTED VA ALTERNATIVES – Reason for Rejection

3.0 Add Hinge in the Hillery Drive Overcrossing

A review by the designers and Caltrans Headquarters determined that a hinge was not required, that no hinge was used at the Rancho Bernardo DAR, and that the current design will work.

4.0 Eliminate Span 1 Structure and Extend Walls

A review by the designers and Caltrans Headquarters determined that a hinge was not required, that no hinge was used at the Rancho Bernardo DAR, and that the current design will work. In addition, extending the walls may impede the construction of a 96-inch-diameter water line due to its location, and it would not be preferred from a visual aesthetic viewpoint.

VA TEAM

The VA team included:

Ron Tanenbaum	VMS, Inc.	VA Team Leader
Andrew Sanford	Simon Wong Engineering	Bridge Structures/Estimating
David Stebbins	Caltrans	Design Manager
Azeb Berhane	Caltrans	Traffic Engineer
Cailyn Le	Caltrans	Bridge Structures/Construction
Yasnia Florentino	Caltrans	Planning
Marlene Gros	Caltrans	Landscape Architect

Key project contacts included:

Andrew Rice	Caltrans	Project Manager
Gerard Chadergian	Caltrans	Design Manager
Jim Lundquist	City of San Diego	Traffic Engineer
Frank Owsiany	SANDAG	Transportation Engineer
Chili Cilch	Caltrans	DVAC

<table>
<tr><td colspan="5">VA ALTERNATIVE IMPLEMENTATION ACTION
D-11 I-15 Mira Mesa/Scripps Ranch Direct Access Ramp</td><td colspan="3">Caltrans</td></tr>
<tr><td colspan="5">TITLE: Replace MSE Wall with Type 1 Wall for Freeway Ramps</td><td colspan="3">ALTERNATIVE NUMBER
1.0</td></tr>
<tr><td colspan="2">RESPONSES</td><td colspan="3">Prepared by: Ron Tanenbaum</td><td colspan="3">Date: 1/29/2010</td></tr>
<tr><td colspan="8">Acceptance of alternatives denotes intent to implement, based on current information, in the given project development phase (PID, PA&ED or PS&E). It is recognized that future conditions may change this disposition. The validation of disposition and the cost and performance changes for the alternative are required by Caltrans to ensure that the project decision makers agree with the study results. These validated results become the basis for the VA Program reportables.</td></tr>
<tr><td colspan="5" rowspan="3">Technical Feasibility / Validated Performance
Alternative is feasible.</td><td colspan="3">DISPOSITION</td></tr>
<tr><td colspan="3">☑ Accept
☐ Conditionally Accept
☐ Reject</td></tr>
<tr><td colspan="3">Validated Performance
+11%</td></tr>
<tr><td colspan="5">Implementable Portions
Already accepted and implemented into the plans.</td><td colspan="3"><u>If Alternative is Rejected</u>
Was rejection due to VA study taking place too late in the project development process to implement the change?
Yes ☐ No ☐</td></tr>
<tr><td colspan="5" rowspan="2">Validated Cost Savings</td><td colspan="3">Validated Savings
$1,228,000</td></tr>
<tr><td colspan="3">Project Development Support Cost Savings
N/A</td></tr>
<tr><td colspan="3" rowspan="5">Project Development Delivery Impacts</td><td colspan="2"></td><td>No Change</td><td>Reduced by</td><td>Increased by</td></tr>
<tr><td colspan="2">PID</td><td>☑</td><td>Mo.</td><td>Mo.</td></tr>
<tr><td colspan="2">PA&ED</td><td>☑</td><td>Mo.</td><td>Mo.</td></tr>
<tr><td colspan="2">PS&E</td><td>☑</td><td>Mo.</td><td>Mo.</td></tr>
<tr><td colspan="2">Const.</td><td>☑</td><td>Mo.</td><td>Mo.</td></tr>
<tr><td colspan="8">Other Comments</td></tr>
</table>

VA ALTERNATIVE IMPLEMENTATION ACTION

D-11 I-15 Mira Mesa/Scripps Ranch Direct Access Ramp

TITLE: Coffman to Build Associated DAR Structures

ALTERNATIVE NUMBER 2.0

RESPONSES | **Prepared by:** Ron Tanenbaum | **Date:** 1/29/2010

Acceptance of alternatives denotes intent to implement, based on current information, in the given project development phase (PID, PA&ED or PS&E). It is recognized that future conditions may change this disposition. The validation of disposition and the cost and performance changes for the alternative are required by Caltrans to ensure that the project decision makers agree with the study results. These validated results become the basis for the VA Program reportables.

Technical Feasibility / Validated Performance

Option B is feasible whereas Option A is not. Caltrans will discuss this with Coffman and Headquarters to finalize magnitude of implementation.

DISPOSITION

☑ Accept
☐ Conditionally Accept
☐ Reject

Validated Performance

+3%

Implementable Portions

May be fully implementable. Construction of drainage within Unit #2 is already implemented.

If Alternative is Rejected

Was rejection due to VA study taking place too late in the project development process to implement the change?

Yes ☐ No ☐

Validated Cost Savings

Validated Savings

$66,000

Project Development Support Cost Savings

N/A

Project Development Delivery Impacts

	No Change	Reduced by	Increased by
PID	☑	Mo.	Mo.
PA&ED	☑	Mo.	Mo.
PS&E	☑	Mo.	Mo.
Const.	☐	3 Mo.	Mo.

Other Comments

<table>
<tr><td colspan="3">VA ALTERNATIVE IMPLEMENTATION ACTION
D-11 I-15 Mira Mesa/Scripps Ranch Direct Access Ramp</td><td>Caltrans</td></tr>
<tr><td colspan="3">TITLE: Add Hinge in the Hillery Drive Overcrossing</td><td>ALTERNATIVE NUMBER
3.0</td></tr>
<tr><td>RESPONSES</td><td colspan="2">Prepared by: Ron Tanenbaum</td><td>Date: 1/29/2010</td></tr>
<tr><td colspan="4">Acceptance of alternatives denotes intent to implement, based on current information, in the given project development phase (PID, PA&ED or PS&E). It is recognized that future conditions may change this disposition. The validation of disposition and the cost and performance changes for the alternative are required by Caltrans to ensure that the project decision makers agree with the study results. These validated results become the basis for the VA Program reportables.</td></tr>
<tr><td colspan="3" rowspan="3">Technical Feasibility / Validated Performance
A review by the designers and Caltrans Headquarters determined that a hinge was not required, that no hinge was used at the Rancho Bernardo DAR, and that the current design will work.</td><td>DISPOSITION</td></tr>
<tr><td>☐ Accept
☐ Conditionally Accept
☑ Reject</td></tr>
<tr><td>Validated Performance
N/A</td></tr>
<tr><td colspan="3">Implementable Portions</td><td><u>If Alternative is Rejected</u>
Was rejection due to VA study taking place too late in the project development process to implement the change?
Yes ☐ No ☑</td></tr>
<tr><td colspan="3" rowspan="2">Validated Cost Savings</td><td>Validated Savings
N/A</td></tr>
<tr><td>Project Development Support Cost Savings
N/A</td></tr>
<tr><td colspan="4">Project Development Delivery Impacts
<table>
<tr><td></td><td>No Change</td><td>Reduced by</td><td>Increased by</td></tr>
<tr><td>PID</td><td>☐</td><td>Mo.</td><td>Mo.</td></tr>
<tr><td>PA&ED</td><td>☐</td><td>Mo.</td><td>Mo.</td></tr>
<tr><td>PS&E</td><td>☐</td><td>Mo.</td><td>Mo.</td></tr>
<tr><td>Const.</td><td>☐</td><td>Mo.</td><td>Mo.</td></tr>
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<tr><td colspan="4">Other Comments</td></tr>
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<table>
<tr><td colspan="6">VA ALTERNATIVE IMPLEMENTATION ACTION
D-11 I-15 Mira Mesa/Scripps Ranch Direct Access Ramp</td><td colspan="3">Caltrans</td></tr>
<tr><td colspan="6">TITLE: Eliminate Span 1 Structure and Extend Walls</td><td colspan="3">ALTERNATIVE NUMBER
4.0</td></tr>
<tr><td>RESPONSES</td><td colspan="5">Prepared by: Ron Tanenbaum</td><td colspan="3">Date: 1/29/2010</td></tr>
<tr><td colspan="9">Acceptance of alternatives denotes intent to implement, based on current information, in the given project development phase (PID, PA&ED or PS&E). It is recognized that future conditions may change this disposition. The validation of disposition and the cost and performance changes for the alternative are required by Caltrans to ensure that the project decision makers agree with the study results. These validated results become the basis for the VA Program reportables.</td></tr>
<tr><td colspan="6">Technical Feasibility / Validated Performance
A review by the designers and Caltrans Headquarters determined that a hinge was not required, that no hinge was used at the Rancho Bernardo DAR, and that the current design will work. In addition, extending the walls may impede the construction of a 96-inch-diameter water line due to its location, and it would not be preferred from a visual aesthetic viewpoint.</td><td colspan="3">DISPOSITION
☐ Accept
☐ Conditionally Accept
☑ Reject

Validated Performance
N/A</td></tr>
<tr><td colspan="6">Implementable Portions</td><td colspan="3"><u>If Alternative is Rejected</u>
Was rejection due to VA study taking place too late in the project development process to implement the change?
Yes ☐ No ☑</td></tr>
<tr><td colspan="6">Validated Cost Savings</td><td colspan="3">Validated Savings
N/A

Project Development Support Cost Savings
N/A</td></tr>
<tr><td colspan="5" rowspan="5">Project Development Delivery Impacts</td><td></td><td>No Change</td><td>Reduced by</td><td>Increased by</td></tr>
<tr><td>PID</td><td>☐</td><td>Mo.</td><td>Mo.</td></tr>
<tr><td>PA&ED</td><td>☐</td><td>Mo.</td><td>Mo.</td></tr>
<tr><td>PS&E</td><td>☐</td><td>Mo.</td><td>Mo.</td></tr>
<tr><td>Const.</td><td>☐</td><td>Mo.</td><td>Mo.</td></tr>
<tr><td colspan="9">Other Comments</td></tr>
</table>

VA ALTERNATIVE IMPLEMENTATION ACTION *D-11 I-15 Mira Mesa/Scripps Ranch Direct Access Ramp*		Caltrans
TITLE: Modify Access from Transit Center to DAR		**ALTERNATIVE NUMBER** 5.0
RESPONSES	**Prepared by:** Ron Tanenbaum	**Date:** 1/29/2010

Acceptance of alternatives denotes intent to implement, based on current information, in the given project development phase (PID, PA&ED or PS&E). It is recognized that future conditions may change this disposition. The validation of disposition and the cost and performance changes for the alternative are required by Caltrans to ensure that the project decision makers agree with the study results. These validated results become the basis for the VA Program reportables.

Technical Feasibility / Validated Performance	**DISPOSITION**
Option 1 that allows for right in to the transit center from Hillery Drive is feasible.	☑ Accept ☐ Conditionally Accept ☐ Reject
	Validated Performance +17%
Implementable Portions Implement Option 1.	**If Alternative is Rejected** Was rejection due to VA study taking place too late in the project development process to implement the change? Yes ☐ No ☐
Validated Cost Savings	**Validated Savings** $184,000
	Project Development Support Cost Savings N/A

Project Development Delivery Impacts

	No Change	Reduced by	Increased by
PID	☑	Mo.	Mo.
PA&ED	☑	Mo.	Mo.
PS&E	☑	Mo.	Mo.
Const.	☑	Mo.	Mo.

Other Comments

VA ALTERNATIVE IMPLEMENTATION ACTION *D-11 I-15 Mira Mesa/Scripps Ranch Direct Access Ramp*		Caltrans
TITLE: Optimize Width of Streetscape Landscaping at Park-and-Ride		**ALTERNATIVE NUMBER** 6.0
RESPONSES	**Prepared by:** Ron Tanenbaum	**Date:** 1/29/2010

Acceptance of alternatives denotes intent to implement, based on current information, in the given project development phase (PID, PA&ED or PS&E). It is recognized that future conditions may change this disposition. The validation of disposition and the cost and performance changes for the alternative are required by Caltrans to ensure that the project decision makers agree with the study results. These validated results become the basis for the VA Program reportables.

Technical Feasibility / Validated Performance	**DISPOSITION**
Optimization of vegetation will be incorporated into the final landscaping design.	☑ Accept ☐ Conditionally Accept ☐ Reject
	Validated Performance **+4%**
Implementable Portions Alternative is fully implementable.	**If Alternative is Rejected** Was rejection due to VA study taking place too late in the project development process to implement the change? Yes ☐ No ☐
Validated Cost Savings	**Validated Savings** **$0**
	Project Development Support Cost Savings **N/A**

Project Development Delivery Impacts

	No Change	Reduced by	Increased by
PID	☑	Mo.	Mo.
PA&ED	☑	Mo.	Mo.
PS&E	☑	Mo.	Mo.
Const.	☑	Mo.	Mo.

Other Comments

VA ALTERNATIVE IMPLEMENTATION ACTION
D-11 I-15 Mira Mesa/Scripps Ranch Direct Access Ramp

Caltrans

TITLE: Initiate Work on Hillery Drive Now

ALTERNATIVE NUMBER 7.0

RESPONSES | **Prepared by:** Ron Tanenbaum | **Date:** 1/29/2010

Acceptance of alternatives denotes intent to implement, based on current information, in the given project development phase (PID, PA&ED or PS&E). It is recognized that future conditions may change this disposition. The validation of disposition and the cost and performance changes for the alternative are required by Caltrans to ensure that the project decision makers agree with the study results. These validated results become the basis for the VA Program reportables.

Technical Feasibility / Validated Performance

Based on the current accelerated schedule that has been modified since the VA study was conducted, this approach is technically feasible, especially when combined with Option B in VA Alternative 2.0.

DISPOSITION

☑ Accept
☐ Conditionally Accept
☐ Reject

Validated Performance
+9%

Implementable Portions

Fully implement to the extent practicable.

If Alternative is Rejected
Was rejection due to VA study taking place too late in the project development process to implement the change?
Yes ☐ No ☐

Validated Cost Savings

Validated Savings
$1,400,000

Project Development Support Cost Savings
N/A

Project Development Delivery Impacts

	No Change	Reduced by	Increased by
PID	☑	Mo.	Mo.
PA&ED	☑	Mo.	Mo.
PS&E	☑	Mo.	Mo.
Const.	☐	9 Mo.	Mo.

Other Comments

Rating Rationale: VA Strategy 1

VA Team Recommended Strategy (VA Alternatives 1.0, 3.0, 4.0, 6.0, and 7.0)

Performance Attribute	Rating	Rationale for Rating
Mainline Operations	5	No significant change from baseline concept; the same operational improvements are expected.
Local Operations	5	Local operations will not be impacted above and beyond what is expected in the baseline concept. Sight distance and turning radius do not appear to be significantly impacted.
Maintainability	5	There is additional wall area to maintain (potentially more graffiti), yet access is improved from the local road. Less bridge maintenance will be required. Additional maintenance required at joint seal assembly due to the new hinge. Type 1 walls generally require less maintenance than MSE walls.
Environmental Impacts	4	Type 1 walls can allow more consistent aesthetic treatment. Eliminating Span No. 1 would further restrict views due to added wall area and may require an environmental reassessment. Adding more vegetation to the Park-and-Ride area would be a benefit.
Construction Impacts	6	Traffic flow during construction will not be impacted. Initiating work on Hillery Drive early allows shorter construction time, which translates to fewer community impacts. Type 1 walls would impact existing concrete pavement, but is easier to construct. Including a new hinge adds a construction step to the process.
Project Schedule	7	Initiating work on Hillery Drive early allows completion of utility and road work that could reduce project length by about 9 months under the best-case situation. Type 1 walls are standard design so shop drawing review (typically needed for MSE walls and consisting of about 6 to 8 weeks) would not be required. Adding the new hinge could add a few weeks to the construction schedule. Obtaining right of way is a critical point on the schedule and needs to be completed.

Rating Rationale: VA Strategy 1

VA Team Recommended Strategy (VA Alternatives 1.0, 3.0, 4.0, 6.0, and 7.0)

Performance Attribute	Rating	Rationale for Rating
Mainline Operations	**5**	No significant change from baseline concept; the same operational improvements are expected.
Local Operations	**5**	Local operations will not be impacted above and beyond what is expected in the baseline concept. Sight distance and turning radius do not appear to be significantly impacted.
Maintainability	**5**	There is additional wall area to maintain (potentially more graffiti), yet access is improved from the local road. Less bridge maintenance will be required. Additional maintenance required at joint seal assembly due to the new hinge. Type 1 walls generally require less maintenance than MSE walls.
Environmental Impacts	**4**	Type 1 walls can allow more consistent aesthetic treatment. Eliminating Span No. 1 would further restrict views due to added wall area and may require an environmental reassessment. Adding more vegetation to the Park-and-Ride area would be a benefit.
Construction Impacts	**6**	Traffic flow during construction will not be impacted. Initiating work on Hillery Drive early allows shorter construction time, which translates to fewer community impacts. Type 1 walls would impact existing concrete pavement, but is easier to construct. Including a new hinge adds a construction step to the process.
Project Schedule	**7**	Initiating work on Hillery Drive early allows completion of utility and road work that could reduce project length by about 9 months under the best-case situation. Type 1 walls are standard design so shop drawing review (typically needed for MSE walls and consisting of about 6 to 8 weeks) would not be required. Adding the new hinge could add a few weeks to the construction schedule. Obtaining right of way is a critical point on the schedule and needs to be completed.

Value Matrix

Proposed Alternatives (Preliminary)

Attribute	Attribute Weight	Concept	Performance Rating										Total Performance
			1	2	3	4	5	6	7	8	9	10	
Mainline Operations	21	Baseline Concept					5						105
		VA Strategy 1					5						105
Local Operations	29	Baseline Concept					5						145
		VA Strategy 1					5						145
Maintainability	14	Baseline Concept					5						70
		VA Strategy 1					5						70
Environmental Impacts	21	Baseline Concept					5						105
		VA Strategy 1				4							84
Construction Impacts	5	Baseline Concept					5						25
		VA Strategy 1						6					30
Project Schedule	10	Baseline Concept					5						50
		VA Strategy 1							7				70

Note: Figures have been rounded.

OVERALL PERFORMANCE	Total Performance	% Performance Improvement	Total Cost ($M)	Value Index (Performance/ Cost)	% Value Improvement
Baseline Concept	500		58.0	8.62	
VA Strategy 1	504	1%	55.2	9.13	6%

Rating Rationale: Accepted VA Alternatives

VA Alternatives 1.0, 2.0, 5.0, 6.0, 7.0

Performance Attribute	Rating	Rationale for Rating
Mainline Operations	5	No significant change from baseline concept; the same operational improvements are expected.
Local Operations	6	Local operations will be improved by prohibiting left turns into the proposed transit center from westbound Hillery Drive and the DAR ramp.
Maintainability	6	Type 1 walls generally require less maintenance than MSE walls.
Environmental Impacts	6	Type 1 walls can allow more consistent aesthetic treatment. Adding more vegetation to the Park-and-Ride area would be a benefit.
Construction Impacts	6	Traffic flow during construction will not be impacted. Initiating work on Hillery Drive early allows shorter construction time, which translates to fewer community impacts. Type 1 walls would impact existing concrete pavement, but is easier to construct.
Project Schedule	7	Initiating work on Hillery Drive early allows completion of utility and road work, which could reduce project duration by about 9 months under the best-case scenario. Type 1 walls are standard design, so shop drawing review (typically needed for MSE walls and consisting of about 6 to 8 weeks) would not be required. Obtaining right of way is a critical point on the schedule and needs to be completed.

Value Matrix

Accepted Alternatives (Final)

Attribute	Attribute Weight	Concept	Performance Rating 1	2	3	4	5	6	7	8	9	10	Total Performance
Mainline Operations	21	Baseline Concept					5						105
		Accepted Alts					5						105
Local Operations	29	Baseline Concept					5						145
		Accepted Alts						6					171
Maintainability	14	Baseline Concept					5						70
		Accepted Alts						6					86
Environmental Impacts	21	Baseline Concept					5						105
		Accepted Alts						6					129
Construction Impacts	5	Baseline Concept					5						25
		Accepted Alts						6					29
Project Schedule	10	Baseline Concept					5						50
		Accepted Alts							7				67

Note: Figures have been rounded.

OVERALL PERFORMANCE	Total Performance	% Performance Improvement	Total Cost ($M)	Value Index (Performance/ Cost)	% Value Improvement
Baseline Concept	500		58.0	8.62	
Accepted VA Alternatives 1.0, 2.0, 5.0, 6.0, 7.0	586	17%	55.1	10.6	23%

Appendix C: Caltrans Value Analysis Activity Chart[198]

Preparation

INITIATE STUDY (1)
- Identify study project
- Identify study roles and
- Responsibilities
- Define study goals
- Select team leader
- Prepare draft Study Charter

ORGANIZE STUDY (2)
- Conduct Pre-Study Meeting
- Select team members
- Identify stakeholders,
- decision-makers, and technical reviewers
- Identify data collection
- Select study dates
- Determine study logistics
- Update VA Study Charter
- Identify and define performance requirements

PREPARE DATA (3)
- Collect and distribute data
- Develop construction cost models
- Develop highway user benefit / life cycle cost (LCC) model

Preparation

Segment 1

INFORM TEAM (4)
- Review study activities and confirm reviewers
- Present design concept
- Present stakeholders' interests
- Review project issues and objectives
- Identify key functions and performance criteria
- Visit project site

ANALYZE FUNCTIONS (5)
- Analyze project data
- Expand project functions
- Prepare FAST diagram
- Determine functional cost drivers and performance

CREATE IDEAS (6)
- Focus on functions
- List all ideas
- Apply creativity and innovation techniques (group and individual)

Evaluate ideas (7)
- Apply key performance criteria
- Consider cost impacts
- List advantages and disadvantages
- Rate each idea
- Rank all ideas
- Assign alternatives for development

Segment 2

DEVELOP ALTERNATIVES (8)
- Develop alternative concepts
- Prepare sketches and calculations
- Measure performance
- Estimate costs, LCC benefits/costs

CRITIQUE ALTERNATIVES (9)
- VA Alternatives Technical Review
- VA Alternatives Team Consensus Review
- Identify mutually exclusive groups of alternatives
- Identify VA strategies
- Validate performance

PRESENT ALTERNATIVES* (10)
- Present findings
- Document feedback
- Confirm pending reviews
- Prepare preliminary report

**Interim presentation of study findings*

Segment 3

ASSESS ALTERNATIVES** (11)
- Review Preliminary Report
- Assess alternatives for project acceptance
- Prepare draft implementation dispositions

***Activities performed by PDT, Technical Reviewers, and Stakeholders*

RESOLVE ALTERNATIVES (12)
- Review implementation dispositions
- Resolve implementation actions with decisionmakers and stakeholders
- Edit alternatives
- Revisit rejected alternatives, if needed

PRESENT RESULTS* (13)
- Present results
- Obtain management approval on implemented alternatives
- Summarize performance, cost, and value improvements

**Final presentation of study results*

Report

Document Study (14)
- Document process and study findings
- Distribute Preliminary VA Report
- Distribute electronic report to HQ VA Branch
- Conduct Implementation Meeting

VA IPLEMENTATION ACTION MEMO (15)

(if Conditionally Accepted Alternatives exist)
- Publish memo to document action plan to complete study
- Resolve Conditionally Accepted Alternatives

PUBLISH RESULTS (16)
- Document process and study results
- Incorporate all comments and implementation actions
- Distribute Final VA Report
- Distribute electronic report to HQ VA Branch
- Update VA Study Summary Report (VASSR)
- Provide HQ the Final VA Report in pdf format

Note:

The dashed boxes indicate steps that ***may*** not be required in some VA Studies.

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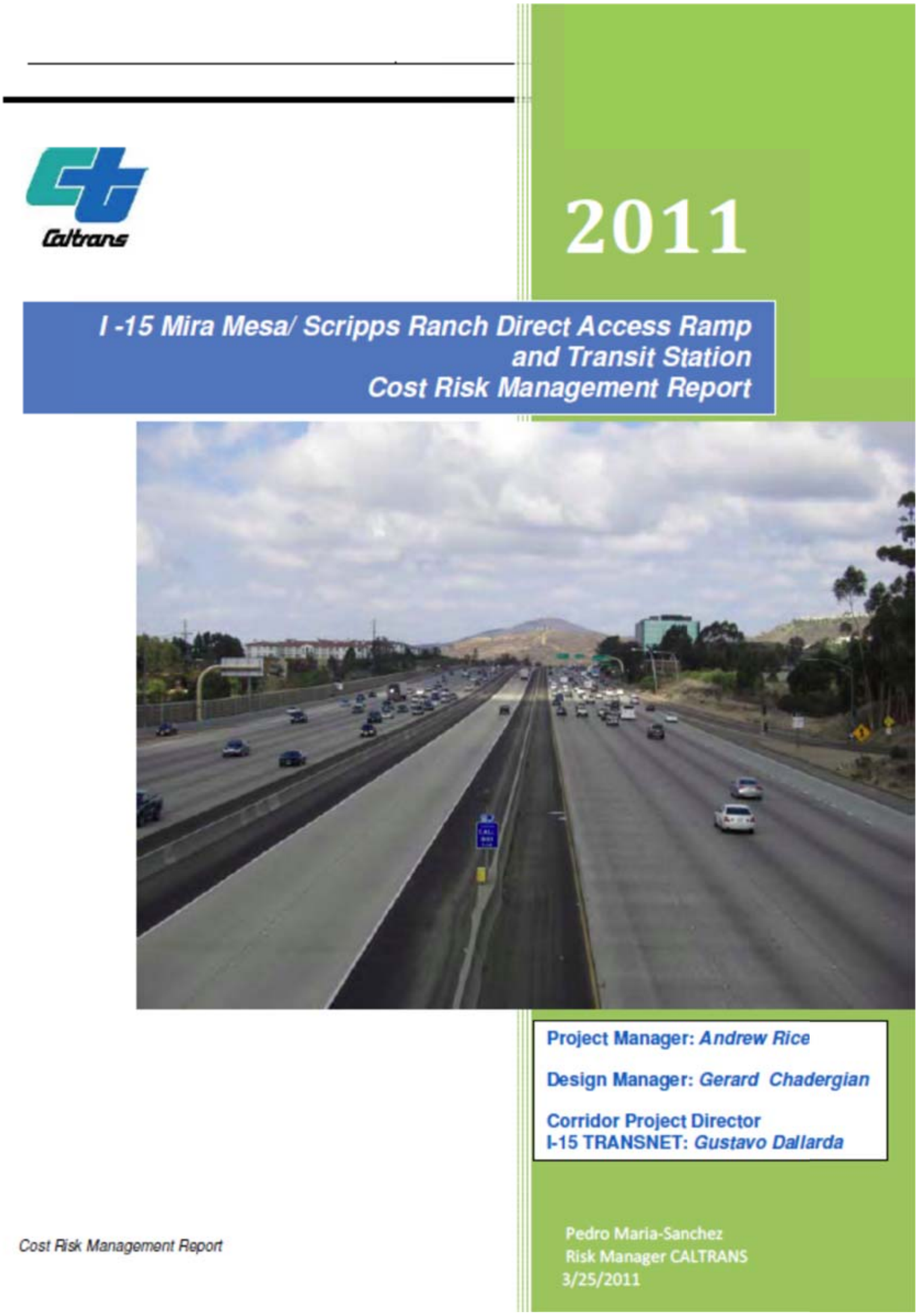
198 (Strategies, Value Management, 05. Feb.2010)

Appendix D: Cost Risk Management Report Risk Register[199]



Caltrans

2011

I -15 Mira Mesa/ Scripps Ranch Direct Access Ramp and Transit Station Cost Risk Management Report

Project Manager: *Andrew Rice*

Design Manager: *Gerard Chadergian*

Corridor Project Director I-15 TRANSNET: *Gustavo Dallarda*

Pedro Maria-Sanchez
Risk Manager CALTRANS
3/25/2011

Cost Risk Management Report

[199] (Maria-Sanchez, 2011)

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APPENDIX

EXECUTIVE SUMMARY

The purpose of this report is to apply the risk management concepts for assessing the project's risk profile, quantify the risks in terms of cost, and to propose mitigation strategies for managing the risks. Caltrans has developed a Project Risk Management Handbook; the guidelines of this document were followed on this study.

The preferred project site, the I-15 Mira Mesa/ Scripps Ranch Direct Access Ramp and Transit Station, is located in the eastern portion of the Mira Mesa community along I-15, at approximately 380 meters (m) north of the Carroll Canyon Road interchange. The total length of the project is approximately 1.28 km. Currently the project is in the design phase and is set for completion by 2014.

The risk management methodology was applied for quantifying the cost of risks implied in the Risk Register. A Risk Management Team (RMT) was formed and its members represent the project's different functional units. Cost risk analysis results were obtained for the Risk Register; these results were put together for obtaining the project's contingency and the total project cost with risk.

Major findings and mitigation recommendations are included at the last section of this report.

1. PROJECT BACKGROUND

The California Department of Transportation (Caltrans), in cooperation with the Federal Highway Administration (FHWA), is proposing to construct a Direct Access Ramp (DAR) and a Transit Station (TS) to connect the Interstate 15 (I-15) Managed Lanes facility with the local street system and the Mira Mesa and Scripps Ranch communities.

The Project will provide congestion relief for local and regional traffic by providing direct access for transit vehicles from the local streets and Transit Center to the I-15 Managed Lanes.

The San Diego Association of Governments' (SANDAG's) "Final 2030 Regional Transportation Plan" (RTP), updated in 2007, identifies DARs as part of the region's Managed Lane/High Occupancy Vehicle (HOV) network. The RTP specifically identifies DARs as features along the I-15 corridor within the Project area. This Project is classified as a Project Development Category 3 project, as defined in the Project Development Procedures Manual for the following reasons: it is on a previously constructed access controlled route; it will require a new or revised Freeway Agreement and new right of way will be required; it provides a new connection to the freeway; and it does not meet Category 5, 6 or 7.

This project was first identified in the I-15 Managed Lanes Project Study Report (PSR) and draft Project Report (PR). Subsequent to circulation of the I-15 Managed Lanes Draft Project Report in 2002 and in response to public comments, the Mira Mesa/ Scripps Ranch DAR was removed from consideration in the I-15 Managed Lanes project. Therefore, Caltrans determined that a separate PR and an Environmental Document were required for this project.

2. PROJECT SCOPE

The project will construct a Transit Station (TS) and Direct Access Ramp (DAR) that will connect to the Interstate 15 Express Lanes in the communities of Mira Mesa and Scripps Ranch. The Transit Station will be located south of the Hillery Drive/Westview Parkway intersection on the north edge of San Diego Miramar College and will join the DAR located at Hillery Drive, just south of Mira Mesa Boulevard. This improvement will provide a seamless connection between the street system and the Express Lanes.

The Mira Mesa/Scripps Ranch DAR will consist of five structures, including one elevated ramp extending at-grade from Hillery Drive and crossing over southbound I-15 and four on- and off-ramps that will extend to the Express Lanes. The DAR will give direct access for carpools, vanpools, buses, motorcycles, permitted clean-air vehicles and FasTrak users into the Express Lanes without having to merge through mainline traffic.

The Mira Mesa/Miramar College Transit Station will have up to 12 bus bays and associated transit furnishings. It will include one center island passenger platform with four bus bays. The remaining bus bays and passenger platforms will be constructed in a circular pattern surrounding the center island. This Transit Station will serve passenger access and transfer needs for local and express bus routes and will also accommodate planned Bus Rapid Transit (BRT) services.

3. REPORT SCOPE

The scope of the risk management report is to identify, analyze, quantify and respond to the project's risks and uncertainties as mandated by the California Department of Transportation (CALTRANS) within its Office of Statewide Project Management Improvement (OSPMI) per the Project Risk Management Handbook (Second Edition, May, 2007). The report presents the cost risk analysis results for determining the project's contingency amount.

4. SUPPORTING DOCUMENTS

The following documents were used as a basis for the risk management process:

- Project Report
- Value Analysis Report
- Environmental Document
- Project Basic Engineering Estimating System (BEES)

5. CALTRANS RISK MANAGEMENT PROCESS

The risk management methodology follows CALTRANS' guidelines and methodology described with the Project Risk Management Handbook developed by the OSPMI. The cost risk analysis process described within the risk management report uses a probabilistic simulation method based on excel and the *Crystal Ball* software. The cost risk analysis results are intended to serve a critical necessity; the establishment of reasonable contingencies (50 percent confidence level whenever is applicable) to successfully accomplish the project work. Furthermore, the scope of the report includes the identification and communication of important steps, logic, key assumptions, limitations, and decisions to help ensure that the cost risk analysis results can be appropriately interpreted.

The cost risk analysis results are also intended to provide project leadership with contingency information for scheduling, budgeting, programming and project control purposes; as well as to provide tools to support decision making and risk management as the project progresses through design and construction. To fully recognize its benefits, risk management should be considered as an ongoing process conducted concurrently with other important project processes such as scope and execution plan development, resource planning, programming, procurement planning, value analysis, cost estimating, budgeting, and scheduling.

6. METHODOLOGY

The RMT was formed from the Project Development Team (PDT); including representatives from other agencies and consultants. A complete list of the RMT is included in Appendix B. The main project functional units were represented, providing very valuable input to the whole process.

For the study, cost data from the Basic Engineering Estimating System (BEES) as February 8, 2011 was used.

The cost risk analysis process for this study is intended to determine the probability of various cost outcomes and to quantify the required contingency needed to achieve any desired level of cost confidence for the project. For that reason, a cost risk analysis model was created from the Risk Register.

In simple terms, contingency is an amount added to an estimate (cost or schedule) to represent realistic risk scenarios implied with the project. The contingency for this report is only referred to the Risk Register. However, this amount should be considered as part of the project total cost estimate. The amount of contingency included with the project cost estimate depends, at least in part, on the project leadership's willingness to accept the risk of project cost overruns. The less risk that the project leadership is willing to accept, the more contingency should be considered with the project cost estimate. The risk for overrunning the project cost is expressed under different scenarios (confidence levels) in Figure 7.

The confidence level adopted by the RMT for addressing the cost contingency was P50, which represents a 50-percent confidence level. It should be noted that using P50 as a decision criteria is a risk neutral approach, whereas the use of >P50 would be a risk adverse approach, and use of levels less than 50 percent would be risk seeking. Consequently, a P50 confidence level results in greater contingency as compared to the project's current contingency estimate for this study (see Figure 4).

The cost risk analysis process uses the *Monte Carlo* technique to determine the probabilities and contingency. The *Monte Carlo* technique was utilized by a commercially available risk analysis software package *Crystal Ball* that is an add-in to Microsoft Excel. The Risk Register was packaged into an Excel format as a cost risk analysis model and used directly for cost risk analysis purposes.

The primary steps, in functional terms of the risk management process, are described in the following subsections. Risk analysis results are provided in section 8.

Overall, the methodology implemented along the entire process followed the standard steps for implementing risk management: planning, identification, analysis, response, monitoring and control.

6.1 Risk Identification

To begin the process, a kick off meeting was held with the RMT for planning the implementation process and determining the number of meetings required for completing the cost risk analysis.

The risk identification meeting held with the RMT provided the first input data for creating the Risk Register. Identifying the risks via the RMT is considered a brainstorming process which results in establishing a Risk Register that serves as the document for further study. Risks are events and conditions that may influence or drive uncertainty in project performance. They may be inherent characteristics or conditions of the project or external influences, events, or situations such as weather or economic conditions. Risks may have either favorable or unfavorable impacts on project cost and schedule.

The RMT was composed of representatives from different functional units, an external agency and consultants. From this risk identification meeting, a draft Risk Register was produced that identified 49 potential risks, emerging from six different areas, containing the brainstorming output of the meeting attendees.

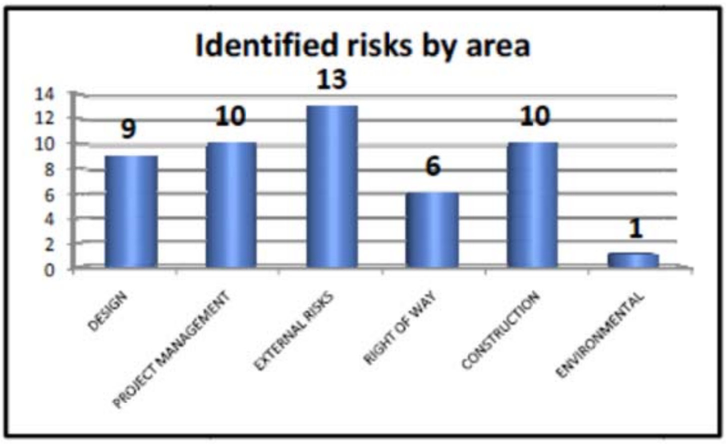


Figure 1. I-15 Mira Mesa/ Scripps Ranch Direct Access Ramp and Transit Station

As can be observed in Figure 1, the highest concentration of risks were within the External (13 risks), Project Management (10 risks) Construction (10 risks) and Design (10 risks) areas. Whereas the areas of Right of Way and Environmental have six and one risks identified respectively.

These risks were identified at the RMT's first meeting, but no risk assessment was performed. This step was part of the subsequent meeting and is described in the next section. For detailed content of the Risk Register refer to Appendix A.

A Caltrans risk checklist was used to facilitate the risk identification. Along with valuable input from the RMT, additional project data from the Project Report, the Environmental Document and the Value Analysis reports was considered.

6.2 Qualitative and Quantitative Cost Risk Analysis

The second meeting of the RMT focused on the qualitative and quantitative risk assessment.

Using the Risk Register developed from the risk identification meeting, the RMT evaluated the probability and impact for each risk. A risk matrix was used in order to combine the risk probability and impact values and for obtaining a risk score. In that way, the risks contained in the Risk Register were classified in terms of their criticality. Refer to appendix A in order to see a detailed example of the qualitative approach used. For example, a risk was considered critical for this study when it's impact was Very High (VH) even though the probability was Low (L). The risk matrix is based on Caltran's Project Risk Management Handbook.

Figure 2 shows the critical risks obtained through the qualitative assessment for the I-15 Mira Mesa/ Scripps Ranch Direct Access Ramp and Transit Station project.

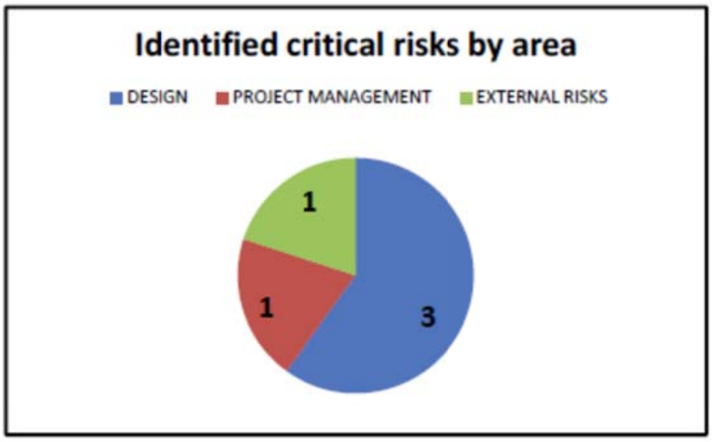


Figure 2. Qualitative Assessment for the I-15 Mira Mesa/ Scripps Ranch Direct Access Ramp and Transit Station Project

The quantitative risk assessment input data was obtained after performing the qualitative risk analysis. This was possible because within the Risk Register, a range of probable risk cost impacts was created and linked to the risk score. In other words, once a risk score was obtained through the qualitative assessment, it was possible to select a cost range representative for its impact. This cost range, represented by minimum and maximum values is used by the simulation model to calculate the probability distribution curve. The risk matrix, the cost range and the risk scores were validated with the RMT.

The quantitative risk impacts were analyzed using a combination of professional judgment and project data. It was an iterative, consensus-building approach to estimate the elements of each risk. Risk impacts were quantified using probability distributions (density functions) that were entered into the *Crystal Ball* software. Refer to appendix A in order to see a detailed example of the quantitative approach used.

As can be observed, from the five identified critical risks in Figure 2, three risks, were assigned to design, one risk to project management and one to external sources.

The risk analysis process is essential for quantifying the risk impacts. Figure 3 describes the process used per Caltrans' risk management guidelines.

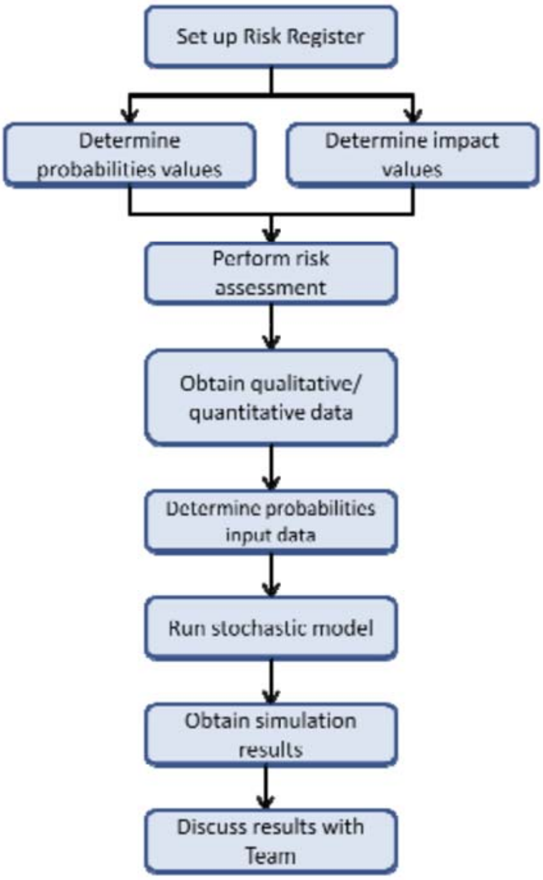


Figure 3. Risk Analysis Approach

The risk analysis results are described in Section 8. The source data for performing the qualitative/quantitative cost risk analysis was the Risk Register as illustrated in Figure 3. It was possible with this approach to determine the total project cost with risk.

6.3 Cost Risk Analysis Model for the Risk Register

The Risk Register is a tool to allow both qualitative and quantitative cost risk analysis to happen simultaneously. A qualitative matrix and scale are used for assessing the risk's probability with its impact which determines a risk score. This risk score is the primary result of the qualitative analysis. If the risk score was identified as critical (red area of risk matrix), the qualitative output was linked to a cost impact table which became the input data for the cost risk analysis model. The cost range provided minimum and maximum values, constituting the input data of the model. A *Monte Carlo* simulation was run for 1000 trials to produce the probability curve that represents the risk contingency behavior.

6.4 Contingency Analysis

Contingency was calculated using *Crystal Ball* software. The *Monte Carlo* simulation technique was performed by using the appropriated estimated cost range values (maximum and minimum) as the risk inputs for the model inserted in the Risk Register. Only the critical risks were considered for the contingency analysis as moderate and low-level risks are typically not considered, but remain within the initial Risk Register created at the identification meeting for monitoring and follow up purposes.

With the Risk Register, the cost obtained with the simulation for each risk represents the contingency. Figure 4 illustrates the contingency quantified by the *Monte Carlo* simulation for this project.

7. KEY ASSUMPTIONS

The following key assumptions are important to ensure that the project leadership and other decision makers understand the steps, logic, limitations, and decisions made in the risk analysis process, as well as any resultant restrictions on the use of findings and results.

In addition, certain risks were excluded due to their nature and triggers (for example earthquakes, Acts of God, etc.).

- The project is in the design phase
- The cost risk analysis was performed only for assessing the project's contingency
- Only the most critical risks were included for the cost risk analysis

8. RISK ANALYSIS RESULTS

This section includes the cost risk analysis results obtained from the *Monte Carlo* simulation for the project. The section is divided into Risk Register analysis results and total project cost risk analysis results.

8.1 Risk Register Contingency

Figure 4 shows the contingencies obtained from the cost risk analysis of the Risk Register. The values of the first column represent the contingency proposed from the project BEES. The simulated cost risk values (50 % confidence level) of the Risk Register items are the ones shown with the second column.

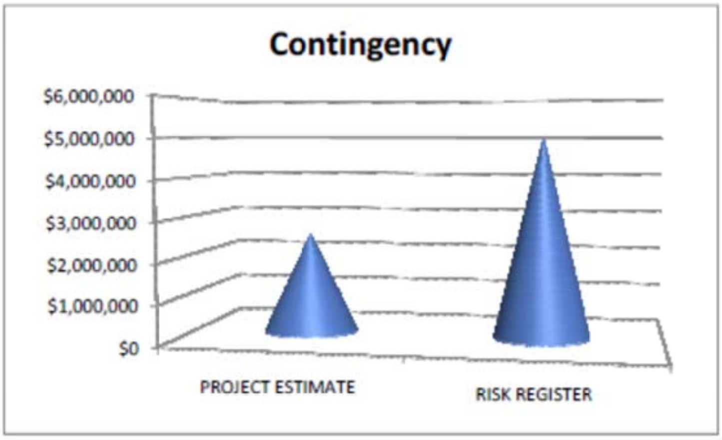


Figure 4: BEES and Risk Register Contingency

The contingency proposed within the project BEES equals $2,499,069 while $5,019,175 of contingency was calculated with the risk analysis exercise. The difference between both contingency amounts is $2,520,106. The Risk Register contingency is based upon those critical risks identified with the RMT which are related to the project's delivery process.

8.2 Total Project Cost

The risk analysis approach was applied as described in Figure 3. The total project cost with and without risks is shown in Figure 5.

Figure 5: Total Project Cost

The total project cost without risk analysis equals $27,487,511(obtained from the project BEES) and with risk analysis is $30,007,616 (project subtotal cost plus risk contingency). Although the project cost including the risk analysis is higher, it is important to clarify that this is due to the contingency calculated with the Risk Register which at the end, provides more certainty to the project delivery because is direct related to specific risks.

9. MAJOR FINDINGS AND CONFIDENCE LEVELS

This section presents the major findings from the cost risk analysis process. Figure 6 illustrates the contingency probability histogram, together with its frequency behavior along the 1000 iterations. The main output of this histogram is the contingency mean value which equals to $5,019,175.

The cumulative probability distribution with confidence levels for the project cost risk analysis (uncertainty behavior) is presented in Figure 7. The objective is to show the risk impact into the final project cost while selecting an appropriate contingency amount depending on the level of confidence desired by project stakeholders.

The contingency proposed without taking into account the cost risk analysis results equals to 10% ($2,499,069 from the project BEES) of the project total cost. Providing this contingency value a confidence level of less than 10% (see Figure 7), meaning that there is a 90% chance of overrunning. The contingency calculated from the cost risk analysis equals to $5,019,175 (Figure 6), representing a 50% confidence level (mean value).

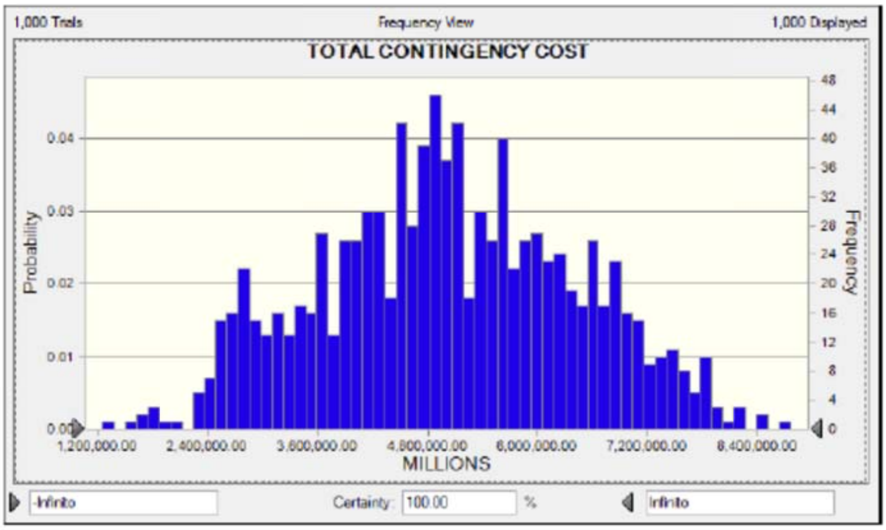


Figure 6: Contingency Probability Histogram

If the desire of the project team is to increase the contingency confidence level to a higher value, for example to 80%, then a contingency of approximately $6,257,361 will be needed. Therefore, the total project cost will be increased.

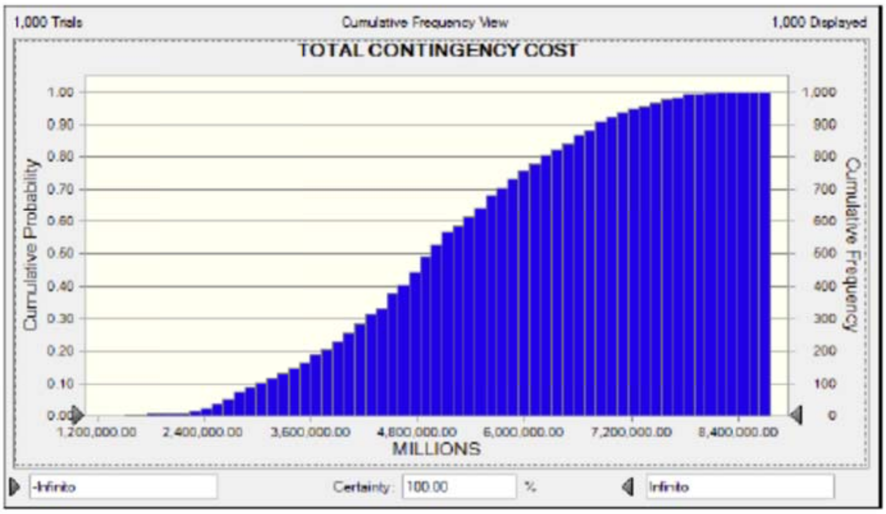


Figure 7: Cumulative Probability Distribution for the Project Contingency (confidence levels)

10. MITIGATION RECOMMENDATIONS

Each critical risk identified in the Risk Register was assigned a risk owner from the RMT. The risk owner was responsible for identifying a response strategy and explaining what actions would be needed to mitigate the risk. Table 1 below shows a summary of these recommendations.

Risk Event	Risk Owner	Strategy	Response Actions
Lack of coordination with adjacent projects (College area and Coffman in Unit 2)	Gerard Chadergian	Avoidance	-Implementation of a 55 day delayed start. Will monitor Unit 2S progress the closer we get to Beginning Construction. -Will have approved TCE in place to ensure contractors rights to accessing the work area needed.
Utility info late, incomplete, inaccurate or discovery of additional utilities,	Gerard Chadergian	Acceptance	-If needed, contractor could relocate cable or AT&T as a CCO. -Hire a subcontractor to do the utility work. -Add work around to contract. -Begin relocations before construction begins.
Loss of project capital funding during construction	Andrew Rice	Transference	Shortfall in funding would be covered with Local TransNet funds as SANDAG and the region have a vested interest in the success of the project. TransNet funds would be repaid once additional bond funds became available.
Unplanned work that must be accommodate	Gerard Chadergian	Transference	Regardless of the impact of this risk into the DAR project, the risk will be monitored and eventually would be removed from the Risk Register once SANDAG minimizes its probability and impact into the Transit Station project.

Risk Event	Risk Owner	Strategy	Response Actions
An agreement between the College and SANDAG/MTS is needed concerning parking for the transit station. There is a risk that the College will not move forward with any Right of Way contract without an approved agreement on the parking. This may require an additional MOU. SANDAG not willing to condemnate the Community College.	Frank Owsiany	Execute a Right of Entry	Right of Entry would be issued between Caltrans and the Community College to commence with construction of the DAR and transit station prior to executing a MOU or agreement.

Table 1: Risk Strategies and Responses

RISK MANAGEMENT TEAM (RMT)	
NAME	FUNCTIONAL UNIT/AGENCY
Gustavo Dallarda	Corridor Project Director I-15 TRANSNET Caltrans
Andrew Rice	Project Manager/ Caltrans
Gerard Chadergian	Design Manager/ Caltrans
Greg Gutierrez	Right of Way/ Caltrans
Frank Owsiany	SANDAG
Josua Reese	Project Manager Assistant/ Caltrans
Dennis Jung	Environmental/ Caltrans
Marlene Gros	Landscape Architect/ Caltrans
Fu Sun	CH2M Hill
Duy Ngoc Hoang	Design/ Caltrans
Michael.Crull	AECOM
Pedro Maria-Sanchez	Risk Manager/ Caltrans

Risk register[200]

Dist - E.A	11-2T0951	I-15 Transit Station and DAR Mira Mesa / Scripps Ranch	
Co-Rte-PM	D-15-M015.0 -M016.5	RISK REGISTER	
Date	28.02.2011		
Project Mngr	Andrew Rice	Telephone Number	(619) 688-3284

Probability	
Very low	0-5%
Low	6-25%
Moderate	26-50%
High	51-75%
Very High	76-95%

COST IMPACT ($)	OPTIMISTIC	PESSIMISTIC
Very Low	10,000	250,000
Low	250,000	500,000
Moderate	500,000	1,000,000
High	1,000,000	1,500,000
Very High	1,500,000	3,000,000

RISK OUTPUT 5000000

0,50093972

RISK REGISTER

Identification

Priority (1)	Status (2)	ID # (3)	Date Identified / Project Phase (4)	Functional Assignment (5)	RISK EVENT (6)	SMART Column (7)	Risk Trigger (8)
1	Active	4	06.10.2010 / PS&E	Design	Lack of coordination with adjacent projects (College area and Coffman in Unit 2)	*Could have Unit 2S delayed and not out of the work areaby the time we are ready to work on freeway portion. *Potential conflict with ongoing construction at the College.	*Unit 2S work delayed. *College begins work in DAR work area.
1	Active	7	06.10.2010 / PS&E	Design	Utility info late, incomplete, inaccurate or discovery of additional utilities.	*Many utilities need to be relocated within the specified work window. Delay could cause entire project delay. * There may be new utilities encountered or incorrect locations of existing utilites as the work to relocate utilities commences.	*Approaching end of window to relocate utility and realizing there is not enough time to complete work. *Finding new utility in the field.
1	Active	26	06.10.2010 / PS&E	Project Management	Loss of project capital funding during construction	Eighty percent of the construction capital funding is programmed with Prop 1B Corridor Mobility Improvement Account (CMIA) bond funds. This funding is dependent on the ability of the State Treasurer's Office (STO) to sell bonds on the open market.	Risk would occur if the STO could not sell enough bonds to replenish the account that pay for the ongoing construction contract.
1	Active	34	06.10.2010 / PS&E	Design	Unplanned work that must be accommodated	PENDING	PENDING
1	Active	61	06.10.2010 / PS&E	External risks	An agreement between the College and SANDAG/MTS is needed concerning parking for the transit station. There is a risk that the College will not move forward with any Right of Way contract without an approved agreement on the parking. This may require an additional MOU. SanDag not willing to condemnate the Community College.	PENDING	PENDING

Qualitative Analysis and Quantitative Analysis

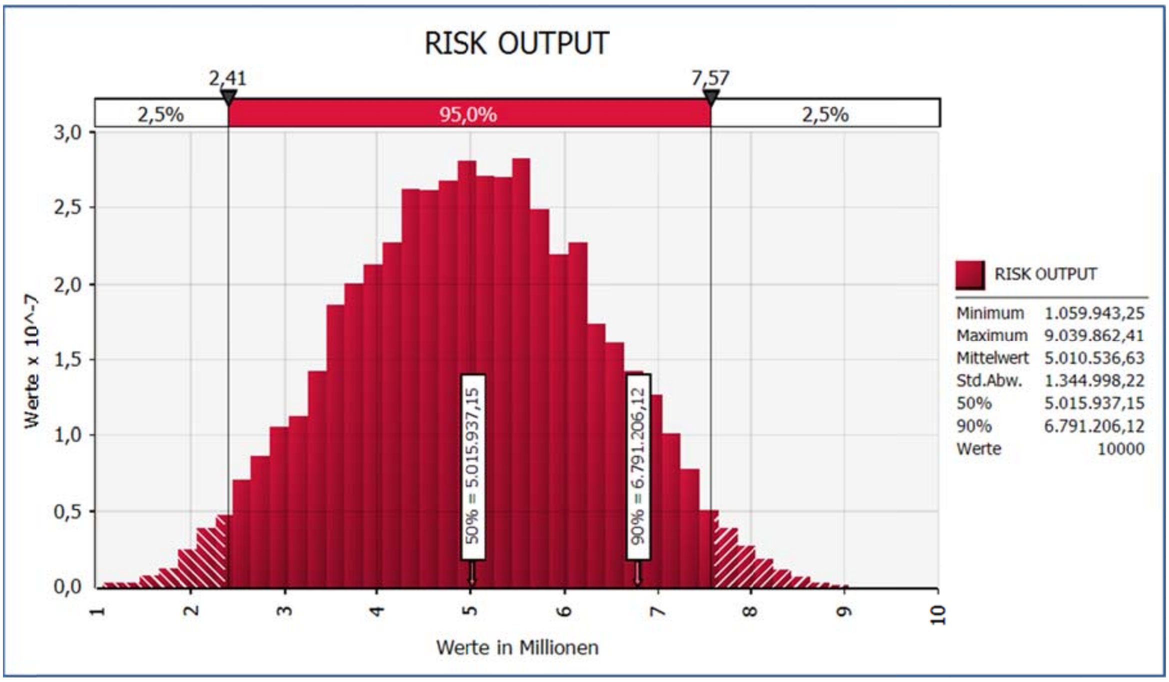
ID # (3)	Type (9)	Probability (10)	Impact (11)	Risk Matrix (12)	Type	Uncertainty Estimate	Value ($ or Days) (13)	50% probable cost/time
4	Cost / Schedule	Moderate	High	Probability VH H M L VL; Impact VL L M H VH; X	COST	MIN / Most Likely / MAX	0 / / 1.000.000	500000
					SCHEDULE	MIN / Most Likely / MAX		
7	Cost / Schedule	Moderate	High	Probability VH H M L VL; Impact VL L M H VH; X	COST	MIN / Most Likely / MAX	0 / / 500.000	250000
					SCHEDULE	MIN / Most Likely / MAX		
26	Cost / Schedule	Moderate	Very High	Probability VH H M L VL; Impact VL L M H VH; X	COST	MIN / Most Likely / MAX	0 / / 3.000.000	1500000
					SCHEDULE	MIN / Most Likely / MAX		
34	Cost / Schedule	High	High	Probability VH H M L VL; Impact VL L M H VH; X	COST	MIN / Most Likely / MAX	500.000 / / 2.000.000	1250000
					SCHEDULE	MIN / Most Likely / MAX		
61	Cost / Schedule	High	High	Probability VH H M L VL; Impact VL L M H VH; X	COST	MIN / Most Likely / MAX	0 / / 3.000.000	1500000
					SCHEDULE	MIN / Most Likely / MAX		

Response Strategy and Monitoring and Control

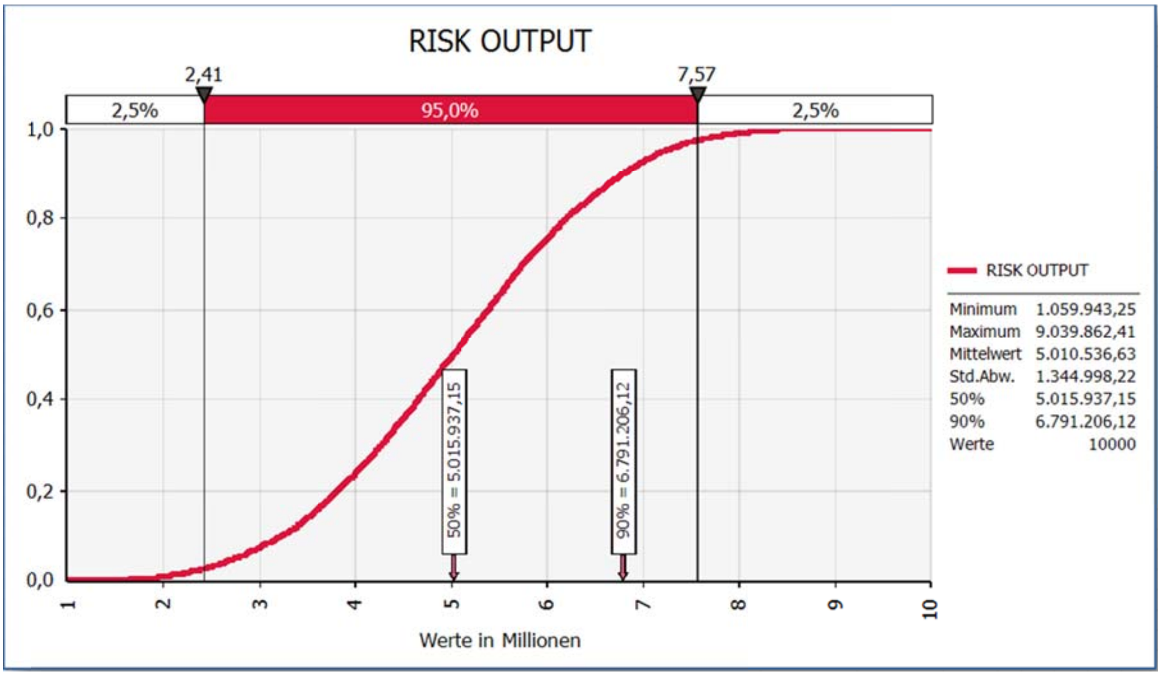
ID # (3)	Strategy (14)	Response Actions including advantages and disadvantages (15)	Affected WBS Tasks (16)	RISK OWNER (17)	Status Interval or Milestone Check (18)	Date, Status and Review Comments (19)
4	Avoidance	*Implementation of a 55 day delayed start. Will monitorUnit 2S progress the closer we get to Beginning Construction. *Will have approved TCE in place to ensure contractors rights to accessing the work area needed.	None	Gerard Chadergian		
7	Acceptance	*If needed, contractor could relocate cable or AT&T as a CCO. *Hire a subcontractor to do the utility work. *Add work around to contract. *Begin relocations before construction begins.	None	Gerard Chadergian		
26	Transference	Shortfall in funding would be covered with Local TransNet funds as SANDAG and the region have a vested interest in the success of the project. TransNet funds would be repaid once additional bond funds became available.	None	Andrew Rice		
34	None	PENDING	None	Gerard Chadergian		
61	N/A	Right of Entry would be issued between Caltrans and the Community College to commence with construction of the DAR and transit station prior to executing a MOU or agreement.	None	Frank Owsiany		

200 (Maria-Sanchez, 2011)

Risk analysis results (confidence interval 50%)



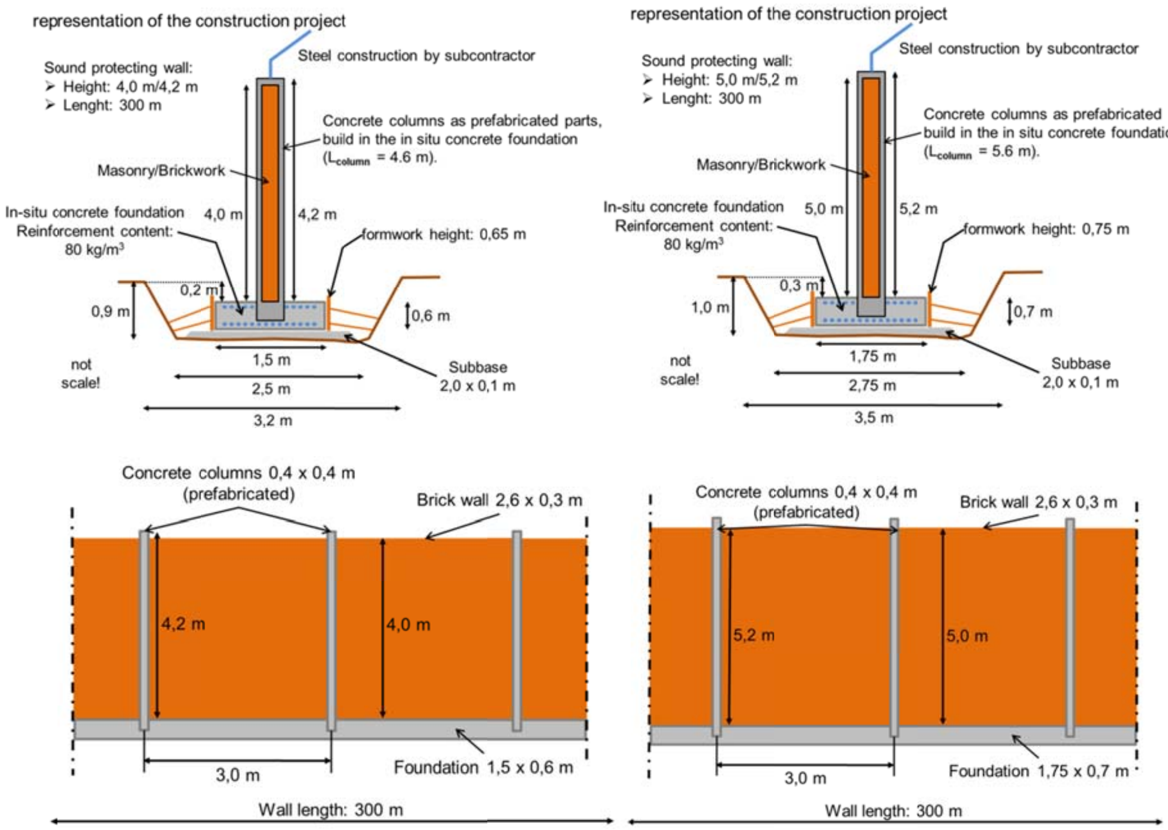
Probabilities histogram MCS



Cumulative curve of probabilities

Appendix E: *Sound protecting wall*[201]

The project is defined as the construction of a 300m long sound protecting wall for a determined street. All the activities for the construction of the wall should be considered but the steel construction and the columns; they will be performed by a subcontractor. The concrete columns will be as prefabricated parts delivered to the site.



Alternatives for the sound protecting wall

For the development of the sound protecting wall project, two different alternatives were developed for its analysis (see figure above). The alternative A was developed for a wall height of 4.0m and the alternative B was created for a height of 5.0m. The complete project description is presented in the Appendix E.

For this project the main objectives are defined as follows:

- Budget: € 360,000.00
- Maximum duration 31 days
- Quality of sound insulation

[201] Example from the lecture notes Baubetrieb (Schwarz, 2010)

Information for the cost estimation

Masses: see specifications and sketches

Cost estimates for materials and subcontractor (all delivered free on site):

- Lean concrete subbase: 67, - Euro/m³
- Formwork: 8, - Euro/m²
- Reinforcement (bent): 800, - € / ton
- Concrete: 100, - Euro/m³
- Steel columns: 240, - € / pcs
- Masonry: 20, - Euro/m² (plus 7.5% waste)
- Mortar: 0.10 € / l and 30 l/m² wall
- Steel Construction (subcontractor) 1.650, - € / ton

Information on the cost approach "backhoe"

- Engine power: 60 kW
- Bucket capacity: 1.0 m3
- Value as new: 77,700, - €
- Years of use: 4 years
- Time of use: 35 months
- imputed interest rate: 6.5% / year
- Repair cost rate: 2.7% / month (from initial)
- Social contract (SZ): 103%
- Fuel costs: 0,12 l / (kWxhr) and 1.10 € / lt
- Operating time: 8 hours / day at 75% utilization

The cost of the backhoe will be charged for the time of the excavation, in the position excavation. For the remaining construction period of the backhoe should be included under overheads.

Information on the cost approach Rough Terrain Crane

- It is the smallest and cheapest with sufficient rated load torque for the reinforcement (L = 4.6 m; $\rho_{concrete}$ = 2.6 ton/m³) can lift at least with a 13 m radius.
- For this crane the average of the maintenance costs (A + V) should be used.
- When the maintenance cost the social contract should be calculated with 103%.
- The consumption of fuel are: 0,15 l / (kWxhr)
- The cost for fuel are: 1,10 € / lt
- The operating time of the crane are: 8 hours / day at 75% utilization

The cost of the mobile crane will be charged for its utilization time in the "concrete columns" position. For the rest of the construction crane should be included under the overheads.

Information on the overhead costs, indirect costs risk and profit and for construction

- More hours in the wage GKdB: 1,500 man-hours
- Other site overheads (per month):
  - Supervision (Construction Manager): 3.000, - €
  - Other device-BE: 3.500, - €
    (Trailer, Dixi-toilet , vibrating plate, mortar mixers, etc.)
  - A backhoe and a crane must be added!
  - Other: 1.000, - €
- General business costs: 11.5%
- Risk and profit: 6.5%
- Working hours: 8 hrs / AT, 20 AT / month

Information to performance factors

- Excavation: 10 m³/hr
- subbase 10 cm: 20 m²/hr
- Reinforced concrete: 5.0 Man-hr/m³
  (peel, reinforcing, concrete rework,)
- Prefabricated columns: 8.0 Man-hr/pcs
- Masonry: 1.75 Man-hr/m²
- Backfill: 10 m³/hr

Information on wage

- Wage costs (average wage): 25,00 € / hour

Appendix F: ANNs Predictions

Data banks and Predictions ANNs, all tests performed with Neuronal Tools of Palisade

Excavation

Excavation for Foundation

Crew	Site conditions	Equipment	Weather	Factor	Result
1,00	***0,90***	***1,10***	***0,90***	***0,26***	
1,20	***0,90***	***0,90***	***1,15***	***0,29***	
1,20	0,90	1,10	0,90	0,27	0,29
0,85	1,00	1,50	0,90	0,27	0,30
1,20	1,00	1,50	0,90	0,27	0,44
0,85	0,90	0,90	1,15	0,28	0,22
1,00	0,90	0,90	1,15	0,28	0,26
0,85	0,90	1,50	0,90	0,29	0,30
1,20	1,10	1,50	1,30	0,29	0,74
0,85	1,10	1,50	0,90	0,29	0,37
0,85	1,10	0,90	0,90	0,27	0,20
0,85	0,90	1,10	0,90	0,27	0,21
1,00	1,10	0,90	1,15	0,27	0,30
1,20	1,10	1,50	1,15	0,29	0,66
0,85	1,10	1,50	1,30	0,27	0,49
1,00	0,90	1,10	1,30	0,26	0,34
1,20	1,10	1,50	1,15	0,29	0,66
1,20	0,90	1,10	1,30	0,28	0,43
0,85	1,10	0,90	0,90	0,29	0,22

Prediction Report: "N

Tag Used	Prediction	Target	Variation
predict	0,233	0,2317	0,63%
predict	0,321	0,3242	-1,07%

Crew	
good	0,85
normal	1
bad	1,2
Site Conditions	
good	0,9
Normal	1
bad	1,1
Equipment	
good	0,9
bad	1,1
very bad	1,5
Weather	
good	0,9
bad	1,15
very bad	1,3

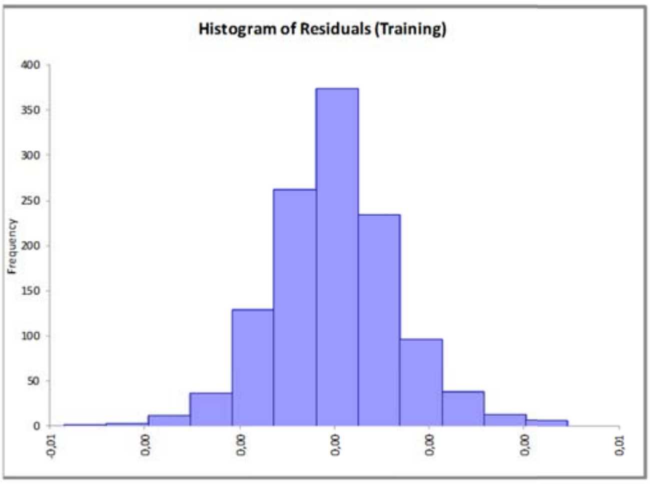
Prediction and variation, excavation performance factor

NeuralTools: Neural Net Training, Auto-Testing, and Auto-Prediction
Performed By: Sandoval
Date: Mittwoch, 25. Mai 2011 10:51:24
Data Set: Data Set #1
Net: Net Trained on Data Set #1

Summary	
Net Information	
Name	Net Trained on Data Set #1
Configuration	GRNN Numeric Predictor
Location	This Workbook
Independent Category Variables	0
Independent Numeric Variables	5 (Crew, Site conditions, Equipment, Weather, Factor)
Dependent Variable	Numeric Var. (Result)
Training	
Number of Cases	1201
Training Time	00:00:15
Number of Trials	53
Reason Stopped	Auto-Stopped
% Bad Predictions (1% Tolerance)	0,1665%
Root Mean Square Error	0,001300
Mean Absolute Error	0,0009858
Std. Deviation of Abs. Error	0,0008469
Testing	
Number of Cases	300
% Bad Predictions (1% Tolerance)	9,0000%
Root Mean Square Error	0,001986
Mean Absolute Error	0,001305
Std. Deviation of Abs. Error	0,001497
Prediction	
Number of Cases	2
Live Prediction Enabled	YES
Data Set	
Name	Data Set #1
Number of Rows	1503
Manual Case Tags	NO

Linear Predictor vs. Neural Net

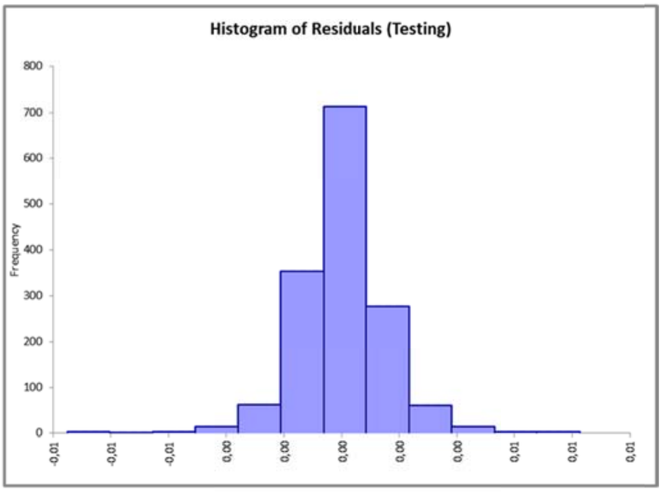
	Linear Predictor	Neural Net
R-Square (Training)	0,9687	–
Root Mean Sq. Error (Training)	0,02048	0,001300
Root Mean Sq. Error (Testing)	0,02041	0,001986



ANNs training report excavation performance factor

NeuralTools: Testing Summary
Performed By: Sandoval
Date: Mittwoch, 25. Mai 2011 10:51:51
Data Set: Data Set #1
Net: Net Trained on Data Set #1

Summary	
Net Information	
Name	Net Trained on Data Set #1
Configuration	GRNN Numeric Predictor
Location	This Workbook
Independent Category Variables	0
Independent Numeric Variables	5 (Crew, Site conditions, Equipment, Weather, Factor)
Dependent Variable	Numeric Var. (Result)
Testing	
Number of Cases	1501
% Bad Predictions (1% Tolerance)	1,9320%
Root Mean Square Error	0,001463
Mean Absolute Error	0,001050
Std. Deviation of Abs. Error	0,001019
Data Set	
Name	Data Set #1
Number of Rows	1503
Manual Case Tags	NO
Variable Matching	Automatic
Indep. Category Variables Used	None
Indep. Numeric Variables Used	Names from training
Dependent Variable	Numeric Var. (Result)



ANNs testing report excavation performance factor

Blinding – Subbase

Blinding - Subbase

Crew	Cement	Conditions	Weather	Factor	Result
normal	F5-F6	very bad	good	0,09	
good	F1-F4	good	very bad	0,08	
normal	F1-F4	very bad	very bad	0,07	0,20
bad	F5-F6	bad	bad	0,09	0,17
normal	F5-F6	very bad	good	0,08	0,12
bad	F5-F6	very bad	good	0,09	0,14
good	F5-F6	good	bad	0,07	0,07
bad	F1-F4	bad	very bad	0,07	0,16
good	F5-F6	very bad	good	0,08	0,09
good	F1-F4	good	good	0,08	0,05
normal	F1-F4	good	very bad	0,10	0,14
bad	F5-F6	very bad	good	0,08	0,12
normal	F5-F6	good	good	0,07	0,05
bad	F5-F6	good	bad	0,08	0,10
normal	F5-F6	bad	bad	0,09	0,15
bad	F1-F4	good	bad	0,08	0,11
normal	F1-F4	good	bad	0,08	0,10
good	F5-F6	bad	bad	0,09	0,13

Prediction Report: "Net

Tag Used	Prediction	Target	Variation
predict	0,1244	0,1239	0,38%
predict	0,0980	0,0979	0,04%

Crew	
good	0,85
normal	1
bad	1,1
Cement	
F1-F4	1
F5-F6	0,9
Conditions	
good	0,9
bad	1,3
very bad	1,7
Weather	
good	0,9
bad	1,4
very bad	1,6

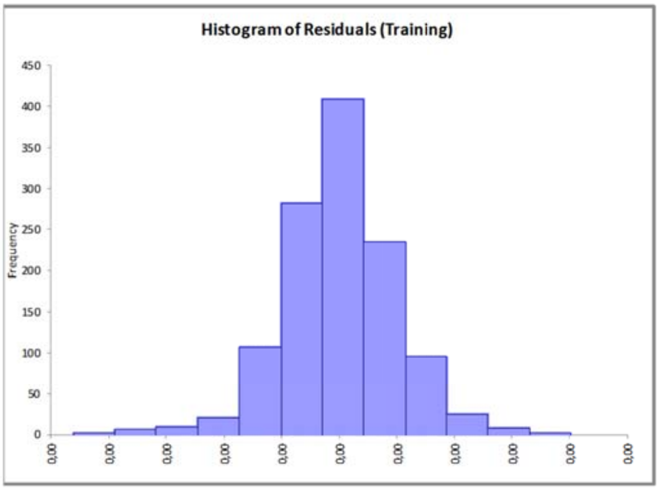
Prediction and variation, blinding - subbase performance factor

NeuralTools: Neural Net Training, Auto-Testing, and Auto-Prediction

Performed By: Sandoval
Date: Mittwoch, 25. Mai 2011 15:55:14
Data Set: Data Set #1
Net: Net Trained on Data Set #1

Summary	
Net Information	
Name	Net Trained on Data Set #1
Configuration	GRNN Numeric Predictor
Location	This Workbook
Independent Category Variables	4 (Crew, Cement, Conditions, Weather)
Independent Numeric Variables	1 (Factor)
Dependent Variable	Numeric Var. (Result)
Training	
Number of Cases	1201
Training Time	00:00:22
Number of Trials	56
Reason Stopped	Auto-Stopped
% Bad Predictions (1% Tolerance)	0,0833%
Root Mean Square Error	0,0004895
Mean Absolute Error	0,0003648
Std. Deviation of Abs. Error	0,0003264
Testing	
Number of Cases	300
% Bad Predictions (1% Tolerance)	20,6667%
Root Mean Square Error	0,001501
Mean Absolute Error	0,0009250
Std. Deviation of Abs. Error	0,001182
Prediction	
Number of Cases	2
Live Prediction Enabled	YES
Data Set	
Name	Data Set #1
Number of Rows	1503
Manual Case Tags	NO

Linear Predictor vs. Neural Net	Linear Predictor	Neural Net
R-Square (Training)	0,9552	-
Root Mean Sq. Error (Training)	0,01073	0,0004895
Root Mean Sq. Error (Testing)	0,01069	0,001501

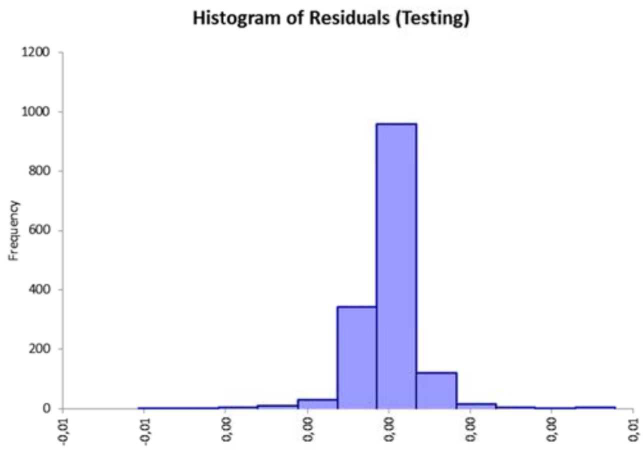


ANNs training report blinding - subbase performance factor

NeuralTools: Testing Summary

Performed By: Sandoval
Date: Mittwoch, 25. Mai 2011 15:55:51
Data Set: Data Set #1
Net: Net Trained on Data Set #1

Summary	
Net Information	
Name	Net Trained on Data Set #1
Configuration	GRNN Numeric Predictor
Location	This Workbook
Independent Category Variables	4 (Crew, Cement, Conditions, Weather)
Independent Numeric Variables	1 (Factor)
Dependent Variable	Numeric Var. (Result)
Testing	
Number of Cases	1501
% Bad Predictions (1% Tolerance)	4,1972%
Root Mean Square Error	0,0008012
Mean Absolute Error	0,0004767
Std. Deviation of Abs. Error	0,0006439
Data Set	
Name	Data Set #1
Number of Rows	1503
Manual Case Tags	NO
Variable Matching	Automatic
Indep. Category Variables Used	Names from training
Indep. Numeric Variables Used	Names from training
Dependent Variable	Numeric Var. (Result)



ANNs testing report blinding - subbase performance factor

Reinforced concrete foundation

Reinforced Concrete Foundation

Crew	Concrete	Conditions	Producer	Factor	Result
good	***F1-F4***	***good***	***bad***	***0,55***	
normal	***F1-F4***	***very bad***	***bad***	***0,53***	
bad	F5-F6	bad	bad	0,50	***1,08***
bad	F5-F6	very bad	bad	0,57	***1,64***
good	F5-F6	very bad	bad	0,52	***1,13***
normal	F1-F4	very bad	good	0,53	***0,96***
normal	F5-F6	bad	very bad	0,51	***1,09***
bad	F1-F4	very bad	good	0,54	***1,18***
bad	F1-F4	good	very bad	0,58	***1,12***
good	F1-F4	bad	good	0,58	***0,70***
bad	F1-F4	good	very bad	0,58	***1,13***
bad	F5-F6	bad	very bad	0,59	***1,52***
bad	F5-F6	good	good	0,58	***0,45***
bad	F1-F4	bad	good	0,60	***0,97***
bad	F1-F4	very bad	good	0,55	***1,19***
normal	F5-F6	very bad	very bad	0,57	***1,64***
normal	F1-F4	very bad	bad	0,52	***1,55***
good	F5-F6	bad	good	0,55	***0,53***
good	F5-F6	very bad	bad	0,53	***1,15***

Prediction Report: "N

Tag Used	Prediction
predict	0,6675
predict	1,5638

Target	Variation
0,668	-0,12%
1,590	-1,65%

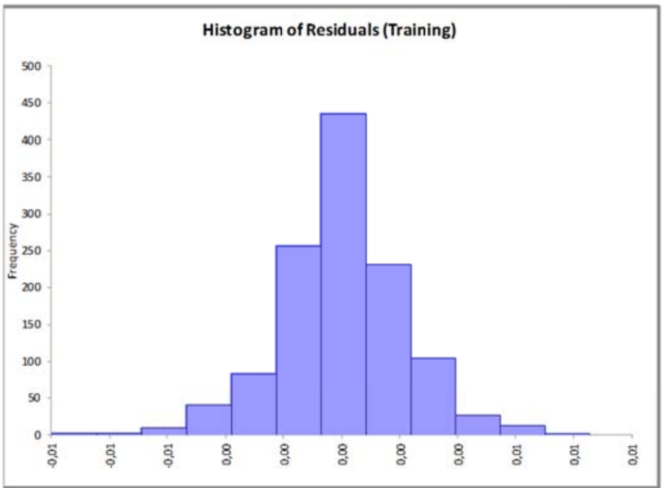
Crew	
Normal	1
good	0,9
bad	1,2
Concrete	
F1-F4	1
F5-F6	0,8
Conditions	
good	0,9
bad	1,5
very bad	2
Concrete Producer	
good	0,9
bad	1,5
very bad	1,8

Prediction and variation, reinforced concrete performance factor

NeuralTools: Neural Net Training, Auto-Testing, and Auto-Prediction
Performed By: Sandoval
Date: Mittwoch, 25. Mai 2011 09:27:03
Data Set: Data Set #1
Net: Net Trained on Data Set #1

Summary	
Net Information	
Name	Net Trained on Data Set #1
Configuration	GRNN Numeric Predictor
Location	This Workbook
Independent Category Variables	4 (Crew, Concrete, Conditions, Producer)
Independent Numeric Variables	1 (Factor)
Dependent Variable	Numeric Var. (Result)
Training	
Number of Cases	1200
Training Time	00:00:24
Number of Trials	61
Reason Stopped	Auto-Stopped
% Bad Predictions (1% Tolerance)	0,0000%
Root Mean Square Error	0,002079
Mean Absolute Error	0,001530
Std. Deviation of Abs. Error	0,001408
Testing	
Number of Cases	300
% Bad Predictions (1% Tolerance)	9,3333%
Root Mean Square Error	0,03957
Mean Absolute Error	0,008111
Std. Deviation of Abs. Error	0,03872
Prediction	
Number of Cases	2
Live Prediction Enabled	YES
Data Set	
Name	Data Set #1
Number of Rows	1502
Manual Case Tags	NO

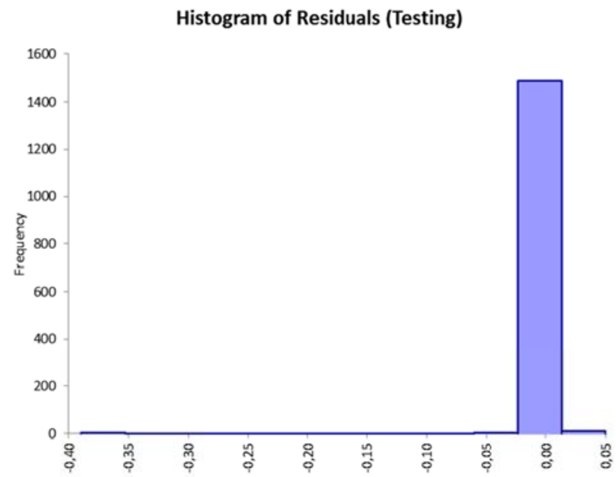
Linear Predictor vs. Neural Net	Linear Predictor	Neural Net
R-Square (Training)	0,9400	–
Root Mean Sq. Error (Training)	0,1183	0,002079
Root Mean Sq. Error (Testing)	0,1142	0,03957



ANNs training report reinforced concrete performance factor

NeuralTools: Testing Summary
Performed By: Sandoval
Date: Mittwoch, 25. Mai 2011 09:27:46
Data Set: Data Set #1
Net: Net Trained on Data Set #1

Summary	
Net Information	
Name	Net Trained on Data Set #1
Configuration	GRNN Numeric Predictor
Location	This Workbook
Independent Category Variables	4 (Crew, Concrete, Conditions, Producer)
Independent Numeric Variables	1 (Factor)
Dependent Variable	Numeric Var. (Result)
Testing	
Number of Cases	1500
% Bad Predictions (1% Tolerance)	1,8667%
Root Mean Square Error	0,01779
Mean Absolute Error	0,002846
Std. Deviation of Abs. Error	0,01756
Data Set	
Name	Data Set #1
Number of Rows	1502
Manual Case Tags	NO
Variable Matching	Automatic
Indep. Category Variables Used	Names from training
Indep. Numeric Variables Used	Names from training
Dependent Variable	Numeric Var. (Result)



ANNs testing report reinforced concrete performance factor

Masonry – Brick working

Masonry Brick working

Crew	Site conditions	Equipment	Weather	Factor	Result
normal	bad	normal	bad	0,78	
good	bad	good	good	0,65	
good	good	normal	bad	0,74	0,70
bad	good	good	good	0,66	0,60
normal	normal	good	bad	0,72	0,72
bad	normal	normal	good	0,79	0,88
good	bad	good	bad	0,75	0,85
bad	good	good	very bad	0,74	1,01
normal	good	normal	bad	0,72	0,71
bad	normal	good	very bad	0,66	1,01
bad	good	good	bad	0,65	0,73
normal	bad	good	good	0,73	0,71
bad	good	good	very bad	0,71	0,97
normal	good	good	very bad	0,65	0,71
good	normal	good	good	0,74	0,57
bad	normal	bad	good	0,66	0,97
normal	normal	bad	bad	0,66	0,95
good	good	good	very bad	0,66	0,69
normal	bad	normal	bad	0,78	1,03

Prediction Report: "N

Tag Used	Prediction
predict	1,0266
predict	0,6029

Target	Variation
1,0296	-0,30%
0,6669	-9,60%

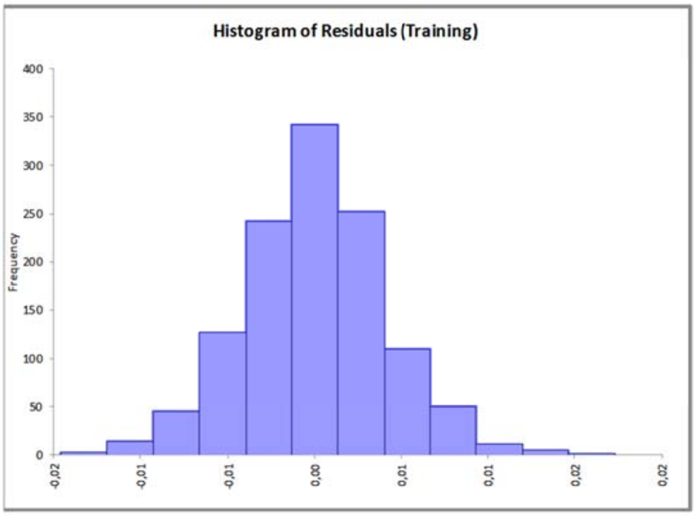
Crew	
good	0,95
normal	1
bad	1,25
Site Conditions	
good	0,9
Normal	1
bad	1,2
Equipment	
good	0,9
normal	1
bad	1,3
Weather	
good	0,9
bad	1,1
very bad	1,35

Prediction and variation, masonry – brick working concrete performance factor

NeuralTools: Neural Net Training, Auto-Testing, and Auto-Prediction
Performed By: Sandoval
Date: Mittwoch, 25. Mai 2011 15:13:47
Data Set: Data Set #1
Net: Net Trained on Data Set #1

Summary	
Net Information	
Name	Net Trained on Data Set #1
Configuration	GRNN Numeric Predictor
Location	This Workbook
Independent Category Variables	4 (Crew, Site conditions, Equipment, Weather)
Independent Numeric Variables	1 (Factor)
Dependent Variable	Numeric Var. (Result)
Training	
Number of Cases	1201
Training Time	00:00:23
Number of Trials	54
Reason Stopped	Auto-Stopped
% Bad Predictions (1% Tolerance)	1,4988%
Root Mean Square Error	0,004096
Mean Absolute Error	0,003175
Std. Deviation of Abs. Error	0,002588
Testing	
Number of Cases	300
% Bad Predictions (1% Tolerance)	23,0000%
Root Mean Square Error	0,01657
Mean Absolute Error	0,008187
Std. Deviation of Abs. Error	0,01440
Prediction	
Number of Cases	2
Live Prediction Enabled	YES
Data Set	
Name	Data Set #1
Number of Rows	1503
Manual Case Tags	NO

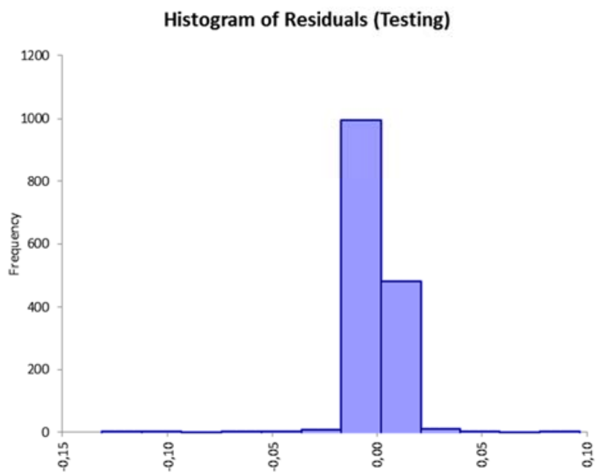
Linear Predictor vs. Neural Net	Linear Predictor	Neural Net
R-Square (Training)	0,9678	--
Root Mean Sq. Error (Training)	0,04879	0,004096
Root Mean Sq. Error (Testing)	0,05614	0,01657



ANNs training report masonry – brick working performance factor

NeuralTools: Testing Summary
Performed By: Sandoval
Date: Mittwoch, 25. Mai 2011 15:14:24
Data Set: Data Set #1
Net: Net Trained on Data Set #1

Summary	
Net Information	
Name	Net Trained on Data Set #1
Configuration	GRNN Numeric Predictor
Location	This Workbook
Independent Category Variables	4 (Crew, Site conditions, Equipment, Weather)
Independent Numeric Variables	1 (Factor)
Dependent Variable	Numeric Var. (Result)
Testing	
Number of Cases	1501
% Bad Predictions (1% Tolerance)	5,7961%
Root Mean Square Error	0,008263
Mean Absolute Error	0,004177
Std. Deviation of Abs. Error	0,007130
Data Set	
Name	Data Set #1
Number of Rows	1503
Manual Case Tags	NO
Variable Matching	Automatic
Indep. Category Variables Used	Names from training
Indep. Numeric Variables Used	Names from training
Dependent Variable	Numeric Var. (Result)



ANNs testing report masonry – brick working performance factor

Backfill

Backfill Foundation					
Crew	Site conditions	Equipment	Weather	Factor	Result
0,85	***1,00***	***1,10***	***0,90***	***0,12***	
1,10	***1,25***	***0,90***	***0,90***	***0,14***	
1,00	0,85	0,90	1,15	0,12	0,11
0,85	0,85	0,90	1,30	0,15	0,12
0,85	1,00	1,10	0,90	0,13	0,11
0,85	1,00	1,50	1,30	0,13	0,21
0,85	1,25	1,10	1,30	0,15	0,22
1,10	0,85	1,50	0,90	0,12	0,15
1,10	1,00	1,50	0,90	0,12	0,18
0,85	1,25	0,90	0,90	0,13	0,11
1,10	1,25	1,50	1,30	0,15	0,40
1,10	0,85	0,90	0,90	0,14	0,11
1,10	0,85	1,10	1,30	0,13	0,18
1,00	1,25	1,50	1,30	0,15	0,36
1,10	1,25	0,90	0,90	0,15	0,17
1,10	1,00	0,90	1,15	0,12	0,14
1,10	1,25	1,50	1,15	0,14	0,34
1,00	1,25	1,10	0,90	0,14	0,17
1,10	0,85	1,50	0,90	0,14	0,18

Prediction Report: "N

	Prediction
predict	0,103
predict	0,155

Target	Variation
0,1010	1,79%
0,1559	-0,73%

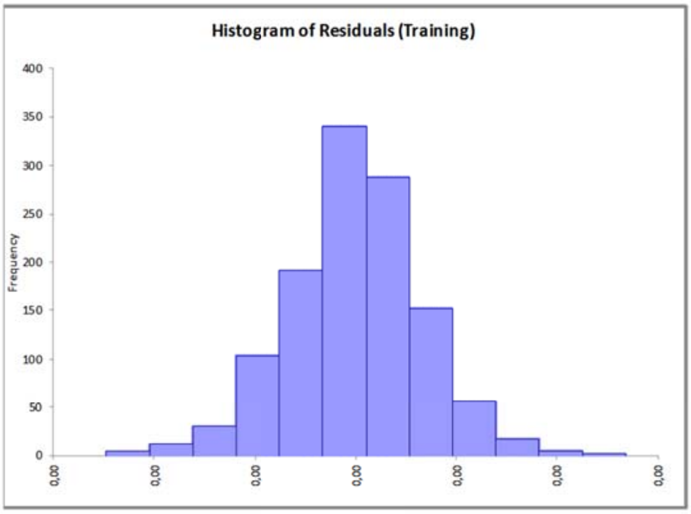
Crew	
good	0,85
normal	1
bad	1,1
Site Conditions	
good	0,85
Normal	1
bad	1,25
Equipment	
good	0,9
bad	1,1
very bad	1,5
Weather	
good	0,9
bad	1,15
very bad	1,3

Prediction and variation, backfill performance factor

NeuralTools: Neural Net Training, Auto-Testing, and Auto-Prediction
Performed By: Sandoval
Date: Mittwoch, 25. Mai 2011 14:30:32
Data Set: Data Set #1
Net: Net Trained on Data Set #1

Summary	
Net Information	
Name	Net Trained on Data Set #1
Configuration	GRNN Numeric Predictor
Location	This Workbook
Independent Category Variables	0
Independent Numeric Variables	5 (Crew, Site conditions, Equipment, Weather, Factor)
Dependent Variable	Numeric Var. (Result)
Training	
Number of Cases	1201
Training Time	00:00:15
Number of Trials	54
Reason Stopped	Auto-Stopped
% Bad Predictions (1% Tolerance)	0,4996%
Root Mean Square Error	0,0006684
Mean Absolute Error	0,0005136
Std. Deviation of Abs. Error	0,0004277
Testing	
Number of Cases	300
% Bad Predictions (1% Tolerance)	19,6667%
Root Mean Square Error	0,001838
Mean Absolute Error	0,001148
Std. Deviation of Abs. Error	0,001435
Prediction	
Number of Cases	2
Live Prediction Enabled	YES
Data Set	
Name	Data Set #1
Number of Rows	1503
Manual Case Tags	NO

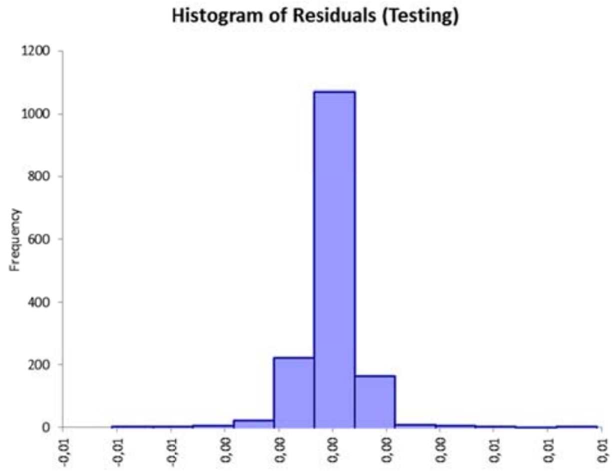
Linear Predictor vs. Neural Net	Linear Predictor	Neural Net
R-Square (Training)	0,9631	--
Root Mean Sq. Error (Training)	0,01154	0,0006684
Root Mean Sq. Error (Testing)	0,01103	0,001838



Prediction and variation, backfill concrete performance factor

NeuralTools: Testing Summary
Performed By: Sandoval
Date: Mittwoch, 25. Mai 2011 14:31:06
Data Set: Data Set #1
Net: Net Trained on Data Set #1

Summary	
Net Information	
Name	Net Trained on Data Set #1
Configuration	GRNN Numeric Predictor
Location	This Workbook
Independent Category Variables	0
Independent Numeric Variables	5 (Crew, Site conditions, Equipment, Weather, Factor)
Dependent Variable	Numeric Var. (Result)
Testing	
Number of Cases	1501
% Bad Predictions (1% Tolerance)	4,3304%
Root Mean Square Error	0,001016
Mean Absolute Error	0,0006404
Std. Deviation of Abs. Error	0,0007890
Data Set	
Name	Data Set #1
Number of Rows	1503
Manual Case Tags	NO
Variable Matching	Automatic
Indep. Category Variables Used	None
Indep. Numeric Variables Used	Names from training
Dependent Variable	Numeric Var. (Result)

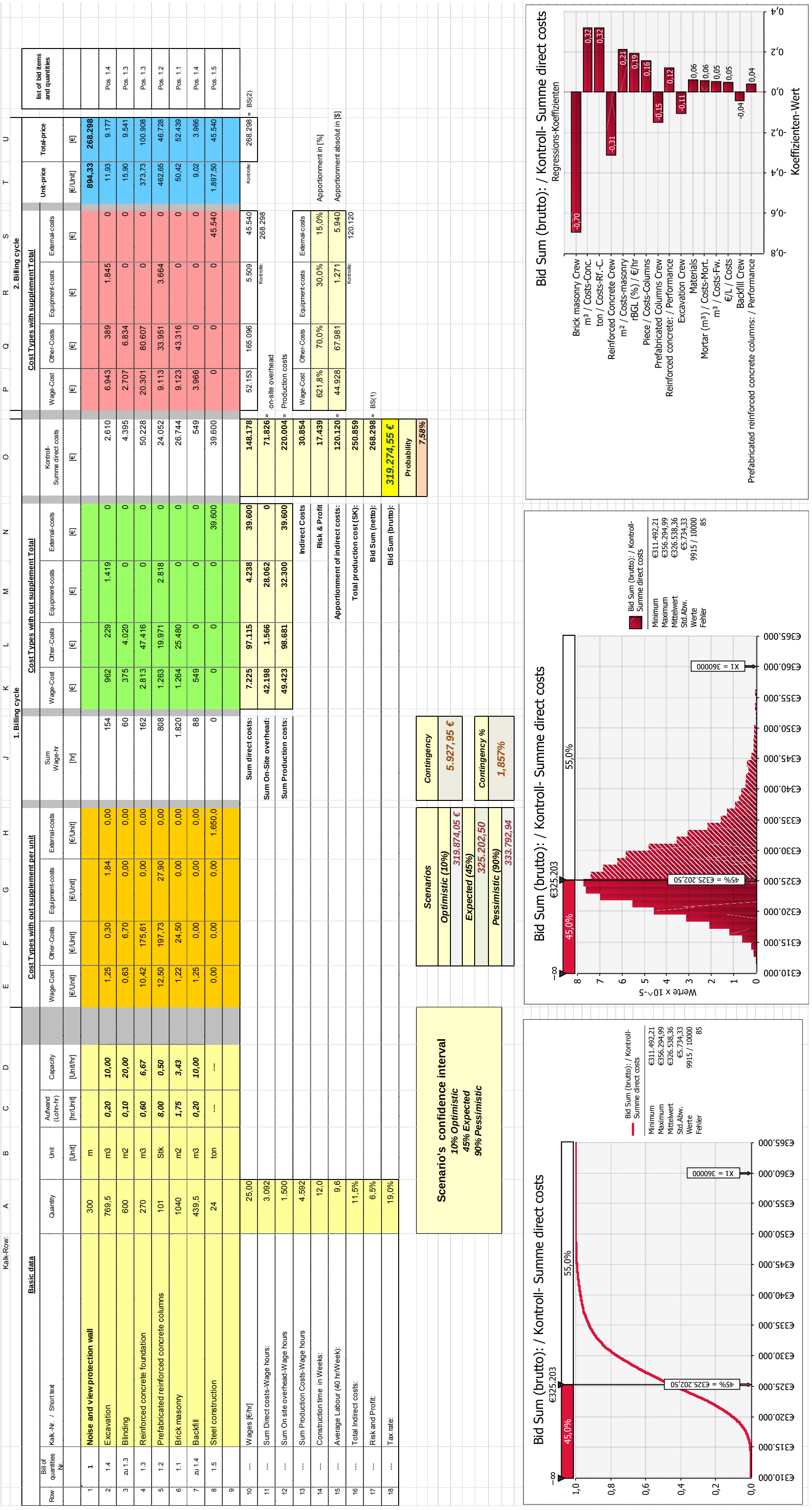


ANNs testing report backfill performance factor

Appendix G: MCS Results

Risk analysis sound protection wall, all tests performed with @Risk of Palisade

Alternative 4.0m without ANNs



Alternative 4.0m with ANNs

Basic data / **1. Billing cycle** – Cost Types with out supplement per unit

Row	Bill of quantities Nr.	Kalk.-Nr. / Short text	Quantity (A)	Unit (B)	Aufwand (Lohn-hr) (C)	Capacity (D)	Wage-Cost (E)	Other-Costs (F)	Equipment-costs (G)	External-costs (H)
				[Unit]	[hr/Unit]	[Unit/hr]	[€/Unit]	[€/Unit]	[€/Unit]	[€/Unit]
1	1	**Noise and view protection wall**	300	m						
2	1.4	Excavation	769,5	m3	*0,23*	*8,58*	1,46	0,35	2,15	0,00
3	zu 1.3	Blinding	600	m2	*0,12*	*16,08*	0,78	6,70	0,00	0,00
4	1.3	Reinforced concrete foundation	270	m3	*0,67*	*5,99*	9,36	175,61	0,00	0,00
5	1.2	Prefabricated reinforced concrete columns	101	Stk	*8,00*	*0,50*	12,50	197,73	27,90	0,00
6	1.1	Brick masonry	1040	m2	*1,03*	*5,84*	0,71	24,50	0,00	0,00
7	zu 1.4	Backfill	439,5	m3	*0,15*	*12,92*	0,97	0,00	0,00	0,00
8	1.5	Steel construction	24	ton	---	---	0,00	0,00	0,00	1.650,0
9										
10	---	Wages [€/hr]	25,00							
11	---	Sum Direct costs-Wage hours:	2.378							
12	---	Sum On site overhead-Wage hours	1.500							
13	---	Sum Production Costs-Wage hours	3.878							
14	---	Construction time in Weeks:	12,0							
15	---	Average Labour (40 hr/Week):	8,1							
16	---	Total Indirect costs:	11,5%							
17	---	Risk and Profit:	6,5%							
18	---	Tax rate:	19,0%							

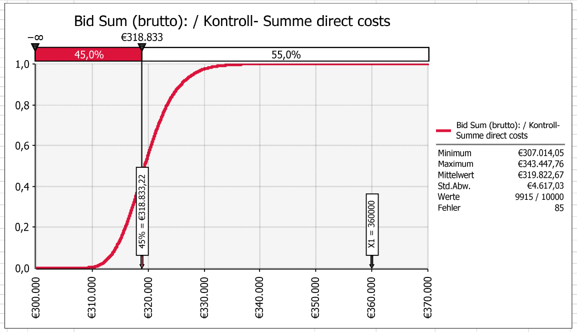
1. Billing cycle – Cost Types with out supplement Total / **2. Billing cycle** – Cost Types with supplement Total

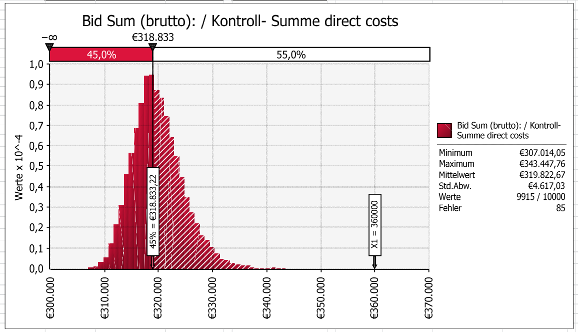
Row		Sum Wage-hr (J)	Wage-Cost (K)	Other-Costs (L)	Equipment-costs (M)	External-costs (N)	Kontroll-Summe direct costs (O)	Wage-Cost (P)	Other-Costs (Q)	Equipment-costs (R)	External-costs (S)	Unit-price (T)	Total-price (U)	list of bid items and quantities
		[hr]	[€]	[€]	[€]	[€]	[€]	[€]	[€]	[€]	[€]	[€/Unit]	[€]	
1												878,46	263.538	
2		179	1.121	266	1.654	0	3.042	8.055	453	2.151	0	13,85	10.658	Pos. 1.4
3		75	467	4.020	0	0	4.487	3.352	6.834	0	0	16,98	10.186	Pos. 1.3
4		180	2.528	47.416	0	0	49.944	18.164	80.607	0	0	365,82	98.771	Pos. 1.3
5		808	1.263	19.971	2.818	0	24.052	9.071	33.951	3.664	0	462,23	46.685	Pos. 1.2
6		1.068	741	25.480	0	0	26.221	5.327	43.316	0	0	46,77	48.643	Pos. 1.1
7		68	425	0	0	0	425	3.055	0	0	0	6,95	3.055	Pos. 1.4
8		0	0	0	0	39.600	39.600	0	0	0	45.540	1.897,50	45.540	Pos. 1.5
9														
10	Sum direct costs:		6.545	97.153	4.473	39.600	147.771	47.023	165.160	5.814	45.540	Kontrolle:	263.538 = BS(2)	
11	Sum On-Site overhead:		41.806	1.435	25.089	0	68.330 =	on-site overhead		Kontrolle:	263.538			
12	Sum Production costs:		48.351	98.589	29.561	39.600	216.101 =	Production costs						
13	Indirect Costs						30.307	Wage-Cost	Other-Costs	Equipment-costs	External-costs			
14	Risk & Profit						17.130	618,5%	70,0%	30,0%	15,0%	Apportionment in [%]		
15	Apportionment of indirect costs:						115.767 =	40.478	68.007	1.342	5.940	Apportionment absolut in [$]		
16	Total production cost (SK):						246.408			Kontrolle:	115.767			
17	Bid Sum (netto):						263.538 =	BS(1)						
18	Bid Sum (brutto):						313.609,90 €							
							Probability							
							7,14%							

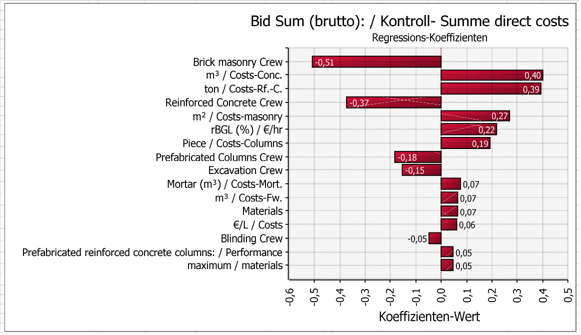
Scenario's confidence interval
10% Optimistic
45% Expected
90% Pessimistic

Scenarios	
Optimistic (10%)	314.285,24 €
Expected (45%)	318.833,22
Pessimistic (90%)	325.910,96

Contingency	
Contingency	5.223,32 €
Contingency %	1,666%







Alternative 5.0m without ANNs

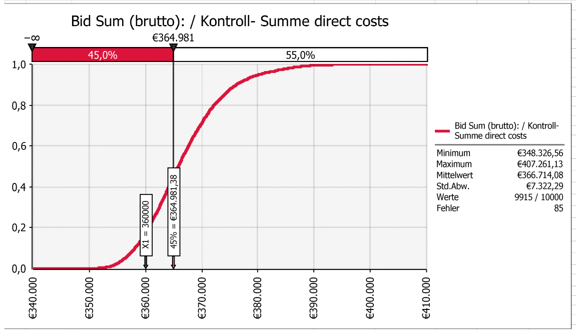
Kalk-Row:			A	B	C	D	E	F	G	H	J
Basic data							Cost Types with out supplement per unit				
Row	Bill of quantities Nr.	Kalk.-Nr. / Short text	Quantity	Unit	Aufwand (Lohn-hr)	Capacity	Wage-Cost	Other-Costs	Equipment-costs	External-costs	Sum Wage-hr
				[Unit]	[hr/Unit]	[Unit/hr]	[€/Unit]	[€/Unit]	[€/Unit]	[€/Unit]	[hr]
1	1	**Noise and view protection wall**	300	m							
2	1.4	Excavation	937,5	m3	*0,20*	*10,00*	1,25	0,30	1,84	0,00	188
3	zu 1.3	Blinding	600	m2	*0,10*	*20,00*	0,63	6,70	0,00	0,00	60
4	1.3	Reinforced concrete foundation	367,5	m3	*0,60*	*6,67*	10,42	173,85	0,00	0,00	221
5	1.2	Prefabricated reinforced concrete columns	101	Stk	*8,00*	*0,50*	12,50	197,73	27,90	0,00	808
6	1.1	Brick masonry	1300	m2	*1,75*	*3,43*	1,22	24,50	0,00	0,00	2.275
7	zu 1.4	Backfill	510	m3	*0,20*	*10,00*	1,25	0,00	0,00	0,00	102
8	1.5	Steel construction	24	ton	---	---	0,00	0,00	0,00	1.650,0	0
9											
10	---	Wages [€/hr]	25,00								**Sum direct costs:**
11	---	Sum Direct costs-Wage hours:	3.653								**Sum On-Site overhead:**
12	---	Sum On site overhead-Wage hours	1.500								**Sum Production costs:**
13	---	Sum Production Costs-Wage hours	5.153								
14	---	Construction time in Weeks:	12,0								
15	---	Average Labour (40 hr/Week):	10,7								
16	---	Total Indirect costs:	11,5%								
17	---	Risk and Profit:	6,5%								
18	---	Tax rate:	19,0%								

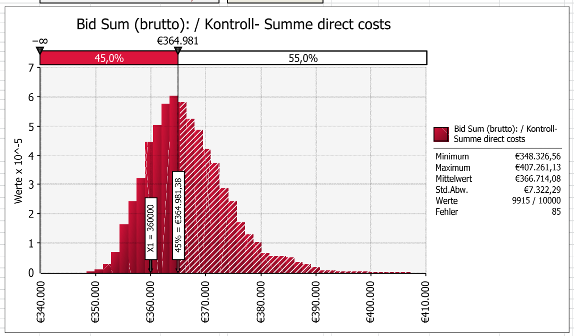
Row	K	L	M	N	O		P	Q	R	S	T	U		
	1. Billing cycle						2. Billing cycle							
	Cost Types with out supplement Total						Cost Types with supplement Total							
	Wage-Cost	Other-Costs	Equipment-costs	External-costs	Kontroll-Summe direct costs		Wage-Cost	Other-Costs	Equipment-costs	External-costs	Unit-price	Total-price		list of bid items and quantities
	[€]	[€]	[€]	[€]	[€]		[€]	[€]	[€]	[€]	[€/Unit]	[€]		
1											**1.002,04**	**300.611**		
2	1.172	278	1.729	0	3.180		5.974	473	2.248	0	9,28	8.696		Pos. 1.4
3	375	4.020	0	0	4.395		1.912	6.834	0	0	14,58	8.746		Pos. 1.3
4	3.828	63.891	0	0	67.719		19.516	108.615	0	0	348,65	128.130		Pos. 1.3
5	1.263	19.971	2.818	0	24.052		6.436	33.951	3.664	0	436,15	44.051		Pos. 1.2
6	1.580	31.850	0	0	33.430		8.054	54.145	0	0	47,85	62.199		Pos. 1.1
7	638	0	0	0	638		3.250	0	0	0	6,37	3.250		Pos. 1.4
8	0	0	0	39.600	39.600		0	0	0	45.540	1.897,50	45.540		Pos. 1.5
9														
10	**8.855**	**120.011**	**4.548**	**39.600**	**173.013**		45.142	204.018	5.912	45.540	Kontrolle:	300.611	=	BS(2)
11	**42.435**	**1.645**	**29.408**	**0**	**73.488**	=	on-site overhead		Kontrolle:	300.611				
12	**51.290**	**121.656**	**33.956**	**39.600**	**246.501**	=	Production costs							
13				**Indirect Costs**	**34.570**		Wage-Cost	Other-Costs	Equipment-costs	External-costs				
14				**Risk & Profit**	**19.540**		409,8%	70,0%	30,0%	15,0%	Apportionment in [%]			
15				**Apportionment of indirect costs:**	**127.598**	=	36.287	84.007	1.364	5.940	Apportionment absolut in [$]			
16				**Total production cost (SK):**	**281.072**				Kontrolle:	127.598				
17				**Bid Sum (netto):**	**300.611**	=	BS(1)							
18				**Bid Sum (brutto):**	***357.727,67 €***									
					Probability									
					8,64%									

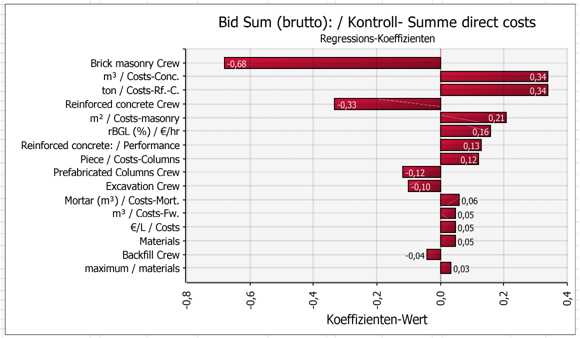
Scenario's confidence interval
10% Optimistic
45% Expected
90% Pessimistic

Scenarios	
Optimistic (10%)	*358.102,76 €*
Expected (45%)	*364.981,38*
Pessimistic (90%)	*376.192,09*

Contingency	*Contingency %*
7.253,70 €	*2,028%*







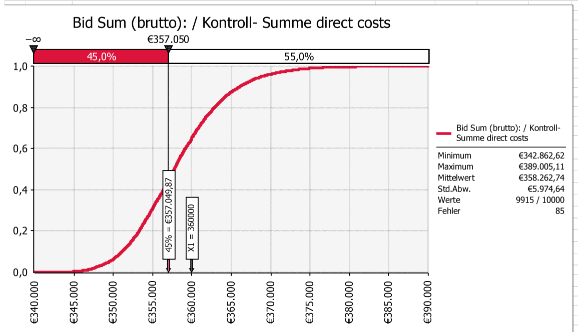
Alternative 5.0m with ANNs

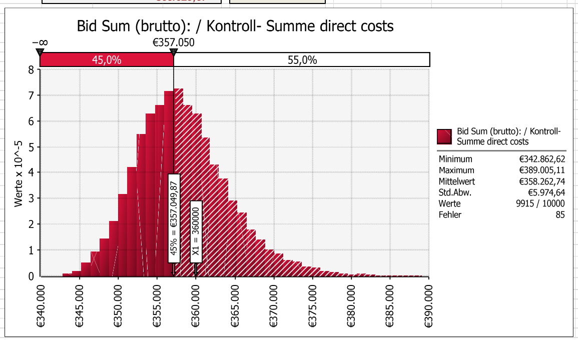
Row	Bill of quantities Nr.	Kalk.-Nr. / Short text	A Quantity	B Unit	C Aufwand (Lohn-hr)	D Capacity	E Wage-Cost	F Other-Costs	G Equipment-costs	H External-costs	J Sum Wage-hr	K Wage-Cost	L Other-Costs	M Equipment-costs	N External-costs	O Kontroll-Summe direct costs	P Wage-Cost	Q Other-Costs	R Equipment-costs	S External-costs	T Unit-price	U Total-price	list of bid items and quantities
		Basic data					Cost Types with out supplement per unit				1. Billing cycle	Cost Types with out supplement Total					2. Billing cycle – Cost Types with supplement Total						
				[Unit]	[hr/Unit]	[Unit/hr]	[€/Unit]	[€/Unit]	[€/Unit]	[€/Unit]	[hr]	[€]	[€]	[€]	[€]	[€]	[€]	[€]	[€]	[€]	[€/Unit]	[€]	
1	1	**Noise and view protection wall**	300	m																	**982,00**	**294.601**	
2	1.4	Excavation	937,5	m3	*0,23*	*8,58*	1,46	0,35	2,15	0,00	219	1.366	325	2.016	0	3.706	6.640	552	2.620	0	10,47	9.813	Pos. 1.4
3	zu 1.3	Blinding	600	m2	*0,12*	*16,08*	0,78	6,70	0,00	0,00	75	467	4.020	0	0	4.487	2.268	6.834	0	0	15,17	9.102	Pos. 1.3
4	1.3	Reinforced concrete foundation	367,5	m3	*0,67*	*5,99*	9,36	173,85	0,00	0,00	245	3.441	63.891	0	0	67.332	16.730	108.615	0	0	341,07	125.345	Pos. 1.3
5	1.2	Prefabricated reinforced concrete columns	101	Stk	*8,00*	*0,50*	12,50	197,73	27,90	0,00	808	1.263	19.971	2.818	0	24.052	6.138	33.951	3.664	0	433,19	43.753	Pos. 1.2
6	1.1	Brick masonry	1300	m2	*1,03*	*5,84*	0,71	24,50	0,00	0,00	1.335	927	31.850	0	0	32.777	4.506	54.145	0	0	45,12	58.651	Pos. 1.1
7	zu 1.4	Backfill	510	m3	*0,15*	*12,92*	0,97	0,00	0,00	0,00	79	493	0	0	0	493	2.399	0	0	0	4,70	2.399	Pos. 1.4
8	1.5	Steel construction	24	ton	---	---	0,00	0,00	0,00	1.650,0	0	0	0	0	39.600	39.600	0	0	0	45.540	1.897,50	45.540	Pos. 1.5
9																							
10	---	Wages [€/hr]	25,00								**Sum direct costs:**	**7.956**	**120.057**	**4.834**	**39.600**	**172.447**	38.680	204.096	6.284	45.540	Kontrolle:	294.601 =	BS(2)
11	---	Sum Direct costs-Wage hours:	2.760								**Sum On-Site overhead:**	**41.945**	**1.482**	**25.699**	**0**	**69.126** =	on-site overhead		Kontrolle:	294.601			
12	---	Sum On site overhead-Wage hours	1.500								**Sum Production costs:**	**49.901**	**121.538**	**30.533**	**39.600**	**241.573** =	Production costs						
13	---	Sum Production Costs-Wage hours	4.260												**Indirect Costs**	**33.879**	Wage-Cost	Other-Costs	Equipment-costs	External-costs			
14	---	Construction time in Weeks:	12,0												**Risk & Profit**	**19.149**	386,2%	70,0%	30,0%	15,0%	Apportionment in [%]		
15	---	Average Labour (40 hr/Week):	8,9												**Apportionment of indirect costs:**	**122.154** =	30.724	84.040	1.450	5.940	Apportionment absolut in [$]		
16	---	Total Indirect costs:	11,5%												**Total production cost (SK):**	**275.452**			Kontrolle:	122.154			
17	---	Risk and Profit:	6,5%												**Bid Sum (netto):**	**294.601** =	BS(1)						
18	---	Tax rate:	19,0%												**Bid Sum (brutto):**	***350.574,90 €***							
																Probability							
																8,04%							

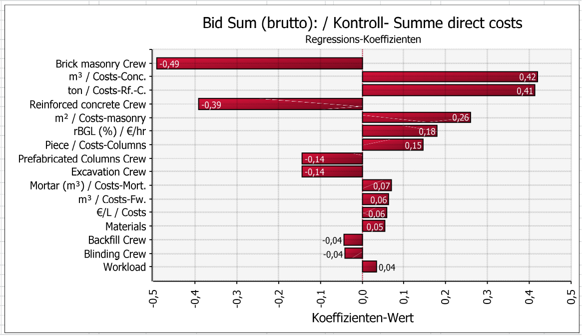
Scenario's confidence interval
10% Optimistic
45% Expected
90% Pessimistic

Scenarios	
Optimistic (10%)	*351.166,35 €*
Expected (45%)	*357.049,87*
Pessimistic (90%)	*366.029,67*

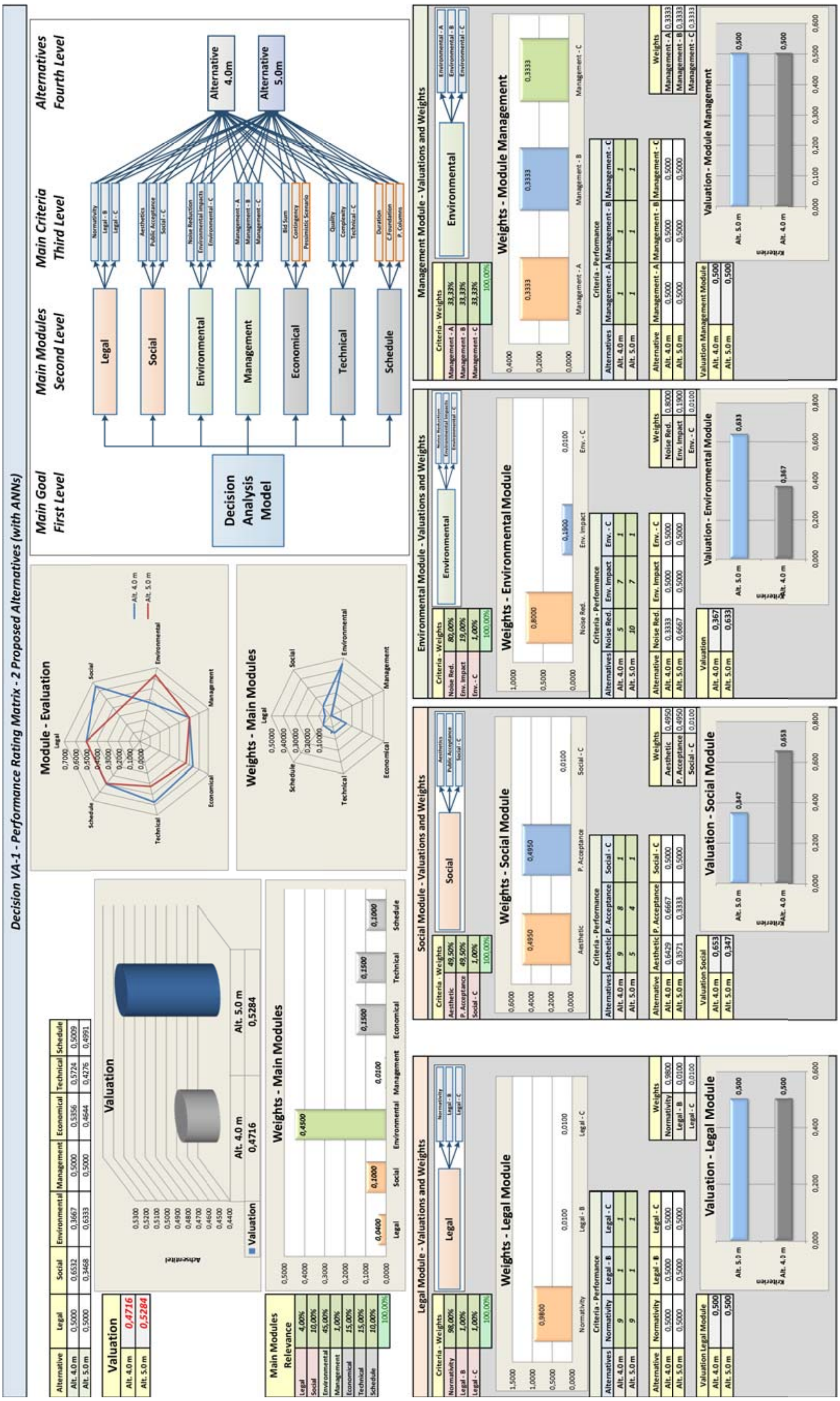
Contingency
6.474,97 €
Contingency %
1,847%

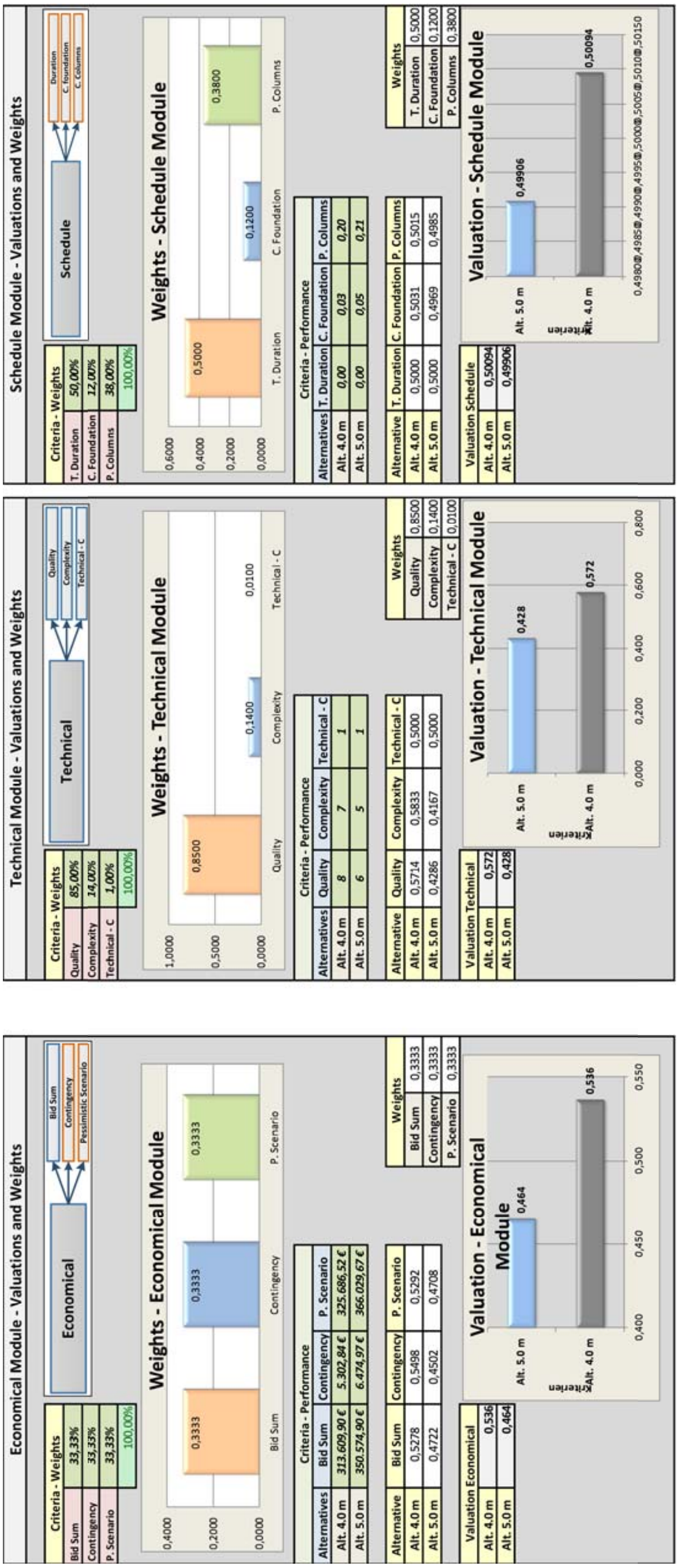






Appendix H: AHP Alternative’s evaluation





Economical Module - Valuations and Weights

Criteria - Weights	
Bid Sum	33,33%
Contingency	33,33%
P. Scenario	33,33%
	100,00%

Criteria - Performance			
Alternatives	Bid Sum	Contingency	P. Scenario
Alt. 4.0 m	313.609,90 €	5.302,84 €	325.686,52 €
Alt. 5.0 m	350.574,90 €	6.474,97 €	366.029,67 €

Alternative	Bid Sum	Contingency	P. Scenario
Alt. 4.0 m	0,5278	0,5498	0,5292
Alt. 5.0 m	0,4722	0,4502	0,4708

Weights	
Bid Sum	0,3333
Contingency	0,3333
P. Scenario	0,3333

Valuation Economical	
Alt. 4.0 m	0,536
Alt. 5.0 m	0,464

Technical Module - Valuations and Weights

Criteria - Weights	
Quality	85,00%
Complexity	14,00%
Technical - C	1,00%
	100,00%

Criteria - Performance			
Alternatives	Quality	Complexity	Technical - C
Alt. 4.0 m	8	7	1
Alt. 5.0 m	6	5	1

Alternative	Quality	Complexity	Technical - C
Alt. 4.0 m	0,5714	0,5833	0,5000
Alt. 5.0 m	0,4286	0,4167	0,5000

Weights	
Quality	0,8500
Complexity	0,1400
Technical - C	0,0100

Valuation Technical	
Alt. 4.0 m	0,572
Alt. 5.0 m	0,428

Schedule Module - Valuations and Weights

Criteria - Weights	
T. Duration	50,00%
C. Foundation	12,00%
P. Columns	38,00%
	100,00%

Criteria - Performance			
Alternatives	T. Duration	C. Foundation	P. Columns
Alt. 4.0 m	0,00	0,03	0,20
Alt. 5.0 m	0,00	0,05	0,21

Alternative	T. Duration	C. Foundation	P. Columns
Alt. 4.0 m	0,5000	0,5031	0,5015
Alt. 5.0 m	0,5000	0,4969	0,4985

Weights	
T. Duration	0,5000
C. Foundation	0,1200
P. Columns	0,3800

Valuation Schedule	
Alt. 4.0 m	0,50094
Alt. 5.0 m	0,49906

Input information

Inputs

Legal Module			
Alternatives	Normativity	Legal - B	Legal - C
Alt. 4.0 m	*9*	*1*	*1*
Alt. 5.0 m	*9*	*1*	*1*

Social Module			
Alternatives	Aesthetic	Public Acceptance	Social - C
Alt. 4.0 m	*9*	*8*	*1*
Alt. 5.0 m	*5*	*4*	*1*

Environmental Module			
Alternatives	Noise Reduction	Env. Impacts	Env. - C
Alt. 4.0 m	*5*	*7*	*1*
Alt. 5.0 m	*10*	*7*	*1*

Management Module			
Alternatives	Management - A	Management - B	Management - C
Alt. 4.0 m	*1*	*1*	*1*
Alt. 5.0 m	*1*	*1*	*1*

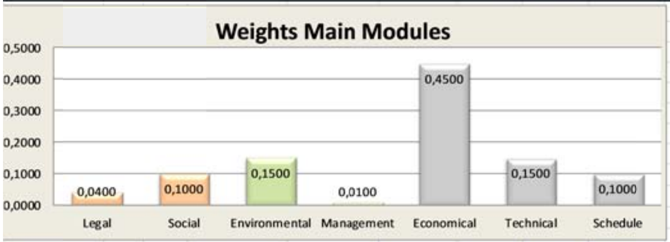
Technical Module			
Alternatives	Quality	Complexity	Env. - C
Alt. 4.0 m	*8*	*7*	*1*
Alt. 5.0 m	*6*	*5*	*1*

Alt.- 4.0 m			
Criteria	Duration (d)	Expected (45 %)	Difference
Total Duration	28,71	28,71	0,00
Excavation	5,61	5,61	0,00
Blinding lean concrete	2,33	2,33	0,00
Concrete (Foundation)	12,64	12,67	0,03
Concrete Columns	6,31	6,52	0,20
Brick masonry	3,71	3,71	0,00
Backfill	2,13	2,13	0,00
Costs	Unit	Probability	
Bid Sum (brutto):	313.609,90 €	6,96%	
Contingency (Expected Scenario)	5.302,84 €		
Optimistic Scenario	314.309,76 €		
Expected Scenario	318.912,74 €		
Pessimistic Scenario	325.686,52 €		
Direct Costs	Expected (45%)	Probability	
Excavation	3.126,78 €	24,99%	
Bliding	4.515,28 €	33,28%	
Prefabricated Columns	24.317,23 €	35,41%	
Reinforced Conrete Foundation	51.333,12 €	20,13%	
Brick Masonry	26.251,36 €	43,98%	
Backfilling	425,40 €	42,84%	

Alt.- 5.0 m			
Criteria	Duration (d)	Expected (45 %)	Difference
Total Duration	29,63	29,63	0,00
Excavation	6,83	6,83	0,00
Blinding lean concrete	2,33	2,33	0,00
Concrete (Foundation)	17,21	17,25	0,05
Concrete Columns	6,31	6,52	0,21
Brick masonry	4,63	4,63	0,00
Backfill	2,47	2,47	0,00
Costs	Unit	Probability	
Bid Sum (brutto):	350.574,90 €	8,04%	
Contingency (Expected Scenario)	6.474,97 €		
Optimistic Scenario	351.166,35 €		
Expected Scenario	357.049,87 €		
Pessimistic Scenario	366.029,67 €		
Direct Costs	Expected (45%)	Probability	
Excavation	3.805,85 €	25,13%	
Bliding	4.515,00 €	33,29%	
Prefabricated Columns	24.333,39 €	34,80%	
Reinforced Conrete Foundation	69.152,75 €	20,99%	
Brick Masonry	32.799,14 €	44,25%	
Backfilling	493,67 €	42,63%	

Weights Main Modules

Main Modules Weights



Main Modules Weights	
Legal	4,00%
Social	10,00%
Environmental	15,00%
Management	1,00%
Economical	45,00%
Technical	15,00%
Schedule	10,00%
	100,0%

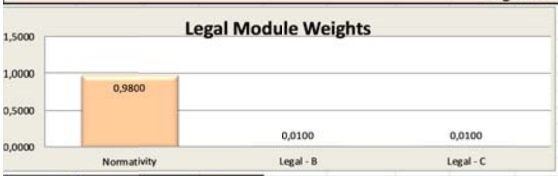
n	R.I.
1	0,00
2	0,00
3	0,52
4	0,89
5	1,11
6	1,25
7	1,35
8	1,40
9	1,45
10	1,49
11	1,51
12	1,55
13	1,56
14	1,57
15	1,58

Main Modules	Legal	Social	Environmental	Management	Economical	Technical	Schedule		
Legal	1,00	0,40	0,27	4,00	0,09	0,27	0,40		
Social	2,50	1,00	0,67	10,00	0,22	0,67	1,00		
Environmental	3,75	1,50	1,00	15,00	0,33	1,00	1,50		
Management	0,25	0,10	0,07	1,00	0,02	0,07	0,10		
Economical	11,25	4,50	3,00	45,00	1,00	3,00	4,50		
Technical	3,75	1,50	1,00	15,00	0,33	1,00	1,50		
Schedule	2,50	1,00	0,67	10,00	0,22	0,67	1,00		
Sum	25,00	10,00	6,67	100,00	2,22	6,67	10,00	*λmax=*	*7,0000*

Main Modules	Legal	Social	Environmental	Management	Economical	Technical	Schedule	Cumulated	Weight	(1/n)*we	CI=(λ -n)/(n-1)
Legal	0,040	0,040	0,040	0,040	0,040	0,040	0,040	0,280	*0,0400*	1,000	0,000000
Social	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,700	*0,1000*	1,000	Consistency CR<0,1
Environmental	0,150	0,150	0,150	0,150	0,150	0,150	0,150	1,050	*0,1500*	1,000	*0,000000*
Management	0,010	0,010	0,010	0,010	0,010	0,010	0,010	0,070	*0,0100*	1,000	
Economical	0,450	0,450	0,450	0,450	0,450	0,450	0,450	3,150	*0,4500*	1,000	
Technical	0,150	0,150	0,150	0,150	0,150	0,150	0,150	1,050	*0,1500*	1,000	
Schedule	0,100	0,100	0,100	0,100	0,100	0,100	0,100	0,700	*0,1000*	1,000	
Sum	1,000	1,000	1,000	1,000	1,000	1,000	1,000	7,000	*1,0000*	7,000	

Legal Module

Legal Module

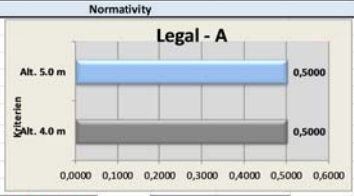


Criteria - Weights	
Normativity	98,00%
Legal - B	1,00%
Legal - C	1,00%
	100,00%

n	R.I.
1	0,00
2	0,00
3	0,52
4	0,89
5	1,11
6	1,25
7	1,35
8	1,40
9	1,45
10	1,49
11	1,51
12	1,55
13	1,56
14	1,57
15	1,58

Legal	Normativity	Legal - B	Legal - C				
Normativity	1,00	98,00	98,00				
Legal - B	0,01	1,00	1,00				
Legal - C	0,01	1,00	1,00				
Sum	1,02	100,00	100,00	λmax=	3,0000		
Legal	Normativity	Legal - B	Legal - C	Cumulated	Weight	(1/n)*we	CI=(λ -n)/(n-1)
Normativity	0,980	0,980	0,980	2,940	0,9800	1,000	0,000000
Legal - B	0,010	0,010	0,010	0,030	0,0100	1,000	Consistency CR<0,1
Legal - C	0,010	0,010	0,010	0,030	0,0100	1,000	0,000000
Sum	1,000	1,000	1,000	3,000	1,000	3,000	

Normativity

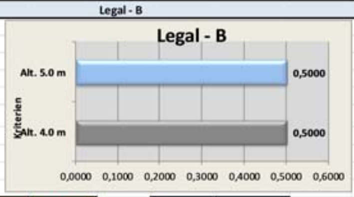


Normativity		
Alternative	Alt. 4.0 m	Alt. 5.0 m
Alt. 4.0 m	1,00	1,00
Alt. 5.0 m	1,00	1,00
Sum	2,00	2,00

Alternative	Alt. 4.0 m	Alt. 5.0 m	Cumulated	Weight	(1/n)*we
Alt. 4.0 m	0,500	0,500	1,000	0,5000	1,000
Alt. 5.0 m	0,500	0,500	1,000	0,5000	1,000
Sum	1,000	1,000	2,000	1,0000	2,000

Alternative	Performance
Alt. 4.0 m	9
Alt. 5.0 m	9

Legal - B

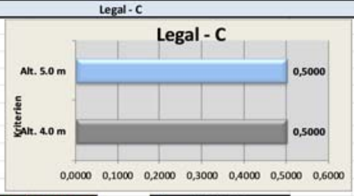


Legal - B		
Alternative	Alt. 4.0 m	Alt. 5.0 m
Alt. 4.0 m	1,00	1,00
Alt. 5.0 m	1,00	1,00
Sum	2,00	2,00

Alternative	Alt. 4.0 m	Alt. 5.0 m	Cumulated	Weight	(1/n)*we
Alt. 4.0 m	0,500	0,500	1,000	0,5000	1,000
Alt. 5.0 m	0,500	0,500	1,000	0,5000	1,000
Sum	1,000	1,000	2,000	1,0000	2,000

Alternative	Performance
Alt. 4.0 m	1
Alt. 5.0 m	1

Legal - C



Legal - C		
Alternative	Alt. 4.0 m	Alt. 5.0 m
Alt. 4.0 m	1,00	1,00
Alt. 5.0 m	1,00	1,00
Sum	2,00	2,00

Alternative	Alt. 4.0 m	Alt. 5.0 m	Cumulated	Weight	(1/n)*we
Alt. 4.0 m	0,500	0,500	1,000	0,5000	1,000
Alt. 5.0 m	0,500	0,500	1,000	0,5000	1,000
Sum	1,000	1,000	2,000	1,0000	2,000

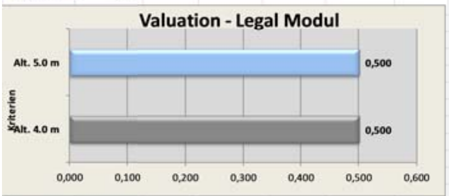
Alternative	Performance
Alt. 4.0 m	1
Alt. 5.0 m	1

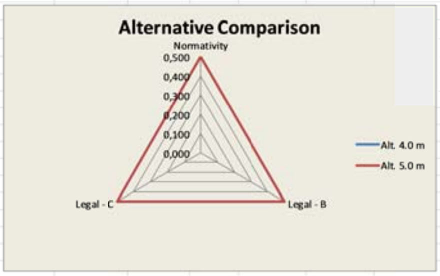
Valuation Legal Module

Alternative	Normativity	Legal - B	Legal - C
Alt. 4.0 m	0,500	0,500	0,500
Alt. 5.0 m	0,500	0,500	0,500

Weights	
Normativity	0,98
Legal - B	0,01
Legal - C	0,01

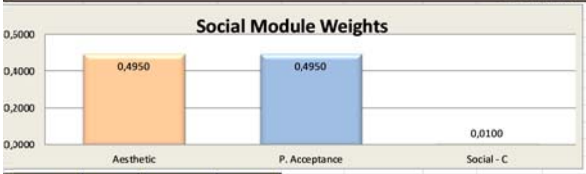
Valuation Legal Module	
Alt. 4.0 m	0,500
Alt. 5.0 m	0,500





Social Module

Social Module

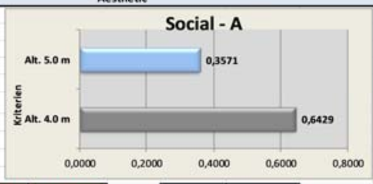


Social	Aesthetic	P. Acceptance	Social - C				
Aesthetic	1,00	1,00	49,50				
P. Acceptance	1,00	1,00	49,50				
Social - C	0,02	0,02	1,00				
Sum	2,02	2,02	100,00	*λmax=*	*3,0000*		
Social	**Aesthetic**	**P. Acceptance**	**Social - C**	**Cumulated**	**Weight**	**(1/n)*we**	**CI=(λ -n)/(n-1)**
Aesthetic	0,495	0,495	0,495	1,485	*0,4950*	1,000	0,000000
P. Acceptance	0,495	0,495	0,495	1,485	*0,4950*	1,000	Consistency CR<0,1
Social - C	0,010	0,010	0,010	0,030	*0,0100*	1,000	*0,000000*
Sum	1,000	1,000	1,000	3,000	*1,000*	3,000	

Criteria - Weights	
Aesthetic	49,50%
P. Acceptance	49,50%
Social - C	1,00%
	100,00%

n	R.I.
1	0,00
2	0,00
3	0,52
4	0,89
5	1,11
6	1,25
7	1,35
8	1,40
9	1,45
10	1,49
11	1,51
12	1,55
13	1,56
14	1,57
15	1,58

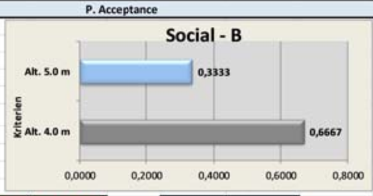
Aesthetic



Aesthetic					
Alternative	**Alt. 4.0 m**	**Alt. 5.0 m**			
Alt. 4.0 m	1,00	1,80			
Alt. 5.0 m	0,56	1,00			
Sum	1,56	2,80			
Alternative	**Alt. 4.0 m**	**Alt. 5.0 m**	**Cumulated**	**Weight**	**(1/n)*we**
Alt. 4.0 m	0,643	0,643	1,286	*0,6429*	1,000
Alt. 5.0 m	0,357	0,357	0,714	*0,3571*	1,000
Sum	1,000	1,000	2,000	*1,0000*	2,000

Alternative	Performance
Alt. 4.0 m	9
Alt. 5.0 m	5

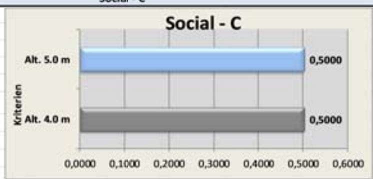
P. Acceptance



P. Acceptance					
Alternative	**Alt. 4.0 m**	**Alt. 5.0 m**			
Alt. 4.0 m	1,00	2,00			
Alt. 5.0 m	0,50	1,00			
Sum	1,50	3,00			
Alternative	**Alt. 4.0 m**	**Alt. 5.0 m**	**Cumulated**	**Weight**	**(1/n)*we**
Alt. 4.0 m	0,667	0,667	1,333	*0,6667*	1,000
Alt. 5.0 m	0,333	0,333	0,667	*0,3333*	1,000
Sum	1,000	1,000	2,000	*1,0000*	2,000

Alternative	Performance
Alt. 4.0 m	8
Alt. 5.0 m	4

Social - C



Social - C					
Alternative	**Alt. 4.0 m**	**Alt. 5.0 m**			
Alt. 4.0 m	1,00	1,00			
Alt. 5.0 m	1,00	1,00			
Sum	2,00	2,00			
Alternative	**Alt. 4.0 m**	**Alt. 5.0 m**	**Cumulated**	**Weight**	**(1/n)*we**
Alt. 4.0 m	0,500	0,500	1,000	*0,5000*	1,000
Alt. 5.0 m	0,500	0,500	1,000	*0,5000*	1,000
Sum	1,000	1,000	2,000	*1,0000*	2,000

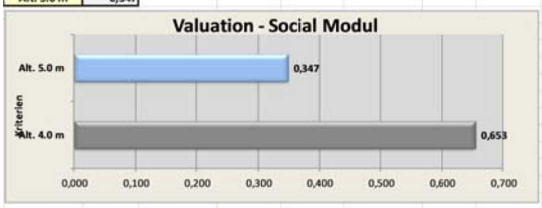
Alternative	Performance
Alt. 4.0 m	1
Alt. 5.0 m	1

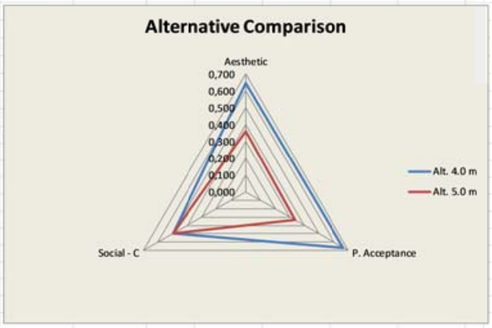
Valuation Social Module

Alternative	Aesthetic	P. Acceptance	Social - C
Alt. 4.0 m	0,643	0,667	0,500
Alt. 5.0 m	0,357	0,333	0,500

Weights	
Aesthetic	0,50
P. Acceptance	0,50
Social - C	0,01

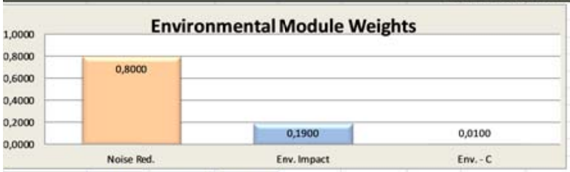
Valuation Social Module	
Alt. 4.0 m	0,653
Alt. 5.0 m	0,347





Environmental Module

Environmental Module



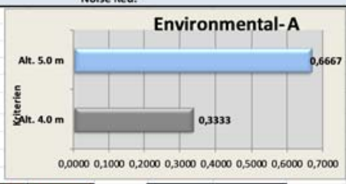
n	R.I.
1	0,00
2	0,00
3	0,52
4	0,89
5	1,11
6	1,25
7	1,35
8	1,40
9	1,45
10	1,49
11	1,51
12	1,55
13	1,56
14	1,57
15	1,58

Criteria - Weights	
Noise Red.	80,00%
Env. Impact	19,00%
Env. - C	1,00%
	100,00%

Environmental	Noise Red.	Env. Impact	Env. - C		
Noise Red.	1,00	4,21	80,00		
Env. Impact	0,24	1,00	19,00		
Env. - C	0,01	0,05	1,00		
Sum	1,25	5,26	100,00	*λmax=*	*3,0000*

Environmental	Noise Red.	Env. Impact	Env. - C	Cumulated	Weight	(1/n)*we	CI=(λ -n)/(n-1)
Noise Red.	0,800	0,800	0,800	2,400	*0,8000*	1,000	0,000000
Env. Impact	0,190	0,190	0,190	0,570	*0,1900*	1,000	Consistency CR<0,1
Env. - C	0,010	0,010	0,010	0,030	*0,0100*	1,000	*0,000000*
Sum	1,000	1,000	1,000	3,000	*1,000*	3,000	

Noise Red.

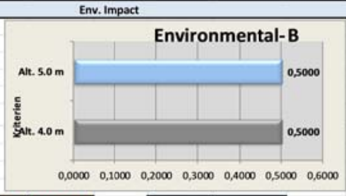


Noise Red.		
Alternative	Alt. 4.0 m	Alt. 5.0 m
Alt. 4.0 m	1,00	0,50
Alt. 5.0 m	2,00	1,00
Sum	3,00	1,50

Alternative	Alt. 4.0 m	Alt. 5.0 m	Cumulated	Weight	(1/n)*we
Alt. 4.0 m	0,333	0,333	0,667	*0,3333*	1,000
Alt. 5.0 m	0,667	0,667	1,333	*0,6667*	1,000
Sum	1,000	1,000	2,000	*1,0000*	2,000

Alternative	Performance
Alt. 4.0 m	5
Alt. 5.0 m	10

Env. Impact

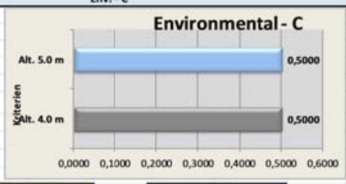


Env. Impact		
Alternative	Alt. 4.0 m	Alt. 5.0 m
Alt. 4.0 m	1,00	1,00
Alt. 5.0 m	1,00	1,00
Sum	2,00	2,00

Alternative	Alt. 4.0 m	Alt. 5.0 m	Cumulated	Weight	(1/n)*we
Alt. 4.0 m	0,500	0,500	1,000	*0,5000*	1,000
Alt. 5.0 m	0,500	0,500	1,000	*0,5000*	1,000
Sum	1,000	1,000	2,000	*1,0000*	2,000

Alternative	Performance
Alt. 4.0 m	7
Alt. 5.0 m	7

Env. - C



Env. - C		
Alternative	Alt. 4.0 m	Alt. 5.0 m
Alt. 4.0 m	1,00	1,00
Alt. 5.0 m	1,00	1,00
Sum	2,00	2,00

Alternative	Alt. 4.0 m	Alt. 5.0 m	Cumulated	Weight	(1/n)*we
Alt. 4.0 m	0,500	0,500	1,000	*0,5000*	1,000
Alt. 5.0 m	0,500	0,500	1,000	*0,5000*	1,000
Sum	1,000	1,000	2,000	*1,0000*	2,000

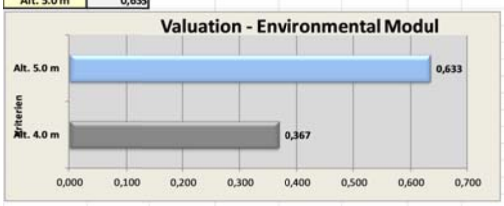
Alternative	Performance
Alt. 4.0 m	1
Alt. 5.0 m	1

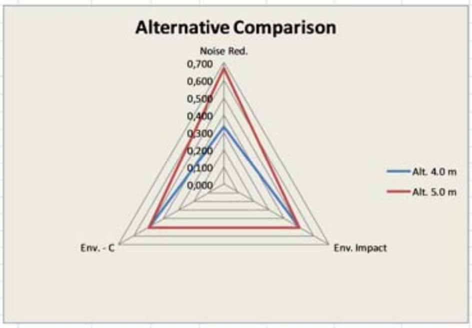
Valuation Environmental Module

Alternative	Noise Red.	Env. Impact	Env. - C
Alt. 4.0 m	0,333	0,500	0,500
Alt. 5.0 m	0,667	0,500	0,500

Weights	
Noise Red.	0,80
Env. Impact	0,19
Env. - C	0,01

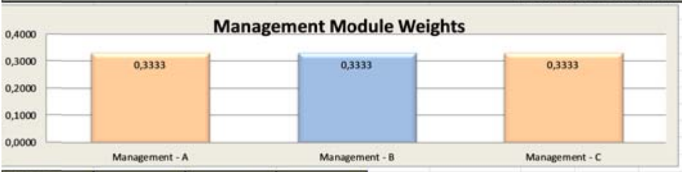
Valuation Environmental	
Alt. 4.0 m	0,367
Alt. 5.0 m	0,633





Management Module

Management Module

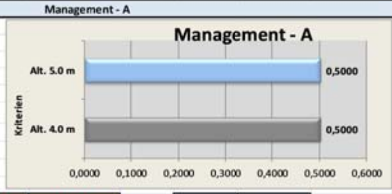


n	R.I.
1	0,00
2	0,00
3	0,52
4	0,89
5	1,11
6	1,25
7	1,35
8	1,40
9	1,45
10	1,49
11	1,51
12	1,55
13	1,56
14	1,57
15	1,58

Criteria - Weights	
Management - A	33,33%
Management - B	33,33%
Management - C	33,33%
	100,00%

Management	Management - A	Management - B	Management - C				
Management - A	1,00	1,00	1,00				
Management - B	1,00	1,00	1,00				
Management - C	1,00	1,00	1,00				
Sum	3,00	3,00	3,00	λmax=	3,0000		
Management	Management - A	Management - B	Management - C	Cumulated	Weight	(1/n)*we	CI=(λ-n)/(n-1)
Management - A	0,333	0,333	0,333	1,000	0,3333	1,000	0,000000
Management - B	0,333	0,333	0,333	1,000	0,3333	1,000	Consistency CR<0,1
Management - C	0,333	0,333	0,333	1,000	0,3333	1,000	0,000000
Sum	1,000	1,000	1,000	3,000	1,000	3,000	

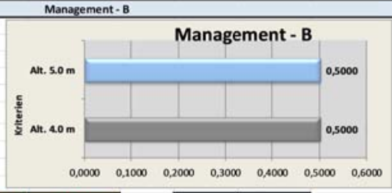
Management - A



Management - A					
Alternative	Alt. 4.0 m	Alt. 5.0 m			
Alt. 4.0 m	1,00	1,00			
Alt. 5.0 m	1,00	1,00			
Sum	2,00	2,00			
Alternative	Alt. 4.0 m	Alt. 5.0 m	Cumulated	Weight	(1/n)*we
Alt. 4.0 m	0,500	0,500	1,000	0,5000	1,000
Alt. 5.0 m	0,500	0,500	1,000	0,5000	1,000
Sum	1,000	1,000	2,000	1,0000	2,000

Alternative	Performance
Alt. 4.0 m	1
Alt. 5.0 m	1

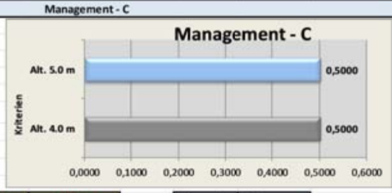
Management - B



Management - B					
Alternative	Alt. 4.0 m	Alt. 5.0 m			
Alt. 4.0 m	1,00	1,00			
Alt. 5.0 m	1,00	1,00			
Sum	2,00	2,00			
Alternative	Alt. 4.0 m	Alt. 5.0 m	Cumulated	Weight	(1/n)*we
Alt. 4.0 m	0,500	0,500	1,000	0,5000	1,000
Alt. 5.0 m	0,500	0,500	1,000	0,5000	1,000
Sum	1,000	1,000	2,000	1,0000	2,000

Alternative	Performance
Alt. 4.0 m	1
Alt. 5.0 m	1

Management - C



Management - C					
Alternative	Alt. 4.0 m	Alt. 5.0 m			
Alt. 4.0 m	1,00	1,00			
Alt. 5.0 m	1,00	1,00			
Sum	2,00	2,00			
Alternative	Alt. 4.0 m	Alt. 5.0 m	Cumulated	Weight	(1/n)*we
Alt. 4.0 m	0,500	0,500	1,000	0,5000	1,000
Alt. 5.0 m	0,500	0,500	1,000	0,5000	1,000
Sum	1,000	1,000	2,000	1,0000	2,000

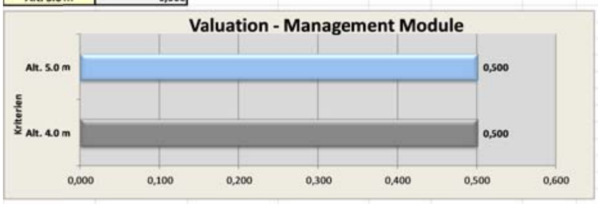
Alternative	Performance
Alt. 4.0 m	1
Alt. 5.0 m	1

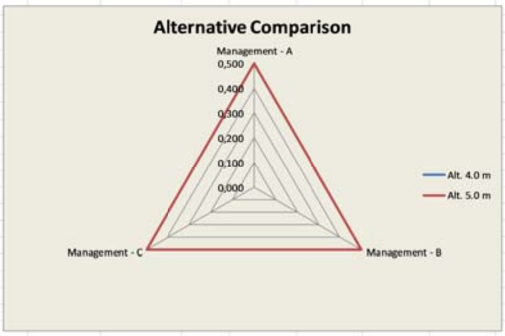
Valuation Management Module

Alternative	Management - A	Management - B	Management - C
Alt. 4.0 m	0,500	0,500	0,500
Alt. 5.0 m	0,500	0,500	0,500

Weights	
Management - A	0,33
Management - B	0,33
Management - C	0,33

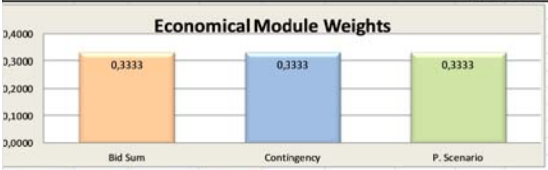
Valuation Management Module	
Alt. 4.0 m	0,500
Alt. 5.0 m	0,500





Economical Module

Economical Module

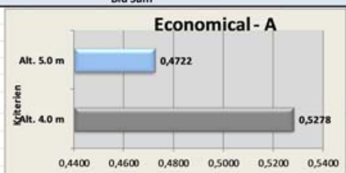


n	R.I.
1	0,00
2	0,00
3	0,52
4	0,89
5	1,11
6	1,25
7	1,35
8	1,40
9	1,45
10	1,49
11	1,51
12	1,55
13	1,56
14	1,57
15	1,58

Criteria - Weights	
Bid Sum	33,33%
Contingency	33,33%
P. Scenario	33,33%
	100,00%

Economical	Bid Sum	Contingency	P. Scenario				
Bid Sum	1,00	1,00	1,00				
Contingency	1,00	1,00	1,00				
P. Scenario	1,00	1,00	1,00				
Sum	3,00	3,00	3,00	λmax=	3,0000		
Economical	Bid Sum	Contingency	P. Scenario	Cumulated	Weight	(1/n)*we	CI=(λ -n)/(n-1)
Bid Sum	0,333	0,333	0,333	1,000	0,3333	1,000	0,000000
Contingency	0,333	0,333	0,333	1,000	0,3333	1,000	Consistency CR<0,1
P. Scenario	0,333	0,333	0,333	1,000	0,3333	1,000	0,000000
Sum	1,000	1,000	1,000	3,000	1,000	3,000	

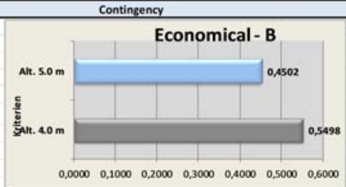
Bid Sum



Bid Sum							
Alternative	Alt. 4.0 m	Alt. 5.0 m					
Alt. 4.0 m	1,00	0,89					
Alt. 5.0 m	1,12	1,00					
Sum	2,12	1,89					
Alternative	Alt. 4.0 m	Alt. 5.0 m	Cumulated	Weight	(1/n)*we	Correction	Weights
Alt. 4.0 m	0,472	0,472	0,944	0,4722	1,000	2,118	0,5278
Alt. 5.0 m	0,528	0,528	1,056	0,5278	1,000	1,895	0,4722
Sum	1,000	1,000	2,000	1,0000	2,000	4,012	1,000

Alternative	Performance
Alt. 4.0 m	313.609,90 €
Alt. 5.0 m	350.574,90 €

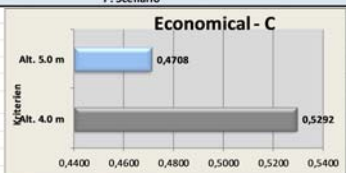
Contingency



Contingency							
Alternative	Alt. 4.0 m	Alt. 5.0 m					
Alt. 4.0 m	1,00	0,82					
Alt. 5.0 m	1,22	1,00					
Sum	2,22	1,82					
Alternative	Alt. 4.0 m	Alt. 5.0 m	Cumulated	Weight	(1/n)*we	Correction	Weights
Alt. 4.0 m	0,450	0,450	0,900	0,4502	1,000	2,221	0,5498
Alt. 5.0 m	0,550	0,550	1,100	0,5498	1,000	1,819	0,4502
Sum	1,000	1,000	2,000	1,0000	2,000	4,040	1,000

Alternative	Performance
Alt. 4.0 m	5.302,84 €
Alt. 5.0 m	6.474,97 €

P. Scenario



P. Scenario							
Alternative	Alt. 4.0 m	Alt. 5.0 m					
Alt. 4.0 m	1,00	0,89					
Alt. 5.0 m	1,12	1,00					
Sum	2,12	1,89					
Alternative	Alt. 4.0 m	Alt. 5.0 m	Cumulated	Weight	(1/n)*we	Correction	Weights
Alt. 4.0 m	0,471	0,471	0,942	0,4708	1,000	2,124	0,5292
Alt. 5.0 m	0,529	0,529	1,058	0,5292	1,000	1,890	0,4708
Sum	1,000	1,000	2,000	1,0000	2,000	4,014	1,000

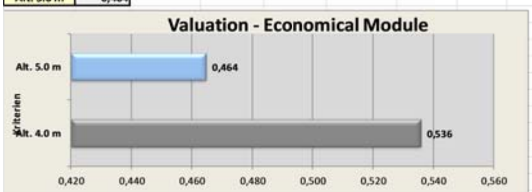
Alternative	Performance
Alt. 4.0 m	325.686,52 €
Alt. 5.0 m	366.029,67 €

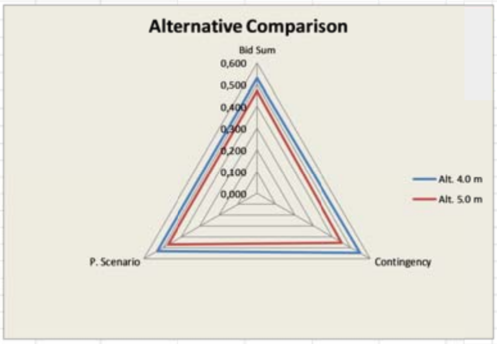
Valuation Economical Module

Alternative	Bid Sum	Contingency	P. Scenario
Alt. 4.0 m	0,528	0,550	0,529
Alt. 5.0 m	0,472	0,450	0,471

Weights	
Bid Sum	0,33
Contingency	0,33
P. Scenario	0,33

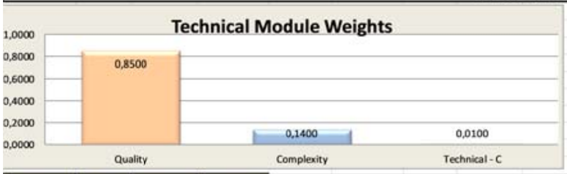
Valuation Economical	
Alt. 4.0 m	0,536
Alt. 5.0 m	0,464





Technical Module

Technical Module



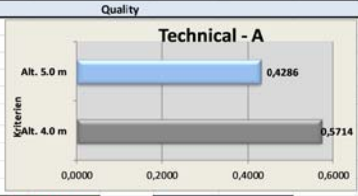
Economical	Quality	Complexity	Technical - C		
Quality	1,00	6,07	85,00		
Complexity	0,16	1,00	14,00		
Technical - C	0,01	0,07	1,00		
Sum	1,18	7,14	100,00	λmax=	3,0000

Economical	Quality	Complexity	Technical - C	Cumulated	Weight	(1/n)*we	CI=(λ -n)/(n-1)
Quality	0,850	0,850	0,850	2,550	0,8500	1,000	0,000000
Complexity	0,140	0,140	0,140	0,420	0,1400	1,000	Consistency CR<0,1
Technical - C	0,010	0,010	0,010	0,030	0,0100	1,000	0,000000
Sum	1,000	1,000	1,000	3,000	1,000	3,000	

Criteria - Weights	
Quality	85,00%
Complexity	14,00%
Technical - C	1,00%
	100,00%

n	R.I.
1	0,00
2	0,00
3	0,52
4	0,89
5	1,11
6	1,25
7	1,35
8	1,40
9	1,45
10	1,49
11	1,51
12	1,55
13	1,56
14	1,57
15	1,58

Quality



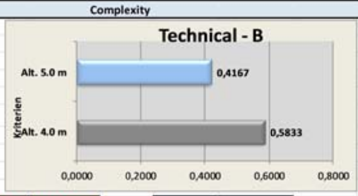
Quality

Alternative	Alt. 4.0 m	Alt. 5.0 m
Alt. 4.0 m	1,00	1,33
Alt. 5.0 m	0,75	1,00
Sum	1,75	2,33

Alternative	Alt. 4.0 m	Alt. 5.0 m	Cumulated	Weight	(1/n)*we
Alt. 4.0 m	0,571	0,571	1,143	0,5714	1,000
Alt. 5.0 m	0,429	0,429	0,857	0,4286	1,000
Sum	1,000	1,000	2,000	1,0000	2,000

Alternative	Performance
Alt. 4.0 m	8
Alt. 5.0 m	6

Complexity



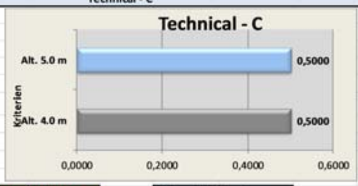
Complexity

Alternative	Alt. 4.0 m	Alt. 5.0 m
Alt. 4.0 m	1,00	1,40
Alt. 5.0 m	0,71	1,00
Sum	1,71	2,40

Alternative	Alt. 4.0 m	Alt. 5.0 m	Cumulated	Weight	(1/n)*we
Alt. 4.0 m	0,583	0,583	1,167	0,5833	1,000
Alt. 5.0 m	0,417	0,417	0,833	0,4167	1,000
Sum	1,000	1,000	2,000	1,0000	2,000

Alternative	Performance
Alt. 4.0 m	7
Alt. 5.0 m	5

Technical - C



Technical - C

Alternative	Alt. 4.0 m	Alt. 5.0 m
Alt. 4.0 m	1,00	1,00
Alt. 5.0 m	1,00	1,00
Sum	2,00	2,00

Alternative	Alt. 4.0 m	Alt. 5.0 m	Cumulated	Weight	(1/n)*we
Alt. 4.0 m	0,500	0,500	1,000	0,5000	1,000
Alt. 5.0 m	0,500	0,500	1,000	0,5000	1,000
Sum	1,000	1,000	2,000	1,0000	2,000

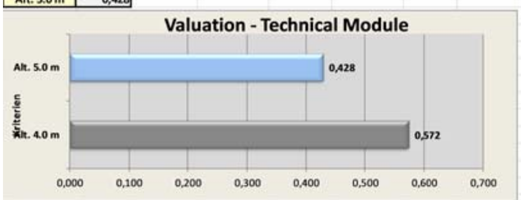
Alternative	Performance
Alt. 4.0 m	1
Alt. 5.0 m	1

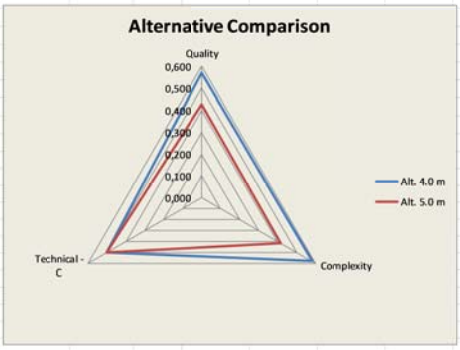
Valuation Technical Module

Alternative	Quality	Complexity	Technical - C
Alt. 4.0 m	0,571	0,583	0,500
Alt. 5.0 m	0,429	0,417	0,500

Weights	
Quality	0,85
Complexity	0,14
Technical - C	0,01

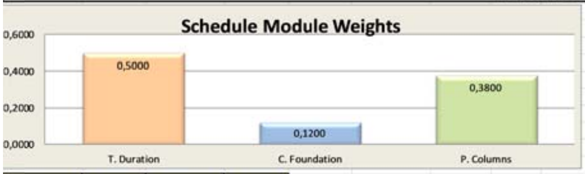
Valuation Technical	
Alt. 4.0 m	0,572
Alt. 5.0 m	0,428





Schedule Module

Schedule Module



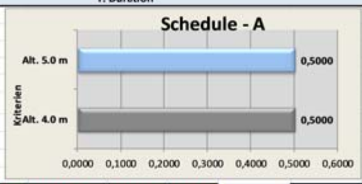
n	R.I.
1	0,00
2	0,00
3	0,52
4	0,89
5	1,11
6	1,25
7	1,35
8	1,40
9	1,45
10	1,49
11	1,51
12	1,55
13	1,56
14	1,57
15	1,58

Criteria - Weights	
T. Duration	50,00%
C. Foundation	12,00%
P. Columns	38,00%
	100,00%

Schedule	T. Duration	C. Foundation	P. Columns		
T. Duration	1,00	4,17	1,32		
C. Foundation	0,24	1,00	0,32		
P. Columns	0,76	3,17	1,00		
Sum	2,00	8,33	2,63	λmax=	3,0000

Schedule	T. Duration	C. Foundation	P. Columns	Cumulated	Weight	(1/n)*we	CI=(λ-n)/(n-1)
T. Duration	0,500	0,500	0,500	1,500	0,5000	1,000	0,000000
C. Foundation	0,120	0,120	0,120	0,360	0,1200	1,000	Consistency CR<0,1
P. Columns	0,380	0,380	0,380	1,140	0,3800	1,000	0,000000
Sum	1,000	1,000	1,000	3,000	1,000	3,000	

T. Duration

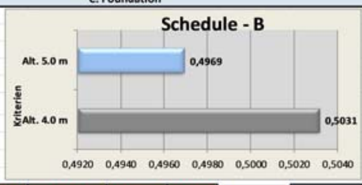


T. Duration		
Alternative	Alt. 4.0 m	Alt. 5.0 m
Alt. 4.0 m	1,00	1,00
Alt. 5.0 m	1,00	1,00
Sum	2,00	2,00

Alternative	Alt. 4.0 m	Alt. 5.0 m	Cumulated	Weight	(1/n)*we	Correction	Weights
Alt. 4.0 m	0,500	0,500	1,000	0,5000	1,000	2,000	0,5000
Alt. 5.0 m	0,500	0,500	1,000	0,5000	1,000	2,000	0,5000
Sum	1,000	1,000	2,000	1,0000	2,000	4,000	1,000

Alternative	Performance
Alt. 4.0 m	1,00
Alt. 5.0 m	1,00

C. Foundation

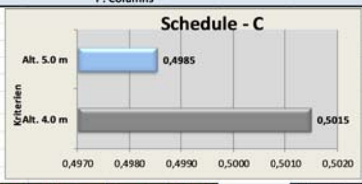


C. Foundation		
Alternative	Alt. 4.0 m	Alt. 5.0 m
Alt. 4.0 m	1,00	0,99
Alt. 5.0 m	1,01	1,00
Sum	2,01	1,99

Alternative	Alt. 4.0 m	Alt. 5.0 m	Cumulated	Weight	(1/n)*we	Correction	Weights
Alt. 4.0 m	0,497	0,497	0,994	0,4969	1,000	2,013	0,5031
Alt. 5.0 m	0,503	0,503	1,006	0,5031	1,000	1,988	0,4969
Sum	1,000	1,000	2,000	1,0000	2,000	4,000	1,000

Alternative	Performance
Alt. 4.0 m	1,03
Alt. 5.0 m	1,05

P. Columns



P. Columns		
Alternative	Alt. 4.0 m	Alt. 5.0 m
Alt. 4.0 m	1,00	0,99
Alt. 5.0 m	1,01	1,00
Sum	2,01	1,99

Alternative	Alt. 4.0 m	Alt. 5.0 m	Cumulated	Weight	(1/n)*we	Correction	Weights
Alt. 4.0 m	0,499	0,499	0,997	0,4985	1,000	2,006	0,5015
Alt. 5.0 m	0,501	0,501	1,003	0,5015	1,000	1,994	0,4985
Sum	1,000	1,000	2,000	1,0000	2,000	4,000	1,000

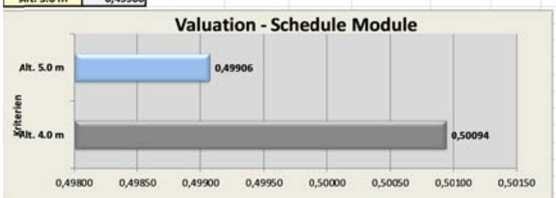
Alternative	Performance
Alt. 4.0 m	1,20
Alt. 5.0 m	1,21

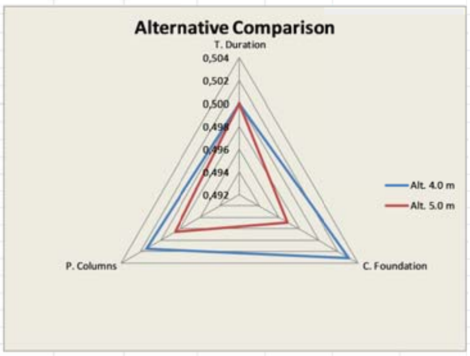
Valuation Schedule Module

Alternative	T. Duration	C. Foundation	P. Columns
Alt. 4.0 m	0,500	0,503	0,501
Alt. 5.0 m	0,500	0,497	0,499

Weights	
T. Duration	0,50
C. Foundation	0,12
P. Columns	0,38

Valuation Schedule	
Alt. 4.0 m	0,50094
Alt. 5.0 m	0,49906

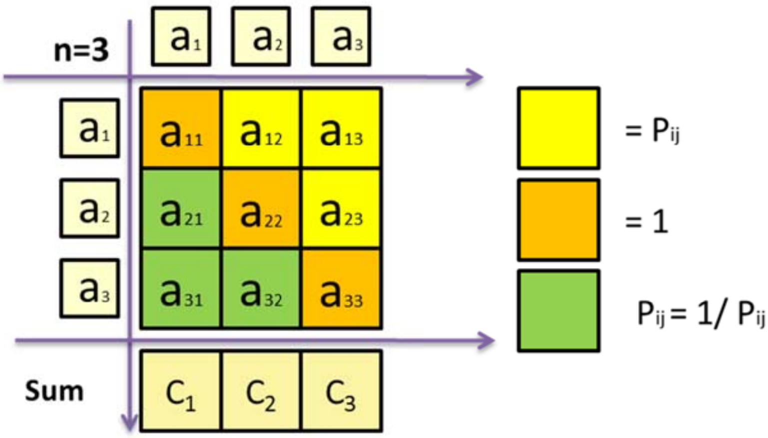




Appendix I: AHP Methodology

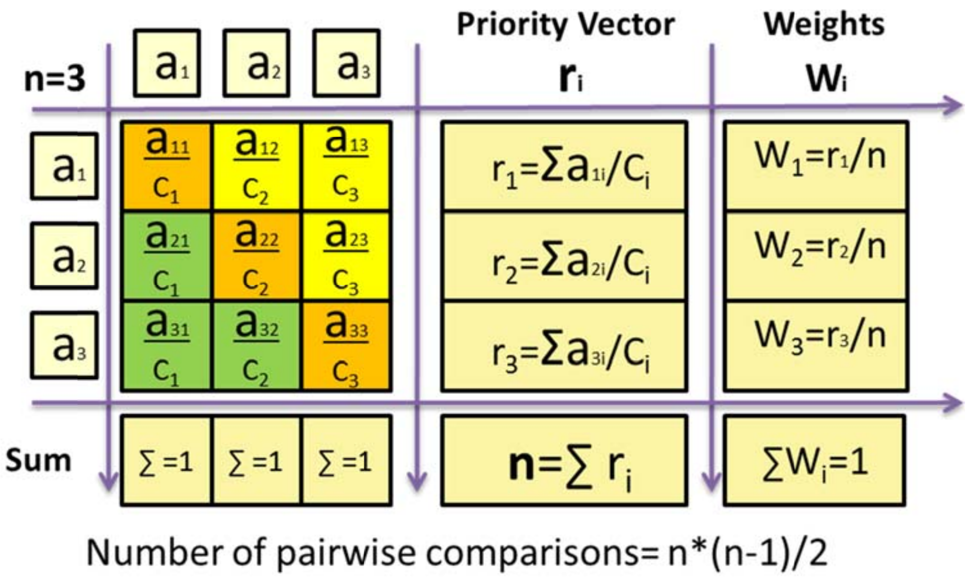
The selected decision analysis methodology involves the use of the AHP method developed by Saaty. This method includes a systematic comparison making use of a pairwise comparison matrix, principal Eigen value, synthesized Eigen vector, maximum Eigen value, consistency index and consistency ratio[202].

The pairwise comparison is performed as shown in the following matrix:



H-1: Parwise comparison in the Input-matrix

The figure H-1 presents the comparison matrix of the AHP method, it is important to see that matrix is divided by a diagonal of "1", and it defines that the elements under the diagonal are exactly the reciprocal of the elements of above the diagonal.



H-2: Principal Eigen value, synthesized Eigen vector and weights determination

[202] (Kulkarni, 2005)

By synthesizing and priority vector determination, the required weights are determined.

The consistency index is given by:

$$Consistency\ Index = \frac{\lambda_{max} - n}{n - 1}$$

Where λ_{max} is the maximum Eigen Value given by:

$$\lambda_{max} = \sum_{i=1}^{n} (C_i * W_i)$$

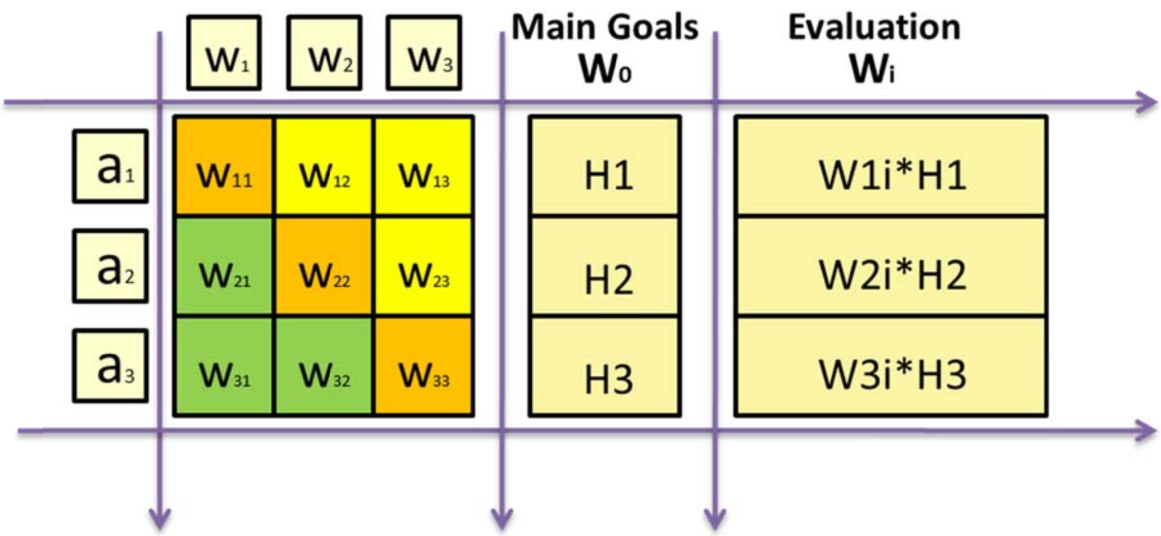
And the Consistency Ratio is determinate by:

$$Consistency\ Ratio = \frac{Cosistency\ Index}{Random\ Index}$$

The random Index is delivered by the following table:

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R.I.	0,00	0,00	0,52	0,89	1,11	1,25	1,35	1,40	1,45	1,49	1,51	1,55	1,56	1,57	1,58

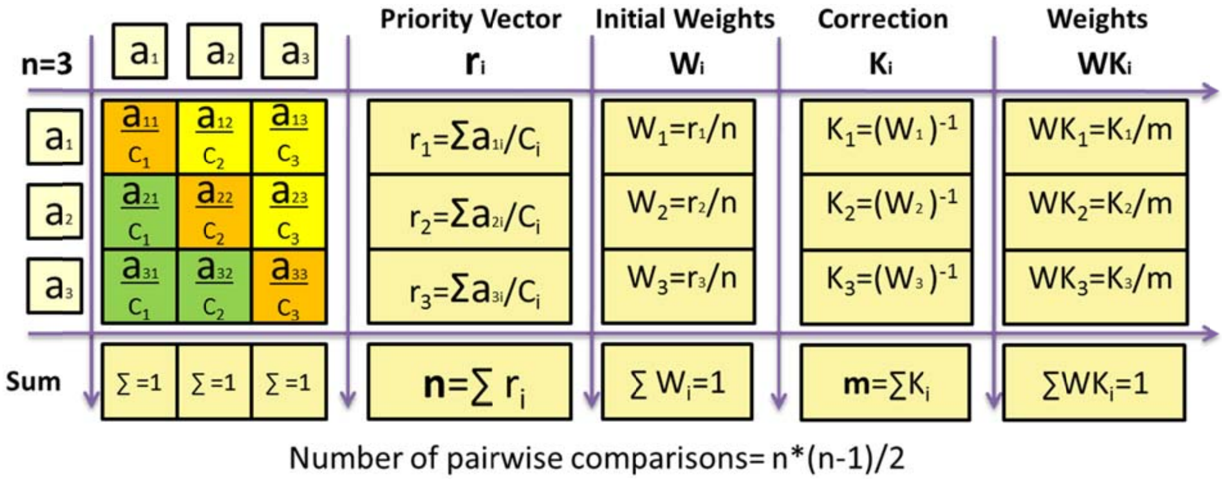
As last step the Matrixes (alternatives evaluations) are multiplied with their corresponding relevance (Goals):



H-3: Total evaluation

Weights modification the for simultaneous maximization and minimization of goals

AHP permits only to pursuit the same goals in an evaluation; this means if we set criteria we can just take the highest or the lowest rank for the selection. In other words, the lowest costs and simultaneously the highest quality cannot be selected in the same weights determination. Thus the proposed modification permits the simultaneous utilization of the expectations.



H-4: Weights modification

With this modification the minimal ranks will be high ranked for the alternatives valuations. Other possibility for avoiding this modification is the application of a utility function or change the basis at the very beginning in the pairwise comparison.