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Impact of combined uncertainty and portfolio's correlations in evaluating its prioritization - Optimized ICT Project Selection Utilizing ROANP

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ABSTRACT

This study deals with the selection and prioritization of Information Communication Technology (ICT) projects that maximize the benefit of a business. The latter may be viewed as a Multi-Criteria Decision Making (MCDM) problem for which traditional project selection methods often fail to solve, as they do not take into account the specific characteristics of uncertainty and interactions between the evaluation criteria and/or different projects. To tackle this problem, a new model is proposed that incorporates Real Option (RO) theory and Analytic Network Process (ANP). In particular, ROs are used to capture project uncertainties, while interactions are modeled through the ANP. The structure of the network model covers all possible dependencies and interactions between criteria and alternatives. The proposed model is examined for its applicability and the effectiveness of procedures through an example. The utilization of this model leads to new results in the ranking of ICT project selection, thus providing further insight on the impact of investment uncertainty and interdependence on project selection.

SUBJECT AREA: Decision Sciences

KEYWORDS: Interdependencies, ANP, Information Communication Technology, Portfolio Prioritization, Multi-Criteria Decision Making (MCDM)

ΠΕΡΙΛΗΨΗ

Η μελέτη ασχολείται με την επιλογή και προτεραιοποίηση έργων τεχνολογίας επικοινωνιών πληροφοριών (ΤΠΕ) που μεγιστοποιούν το όφελος μιας επιχείρησης. Τα τελευταία μπορούν να θεωρηθούν ως προβλήματα λήψης αποφάσεων πολλαπλών κριτηρίων (MCDM) για την επίλυση των οποίων οι παραδοσιακές μέθοδοι επιλογής έργων συχνά αποτυγχάνουν, εφόσον δεν λαμβάνουν υπόψη τους τα ιδιαίτερα χαρακτηριστικά αβεβαιότητας και αλληλεπίδρασης μεταξύ των κριτηρίων αξιολόγησης ή/και των εναλλακτικών έργων. Για να αντιμετωπιστεί αυτό το πρόβλημα, προτείνεται ένα νέο μοντέλο που ενσωματώνει τη θεωρία των πραγματικών δικαιωμάτων προαίρεσης (Real Options) και τη διαδικασία δικτυακής ανάλυσης (Analytic Network Process – ANP). Συγκεκριμένα, τα πραγματικά δικαιώματα προαίρεσης χρησιμοποιούνται για να καταγράψουν την αβεβαιότητα που υφίσταται στην υλοποίηση ενός έργου, ενώ οι αλληλεπιδράσεις μοντελοποιούνται μέσω της διαδικασίας ANP. Η δομή του μοντέλου δικτύου καλύπτει όλες τις πιθανές εξαρτήσεις και αλληλεπιδράσεις μεταξύ κριτηρίων και εναλλακτικών λύσεων. Το προτεινόμενο μοντέλο εξετάζεται ως προς τη δυνατότητα εφαρμογής του και την αποτελεσματικότητα των διαδικασιών μέσω ενός παραδείγματος. Η χρήση αυτού του μοντέλου οδηγεί σε νέα αποτελέσματα στην κατάταξη της επιλογής έργων ΤΠΕ, παρέχοντας έτσι μια καλύτερη εικόνα για τον αντίκτυπο της αβεβαιότητας των επενδύσεων και της αλληλεξάρτησης στην επιλογή των έργων.

ΘΕΜΑΤΙΚΗ ΠΕΡΙΟΧΗ: Επιστήμες Λήψης Αποφάσεων

ΛΕΞΕΙΣ ΚΛΕΙΔΙΑ: Αλληλεξαρτήσεις, Διαδικασίας Δικτυακής Ανάλυσης, Τεχνολογία Επικοινωνιών Πληροφορίας, Προτεραιότητα Χαρτοφυλακίου Έργων, Πολυκριτηριακή Ανάλυση Λήψης Αποφάσεων

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PREFACE

This dissertation is submitted for the Master's Degree in Management and Economics of Telecommunication Networks at the University of Athens. The research described herein was prepared at the Department of Informatics and Telecommunications of the University of Athens. The start of the diploma thesis is scheduled in September 2017 and completed in June 2018.

This work is to the best of my knowledge original, except where acknowledgements and references are made to previous work.

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Athens, Greece, 01/06/2018,

Dimitrios C. Stamos

1. INTRODUCTION

Many organizations have been increasing their investment in Information Communication Technologies (ICT) to meet the growing demands for efficiency and effectiveness [7]. Well-planned ICT investments that are carefully selected with respect to business mission requirements can have a positive impact on organizational performance. Conversely, ICT investments that are poorly planned can postpone or severely limit organizational performance.

Often organizations need to choose between a number of competing investments for various reasons including limited resources and capacity constraints. To select the best set of proposed projects in an organization can be difficult because lots of factors, such as project risk, corporate goals, limited availability of firm's resources, etc., in the candidate projects have to be taken into account. Farbey et al. (1999) [11] have commented "There is concern that poor evaluation procedures mean it is difficult to select projects for investment, to control development and to measure business return after implementation [p. 189]". As a result, numerous methodologies for project selection have been developed and reported on, in the last two decades, with most important being multi-criteria decision making (MCDM) models. These are tools designed to support decision-makers who face many contradictory assessments. The MCDM aims to highlight these conflicts and to find a way to achieve a compromise in a transparent process. Many researchers have studied the tools used in the decision making process to ensure the most appropriate alternative. Meanwhile, they applied the multi-criteria decision making for supporting any decision information process such as Affinity Diagram, Analytic Hierarchy Process (AHP), fuzzy TOPSIS, Analytic Network Process (ANP) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

Furthermore, ICT projects may be regarded as R&D (Research and Development) projects with some distinctive features [13], [21]. They have certain attributes that differentiate them from the other types of R&D projects, for example, can be more lengthy, expensive and complex. One of the most critical characteristics of such investments that differentiate them from the other types of R&D projects is the high degree of risk and uncertainty associated with them. ICT projects involve technological as well as organizational uncertainties. Technological uncertainty originates from rapid change in such technologies; therefore, investments might become obsolete quickly. Organizational uncertainty ranges from unpredictable user resistance, the cost of employee burnout, and the maintenance expenses. Moreover, ICT investments tend to have a high failure rate that might have potentially devastating impacts. Interdependencies also exist among the projects because they normally support common objectives [10], use shared input and often impact each other's output. The complexity of ICT projects as well as their interdependencies poses a challenge when applying methods for the prioritization of these investments [3]. This is why researchers have criticized conventional methods for their evaluation.

Some prior studies have considered the interaction among ICT projects in deterministic environments [3], [10]. Others have dealt with stochastic environments but have not considered project interdependencies [7], [14]. As a result, these models have not found widespread use in practice [10]. Prior proposed project selection techniques, ROAHP [1] and its extension GROAHP [2], are useful providing a better understanding of projects financial tangible and intangible factors and various goals and constraints enabling ICT projects to be valued and prioritized with higher accuracy. The related alternative methods consider the managerial flexibility of responding to a change or new situation in business conditions [29]. For example, an ICT infrastructure project may have a negative NPV (Net Present Value) when evaluated on a stand-alone basis, but may also provide the option to launch future value-added services if business conditions are favorable. Real Options (ROs) analysis presents an alternative method since it takes into account the managerial flexibility of responding to a change or new situation in business conditions [10]. In addition, the use of the Analytical Hierarchy (AHP) allows the quantification of intangible assets related to the analysis. Although the latter two approaches are in the right direction, there is a serious gap, because they only consider independent projects or evaluation criteria.

This study aspires to fill this gap in the project portfolio selection literature. Unfortunately, there are many clearly interdependent cases in real-world subset selection problems. In other words, in such portfolio projects, there exists a great amount of sharing a variety of different resources among various ICT applications. For example, infrastructure reuse for many other implementation projects, providing significant cost savings. Consequently, the study of interdependent properties between investments provides valuable cost savings and greater benefits for organizations. Using ANP and expanding previous methods, the selection of the best project portfolio through the proposed methodology of the present study is achieved, taking into account project uncertainties, which are simulated as real options (ROs) at the same time as project interactions. This approach has not been done before and promises to significantly enrich decision-making literature. ANP is suggested to be applied prior to any further necessary mathematical programming formulation in order to provide a systematic approach to set priorities among multi-criteria and trade-off among objectives.

The rest of this work is organized as follows. The following section provides a brief bibliographic review of the project portfolio selection. Then, the analytic network process (ANP), on which the proposed methodology is based, is presented in Section 3. In Section 4, the proposed method is implemented by means of a numerical example and a sensitivity analysis is performed. The final section presents concluding remarks, research constraints and future directions.

2. LITERATURE REVIEW

2.1 ICT project selection methodologies

Projects are generally selected using a concept approach, such as maximizing profit or minimizing negative effects. Project selection is important and complicated because multiple dimensions usually exist for measuring the impact of individual projects, particularly in situations involving multiple decision makers. For ICT project selection methodology, research and practical implementations by businesses have generally focused on group opinions, expert opinions, management decision models, and mathematical programming.

- Focus group opinions

A group of managers meet and collectively assess supplier quality, flexibility, price, and maintenance performance. The group frequently uses factor analysis to identify qualified suppliers. Sun et al. (2008) [26] developed a group decision support approach to assess experts for project selection. The criteria and their attributes for evaluating experts are summarized mainly based on experts experience with the National Natural Science Foundation of China (NSFC). A formal procedure that integrates both objective and subjective information on experts is also presented.

- Expert opinions

Various experts survey performance criteria and evaluation methods. Expert systems and knowledge decision systems are commonly used. Lee and Kim (2001) [17] proposed an integrated approach for solving interdependent IS project selection problems using Delphi, analytic network process concept and zero-one goal programming. Dodangeh et al. (2009) [9] use expert opinion as determined by a group decision making model, namely the TOPSIS method, for project selection. Four major criteria, including qualitative, quantitative, negative and positive criteria, are considered in project selection.

- Mathematical programming

Mathematical programming models use linear programming, mixed-integer programming, goal programming, and dynamic programming to simultaneously select vendors and order quantities. The purpose of mathematical programming models is to select several vendors to minimize or maximize an objective function subject to vendor and buyer constraints. Santhanam and Kyparisis (1996) [25] developed an IS project selection model based on a nonlinear 0-1 programming model. The model is tested by applying it to real-world IS project selection data. Comparing the performance of the proposed model with existing selection models highlights its contribution.

- Management decision models

Due to the different criteria for assessing the technology and the various existing alternative telecommunication applications, the project selection process becomes complex. There is uncertainty and multiple conflicting objectives with sociological, demographical, environmental, political, cultural, economic and technical aspects. This raises the need for some kind of structure or model, based on a suitable multicriteria decision making (MCDM) method. A broad multi-criteria decision model is generated that allows a business to evaluate supplier performance and thus select suitable suppliers. The fuzzy approach, analytic hierarchical process (AHP), analytic network process (ANP), and information technology are frequently used to build the decision model [6]. Chen and Gorla (1998) [5] used fuzzy logic to establish a project selection model. This decision model helps decision makers to deal with uncertain or incomplete information without losing existing quantitative information. Some relevant papers cited in literature tackling such problems using methods, with particular focus on the application of analytic hierarchy process (AHP). AHP [20] is a well known method which is applied in IS/ICT project selection. Marc, 1991 [18] proposed goal programming using AHP to solve this problem. However, they did not consider interdependence property itself but consider independence property among alternatives or criteria. Ranking, scoring and AHP methods do not apply to problems having resource feasibility, optimization requirements or project interdependence property constraints. Various real-world problems have an interdependent property among the criteria or candidate projects. Consideration for these interdependencies among criteria provides valuable cost savings and greater benefits to organizations.

2.2 Managing project-criteria interdependencies

As abbreviated in previous section, interdependencies are an eminent characteristic of ICT projects. Consequently, a few approaches have been developed to consider interdependencies. The IS project selection method developed by Santhanam and Kyparisis (1996) [25] that models benefit, resource and technical interdependencies among projects is formulated as a nonlinear 0-1 programming problem and is among the first to consider higher order interactions. However, usually only intratemporal interdependencies are incorporated while only few approaches account for intertemporal interdependencies. Yeh et al. (2010) [30] presented a fuzzy multicriteria group decision making approach for selecting IS projects. An IS project selection problem was presented to demonstrate the effectiveness of the proposed approach. Moreover, Chen and Cheng (2009) [7] presented a multiple-criteria decision-making method (MCDM) for selecting an IS project based on the fuzzy measure and fuzzy integral. A numerical example is presented to demonstrate the procedure for the proposed method. The result shows that the selection model is effective. Eilat et al. (2006) [10] combined Balanced Scorecard (BSC) and Data Envelopment Analysis (DEA), and proposed a new approach for IT project selection. The proposed approach used BSC as a comprehensive framework for defining IT project evaluation criteria, and used DEA as a nonparametric technique to rank IT projects.

The latter approaches in particular make use of real options theory [1], [3]. Bardhan et al. (2004) [3] provided a nested real options approach to support the selection of IT project portfolios. The effect of interactions on the projects values (in terms of NPV) is investigated. In addition, Pendharkar (2010) [19] proposed a real options model to solve IT project selection problem where there are cash flow interdependencies between multi-stage projects.

2.3 Specific characteristics of IT project portfolios

As was mentioned above, ICT projects have specific characteristics that differentiate them from other investments. First of all, it should be mentioned that IT projects underlie strong interdependencies and interactions of different kinds (taxonomy for different kinds of interdependencies between IT projects has been proposed by Kundisch & Meier, 2011a [15]).

Managing project interdependencies within ICT project portfolio environments tend to be a complicated, rather a complex task. Much of this management complexity is due to the total number of projects and their related parts alongside the degree of interdependence between these parts. Another source of complexity can be attributed to the possible number of states (variety) project interdependency can have. Bearing this in mind, managers would have to consider dealing with various project interdependency types including resource, technology, technical, learning-based, and market interdependencies. Each of these types would have to serve a distinctive purpose with regard to its role in fulfilling the overall portfolio goals. Another issue for consideration is the interdependence form that two or more projects should have and the patterns of interaction accompanying each. Thompson (1967) [27] has distinguished between three forms of interdependence including reciprocal, sequential and pooled. A reciprocal form tends to be complex while the other forms tend to be complicated and simple, respectively. In company with these interdependency forms and in order to produce the intended outcomes from each, different patterns of interaction would take place including Resource-Resource, Output-Output, and Output-Resource interactions. As a result of these interactions, managers should realize that different cost / benefit outcomes can be produced according to their respective targets.

Hence, identification of the interdependencies between projects must be undertaken in a consistent and repeatable manner that scales well with the number of projects. Project interdependencies have a considerable impact on the selection of project portfolios. It is important to identify and incorporate interdependencies among the selection criteria in the analysis as careful consideration of such interrelationships would provide greater cost savings and benefits to the organizations, while not considering such relationships would result in a poor resource allocation in an organization.

Furthermore, a high option value and difficult assessment of IT projects, combined with a high level of uncertainty, have frequently been reported. An IT infrastructure, which by itself might not create much value, might enable another project, and completion of both may yield significant value. Therefore, the infrastructure project deserves partial credit for future benefits that it enables. Similarly, some projects are broken into phases, with funding considered at each phase. One phase might not appear attractive on its own, but it might enable a later phase that facilitates completion of the entire project. Most managers realize that ICT projects provide leverage to launch future value-added services and take them into consideration when evaluating technology decisions. This works well when there are few options to consider. However, when dozens of projects with complex interdependencies are considered, this decision is not as clear and the risks to making suboptimal decisions are high.

Risks produced by market conditions and competitive environments are also important. Even when private risks have been controlled to low levels, an ICT investment project could still fail to generate the expected payoffs due to an uncertain environment. The efficacy of the adopted technology may change, or a competitor may make a preemptive move. Such risks are generally produced by factors external to the project, and are applicable to all investment projects that have similar features. The unsuccessful management of ICT risks can lead to a variety of problems, such as cost and timing overruns, unsatisfied user demands and the failure of ICT investment to be profitable.

In conclusion, due to the nature of the high levels of risk and interactions that characterize most ICT projects, a decision-making method is required that takes both of them into account simultaneously.

2.4 Related work - ROAHP

The inadequacy of traditional quantitative cost-benefit analysis for evaluating investment in business projects with an IT component have led researchers to suggest real options (RO) analysis for valuating ICT projects. However, RO models are strictly quantitative and often, ICT investments may contain qualitative factors that cannot be quantified in monetary terms. In addition, RO analysis results in some factors that can be treated more efficiently when taken qualitatively. Real Options Analytical Hierarchy Process has been suggested as a method that combines RO and the analytical hierarchy process into a combined multi-objective, multi-criteria model for prioritizing a portfolio of interdependent ICT investments. Initially, this RO approach fits the nature of IT-investment decision making, which is characterized by flexibility and the capability to expand or launch other applications (Angelou & Economides, 2008) [1] which might add value. This research extends on the idea of using a nested RO model by adding analytical hierarchy process (AHP) to the existing RO model. Angelou and Economides (2008) [1] present a MCDA method for prioritizing a portfolio of IT projects. The nested real options model helps to include the intertemporal interdependencies between projects during the valuation of the projects and will allow the Expanded NPV (ENPV) to be calculated for each project. Their model enables evaluating IT projects with higher accuracy by combining RO with AHP in order to combine tangible and intangible factors. The tangible and intangible factors are made compatible and the project priority ranking is calculated using the Expert Choice tool (Expert Choice is a commercial AHP tool).

Angelou and Economides (2008) [1] method's end goal is to calculate the overall benefit factor of each project. It combines tangible (one-time costs and ENPV) and intangible factors from each project and allows the user to calculate the overall benefit factor, according to the user's preferences. The method starts by calculating the extended net present value (ENPV). This differs from the NPV value of a project due to the fact that it adds the value of future options by using the RO method. It takes into account the managerial flexibility companies have. Companies can choose to, e.g., pause or abandon projects in case of a negative development or to extend it in case of a positive development. This flexibility is also called active management [1]. Following this method for a portfolio of projects it will produce a ranking of all the projects according to the criteria which defined important and the related important ranking.

The method follows the steps below for performing a prioritization of projects within a portfolio:

1. Define all (potential) projects in a portfolio
2. Define all dependencies between the projects (e.g. project A enables project B)
3. Define all options (e.g. option to continue the project or abandon)
4. Weigh all decision criteria relative to each other following Analytical Hierarchy Process (AHP). AHP can assess the relative importance of each criterion compared to the other criteria. This is done for all criteria. Next, the value of all criteria per project needs to be determined.
5. Perform a sensitivity analysis of each criterion (by means of the method AHP). This is an indicator of how much each criterion influences the final 'score' of each project.
6. Calculate the ICT utility factor. This is done based on the dependencies, options and cost and benefit factors. All projects get an ICT utility factor and the ranking is based on this final 'score'.

The main forthcoming of the ROAHP is the assumption that ICT projects are mutually exclusive. In real life cases, portfolio's projects may experience interdependencies. In this case, the implementation of one project may influence negatively or positively another one. In real life cases, further analysis is required for portfolio's projects ranking before adopting the final solution. In particular, the decision makers should perform extended sensitivity analysis for extracting the amount of influence of each priority as well as weight factor before adopting the final solution of ranking.

Basically, the AHP is a suitable method when optimization is not pursued, resources are not restricted, and interdependencies between factors do not exist. However, such models do not consider important issues such as interaction among and between decision making levels/clusters as well as dependency among qualitative factors. These are important issues in telecommunications investments decision problems which cannot be structured hierarchically because they involve many interactions and dependencies requiring a MCDM method to holistically deal with qualitative and quantitative data, with different conflicting objectives, to arrive at a consensus decision in relation to the choice of a suitable investment.

2.5 A ROAHP Case illustration

The case study proposed by Angelou & Economides, 2008 [1] and applied in the ICT sector on the basis of their relevant model, is presented here in order to point out in following chapter the extensions and differentiations of the new proposed approach.

It concerns an ICT portfolio investment decision for a growing water and sewage company, referred as WSSC, to protect its identity and its projects. WSSC faces challenges in several areas. First, there is an opportunity for the WSSC to offer advanced water management services to its existing customers. This results in enhanced service quality and efficient control of its operating expenses. In addition, its service area will significantly increase, thus attracting new customers. To achieve all this, WSSC management is focusing on the significance of ICT applications that could transform the company's relationships with customers, suppliers, other partners and environment regulators. WSSC is interested in prioritizing four ICT infrastructure projects. Moreover, each project will generate a number of future investment opportunities in order to improve automation aspects of its operations, decision taking methods, customer services as well as new strategic opportunities in long-term perspective. Each project owns one clearly defined expand/growth option. The management also considers that there are some possible future investment opportunities, however not clearly defined at the time of the initial valuation.

Hence, there are 8 projects clearly defined. The portfolio's projects are grouped into two phases. Phase 1 (infrastructure) projects P_{1i} (i=1,…,4) represent projects that do not have any prerequisites and serve as building blocks for future projects in phase 2. Phase 2 projects P_{2j} (j=1,…,4), treated as ROs, involve significant investment decisions that depend on the capabilities deployed in phase 1.

- $P_{1,1}$ StruMapOut - a Hydraulic Analysis Application, which helps the Water Network Modeling and therefore the Water Management. It is focusing on the outside (backbone network) water network
- $P_{1,2}$ GIS Platform - a Geographical Information System (GIS) that allows users to create, view, access and analyze map (geo-referenced) data.
- $P_{1,3}$ Siebel/Asset Management – An ICT application that provides capabilities for efficient asset management and customers services support.
- $P_{1,4}$ ICAT-Telemetry – Information Communication and Automation Technology Infrastructure to enable WSSC to perform more efficient water network management

- $P_{2,1}$ StruMapIn - Extension of StruMap on Internal (distribution network) optimization
- $P_{2,2}$ Extension of GIS platform application to Equipment Management providing an information portal for factors affecting customers demand and support
- $P_{2,3}$ Extension of Siebel to information portal (customers support) providing also on line question and answer service to WSSC customers.
- $P_{2,4}$ Expand Operation Capability of the existing ICAT platform

The first task is the definition of the criteria that will be used for the selection of the appropriate ICT technology. The overall utility factor of the AHP structure is divided into cost and benefit factors. These factors may be further decomposed into their applicable sub-criteria, which are closely related to the ROs and the investment issues coming from this analysis.

The terms costs and benefits mean any factor, tangible and intangible that can affect overall costs and benefits of the portfolio's projects. The positive (good) attributes are represented in the benefits hierarchy, while the negative attributes are represented in the costs hierarchy.

Considering the costs factors these are listed as follows.

- One time Cost that corresponds to the sunk, irreversible cost to exercise the option and implement the project (C, Tangible).

The core idea of ROs is the value of investment delay for more efficient control of uncertainties. However, postponing the investment for a period may be costly, therefore, the following cost factors arise:

- Option Cost of delay coming from revenue losses due to high Customers' Demand (OCCD, Intangible).
- Option Cost of delay coming from Competition Threat (OCCT, Intangible).
- Option Cost of delay due to Environmental or regulatory Changes (OCEC, Intangible).

The benefits factors are analyzed as follows.

- ENPV is the maximum or minimum value of a potential investment that contains the option(s) contribution of future investment opportunities (Tangible). Without loss of perspective, this factor is associated with benefits, though it integrates both tangible benefits (revenues) and costs.
- Information Effects - Transformation Effects (ITE, Intangible) are benefits that apply especially to cases where the project is focusing more on internal use and exploitation, having the goal of reengineering the firm.
- Strategic - Long Term benefits (investment opportunities modeled as growth options) are created by the initial project and its predefined options and cannot be clearly quantified (SE, Intangible).
- Competition Effects - Increased Market Share (CA, Intangible). The firm can gain competitive advantage by the project implementation, which can be translated to increase of market share. These are modeled as intangible factors.

As described above there exists two tangible and six intangible factors. While numerical values pertaining to quantitative objectives have been readily used for tangible factors, AHP priorities have been elicited and used for qualitative objectives. To achieve homogeneity between various types of objectives, as shown below, the quantitative values for the ENPV and One-Time costs are normalized into the range of [0, 1].

Initially, the nested options model is applied to prioritize portfolio projects according to ENPV values. A nested binomial option-pricing model provided by Trigeorgis (1996) [29] is used. The AHP methodology is then introduced to combine the tangible and intangible factors derived from the analysis of ROs.

The next steps in the process can be summarized as follows:

- Construction of template-board
- Comparison of two of the Criteria and their rating on the basis of the template-board
- Comparison of two of the Alternatives and their rating based on the template-board

In common with what Angelou argues (2008) [1], it is sometimes difficult to find technical people who can compare choices so it is necessary for the analyst to learn in detail about each option and to do only the graduation. This is also the case here and there is a ranking of selection criteria according to their relative importance based on personal subjective assessment. The level of affinity will be taken into account, since according to the AHP method a stability ratio of less than 0,10 should be acceptable[20]. After making all paired comparisons, for all alternatives, according to the principles of AHP with respect to all criteria defined in the RO and AHP model, the total priorities for the alternatives are computed with the Expert Choice tool.

The following figure gives the prioritization result for the phase 1 projects. As seen, project P_{13} has the first priority to be implemented though project P_{14} presents the higher ENPV value. It is the intangible factors contribution that changes the list of the final ranking compared to the result extracted by the simple ROs analysis where only the ENPV value was taken into account.

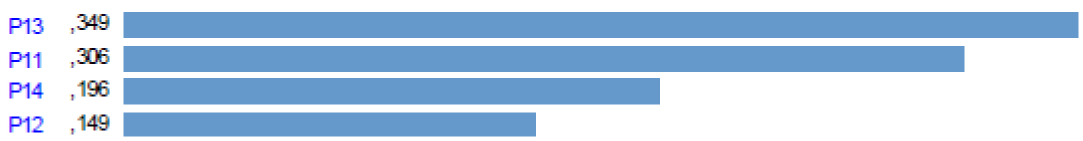

Figure 1: Projects prioritization performed with Expert Choice tool

3. OVERVIEW OF THE ANP DECISION MODEL

3.1 Introduction

This work attempts to particularly allow for the explicit consideration of dependencies and interactions in the decision making process. The ANP is chosen in this thesis because of its several advantages over the AHP and other MCDM methods, such as its holistic approach, in which all the factors and criteria involved are laid out in advance in a network system that allows for dependency. Its power lies in its use of special ratio scales to capture interactions for making accurate predictions and reach better decisions. Moreover, its suitability in offering solutions in a complex multicriteria decision environment, together with the availability of software supporting its functions, further acknowledge its applicability to tackle such a problem. It has also proved to be successful in utilizing expert knowledge to tackle several selection problems.

The ANP is a multi-attribute decision making approach developed by Thomas L. Saaty [22], [23] and was originally called the supermatrix technique. It is a generalization of the AHP decision methodology where hierarchies are replaced by networks, allowing the capturing of the outcome of dependence and feedback within and among the clusters of elements. Its network structure differs from a hierarchy as illustrated in Fig. 2. The hierarchy has a goal, levels of elements and connections between the elements. It has no inner dependence and no feedback from lower to higher levels. Unlike the hierarchy, the network structure has no levels but clusters of elements where every element can depend on any other element. The influence is transmitted from one cluster to another (outer dependence) and back, either directly from the second cluster, or, by transiting through intermediate clusters along a path which sometimes can return to the original cluster forming a cycle. The existence of feedback indicates there is mutual outer dependence of criteria in two different clusters, which prevents the problem from being modeled hierarchically due to the difficulty in deciding which cluster is higher/lower than the other. Also, because of inner dependence, the relationships between same level criteria are not represented hierarchically.

The specific ANP model is based on the reasoning, knowledge and experience of experts in the field and relies on the process of eliciting managerial inputs, allowing for a structured communication among decision makers, so that it can act as a qualitative tool for strategic decision-making problems. Saaty (1996) [22] have commented “It is a relatively new methodology that is still not well-known to the operations research community and practitioners”. With its capability to deal with dependence and feedback, it is the most general framework for a detailed analysis of societal, governmental and corporate decisions that is available today to the decision-maker. Therefore, in recent years, there has been an increased use of the ANP in a variety of decision making problems and numerous applications have been published in literature.

The ANP is a coupling of two parts. The first part consists of a control network of criteria that controls the interactions in which the criteria should be identified, organized and prioritized in the framework of a control network. The second part is to derive a network of influences among the factors and clusters, i.e., the influence of elements in the feedback system with respect to each of these criteria. Paired comparison judgments of homogeneous elements are performed and synthesized to obtain the priorities of these criteria. The ANP then joins all possible outcomes together in its structures and both judgement and logic are used to estimate the relative influence from which the overall answer is to be derived.

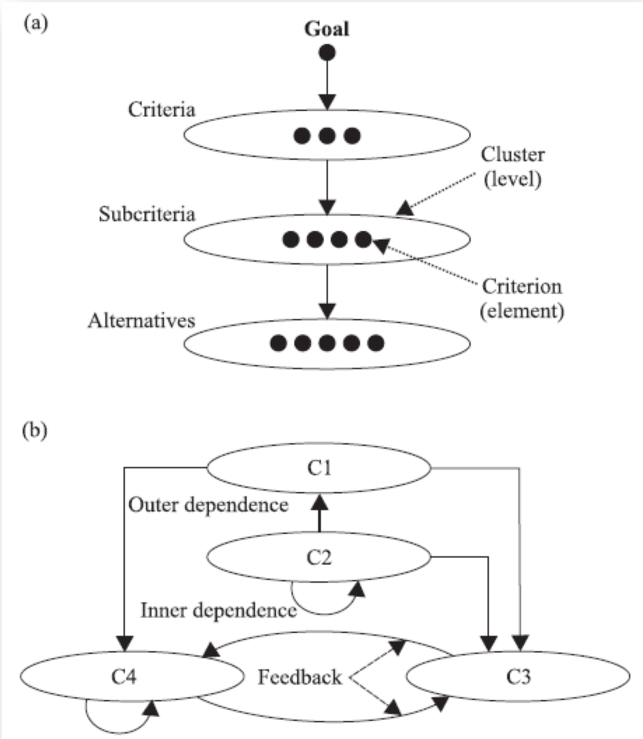

Figure 2: Examples of a hierarchy (a) and a network (b)

3.2 The Analytic Network Process Method

In constructing an ANP model, there are three important nodes:

- The Goal – this is the decision which is sought. In this case, the goal is to answer the question "what is the most sustainable learning technology intervention?"
- The Alternatives – are the possible choices which fulfil the goal or objective.
- The Criteria – are those factors which should be considered in selecting the alternative that best fulfils the goal.

The following are the main steps in formulating an ANP model:

- Thorough understanding and a clear description of the decision problem and the overall objective/goal.
- Identification of important criteria and relevant factors. This may be achieved through a structured brainstorming technique.
- Precise definition of alternatives, criteria and other factors.
- Systematic investigations of interconnections between nodes of the network.
- Critical assessment of eventual model outcome – the result is only as good as the model.

Besides the general steps in creating an ANP model, it is also important to discuss the quantitative aspect of this modelling technique.

According to Saaty [22] the steps in the quantitative component of the ANP are:

1. Design a questionnaire for collecting responses from experts. The questionnaire used in this study involved pairwise comparisons of elements on a nine-point scale with nine points awarded if one element was extremely more important than the other and one point awarded if the two elements were equally important.

The scale is obtained from conducting pairwise dominance comparison based on informed user judgment, as shown in Table 1.

Table 1: Measurement scale for pair-wise comparison in AHP [20] and ANP [22]

Intensity of Importance	Definition	Decription
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one over another
5	Strong importance	Experience and judgment strongly favor one over another
6	Very strong importance	Activity is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	Importance of one over another affirmed on the highest possible order
2,4,6,8	Intermediate values	Used to represent compromise between the priorities listed above
Reciprocal	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	

2. The next step involves arranging the results of the pairwise comparisons in the pairwise comparison matrix. This matrix is then normalised by dividing each entry by its corresponding column sum to get the normalised matrix. The rows of the normalised matrix are then averaged to get the priority vector for each element under consideration.

The following procedure is used to synthesize priorities

- Sum the value in each column of the pair-wise matrix.
- Divide each element in a column by the sum of its respective column. The resultant matrix is referred to as the normalized pair-wise comparison matrix.
- Sum the elements in each row of the normalized pair-wise comparison matrix, and divide the sum by the n elements in the row. These final numbers provide an

estimate of the relative priorities of the elements being compared with respect to its upper level criterion

3. The next step is the consistency test to certify that the original preference ratings made by the expert were consistent. The consistency ratio is a measure of the consistency of the individual judgements. For instance, if A is more important than B and B is more important than C; it therefore follows that A should be more important than C. If an expert then rates A the same as, or more important than C, that set of comparisons will prove inconsistent and a review would be necessary. Determining the consistency of each set of pairwise comparisons involves the following three steps:

- Computing the consistency measure λmax. The consistency measure is evaluated by first calculating the product of the original pairwise comparison matrix and the priority vector, dividing each entry in this new matrix by its corresponding priority and finally averaging the results to get the consistency measure λmax.
- The second step is to compute the consistency index (CI) given by

$$CI = (\lambda_{max} - n) / (n - 1)$$

Where n is the size of the pairwise matrix.

- The final step is to compute the consistency ratio (CR) given by

$$CR = CI / RI$$

Where RI is a random consistency index computed for $n \leq 10$. For perfect consistency, the consistency measure λ_{max} equals n and therefore the consistency index CI will equate to zero and this will result in a consistency ratio CR of zero. On many occasions however, this is not the case and CR will usually have a value greater than zero. Saaty [22] recommends that CR should be 0.1 or less and the judgements should be revised by the expert if CR is significantly greater than 0.1.

4. The other steps in the ANP include forming the "unweighted supermatrix" which contains local priorities derived from the pairwise comparisons throughout the model's network and using this to construct the "weighted supermatrix".

Saaty [22] explains the supermatrix concept parallel to the Markov Chain Processes. By incorporating interdependencies (i.e. addition of the feedback arcs in the model), the supermatrix is created. Feedback arcs are important because there should exist complete loops for supermatrix application. In other words, from the Markov Chains point of view, all the elements (nodes) should be recurrent instead of being transient so that the effects of the influences on the final results do not vanish for some elements (nodes) during the application.

Assume that there is a system of N clusters where the elements in each cluster have impact on or are influenced by some or all of the elements of that cluster or of other clusters with respect to a property governing the interactions of the entire system. Assume that cluster h, denoted by C_h, h=1,…,N, has n elements denoted by e_{h1}, e_{h2},…,e_{hn}. The structure of the corresponding supermatrix is illustrated in Figure 3.

During building up the supermatrix, it is extremely important to be consistent about the question asked to the decision maker. Saaty (1999) [23] proposes two types of questions formulated in terms of dominance or influence. Given a parent element, which of two elements being compared with respect to it has greater influence (is more dominant) on that parent element? Or, which is influenced more with respect to that parent element?

For example, in comparing A to B (elements in a cluster) with respect to a criterion, the question asked is whether the criterion influences A or B more. Then if for the next comparison involving A and C the question asked is whether A or C influences the criterion more, this would be a change in perspective that would undermine the whole process. One must keep in mind whether the influence is flowing from the parent element to the elements being compared, or the other way around. Considering this, it is crucial to stick to the perspective during the pairwise comparisons

$$
\begin{array}{cc|cccc}
 & & C_1 & C_2 & \cdots & C_N \\
 & & e_{11}e_{12}\cdots e_{1n_1} & e_{21}e_{22}\cdots e_{2n_2} & \cdots & e_{N1}e_{N2}\cdots e_{Nn_N} \\
\hline
 & e_{11} & & & & \\
 & e_{12} & & & & \\
C_1 & \vdots & W_{11} & W_{12} & \cdots & W_{1N} \\
 & e_{1n_1} & & & & \\
 & e_{21} & & & & \\
 & e_{22} & & & & \\
C_2 & \vdots & W_{21} & W_{22} & \cdots & W_{2N} \\
 & e_{2n_2} & & & & \\
\vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\
 & e_{N1} & & & & \\
C_N & e_{N2} & W_{N1} & W_{N2} & \cdots & W_{NN} \\
 & \vdots & & & & \\
 & e_{Nn_N} & & & &
\end{array}
$$

Figure 3: Supermatrix

Saaty [22] suggests one of the following two questions throughout a process:

- Given a parent element and comparing elements A and B under it, which element has greater influence on the parent element? (The direction of the arrow is to the parent element)

- Given a parent element and comparing elements A and B, which element is influenced more by the parent element? (The direction of the arrow is from the parent element)

To be consisted throughout this study, the first question is posed during the pairwise comparisons. That is, the eigenvector in the column of an element (either the main goal or any of the criteria) in the supermatrix indicates the relative influences of the row elements on the column element. In other words, the numbers in a column are the relative priorities of the elements with respect to the element corresponding to that column.

5. This next step is only required when there are more than two clusters in a node of the network and involves performing cluster comparisons to get the cluster matrix. This cluster matrix is then multiplied by the unweighted supermatrix to give the weighted supermatrix.

After the pairwise comparisons, each eigenvector is obtained and introduced in the appropriate position as a column vector as shown in Figure 3. While building up the supermatrix, the eigenvectors in the individual matrices are adjusted by normalization with respect to the relative weights of the clusters they belong. When this is done, the supermatrix becomes column stochastic and from this point on it is called "weighted supermatrix". This should be performed before any operation on the supermatrix in order to derive meaningful limiting priorities. From the network perspective, this operation makes the sums of the arrows emanating from an element equal to unity, which is essential from the Markov Chains point of view before any limiting operations on the supermatrix. In general the supermatrix is rarely stochastic because, in each column, it consists of several eigenvectors each sums up to one, and hence the entire column of the matrix may sum up to an integer greater than one. Normalization would be meaningless and such weighting does not call for normalization.

6. This step is composition of a limiting supermatrix, which is created by raising the weighted supermatrix to powers until it stabilizes. Stabilization is achieved when all the columns in the supermatrix corresponding to any node have the same values.

7. After the limit supermatrix is obtained, the final step is to rank the projects based on their priority. As a result of the process, a table summarizes the final score of the projects analyzed, sorted by their priority.

4. APPLICATION OF THE ROANP MODEL

To illustrate the use and advantages of the combined ANP and ROs model in ICT project selection, the hypothetical example of Angelou [1] will be used. Their problem consisted of prioritizing four ICT projects on the basis of four benefits factors and four costs factors criteria as described above based on a corresponding analysis. In this example, the criteria were considered independent. That is, they applied this problem to Saaty's AHP without considering interdependence property among the criteria. However, there is a relationship of interdependence between these criteria to problems of choosing similar projects. For instance, Strategic-Long Term benefits (e.g. the entrance of more value added advanced telecommunication services) impact on ENPV for companies. Another example is the effect of competitive advantage gain on ENPV. The justification is that the business can gain a competitive advantage from the implementation project, which can be translated to an increase in market share. These examples illustrate the shortcomings of the AHP in this particular research study, thus the preference for the ANP becomes evident. The feedback relationships described above are shown in Figure below.

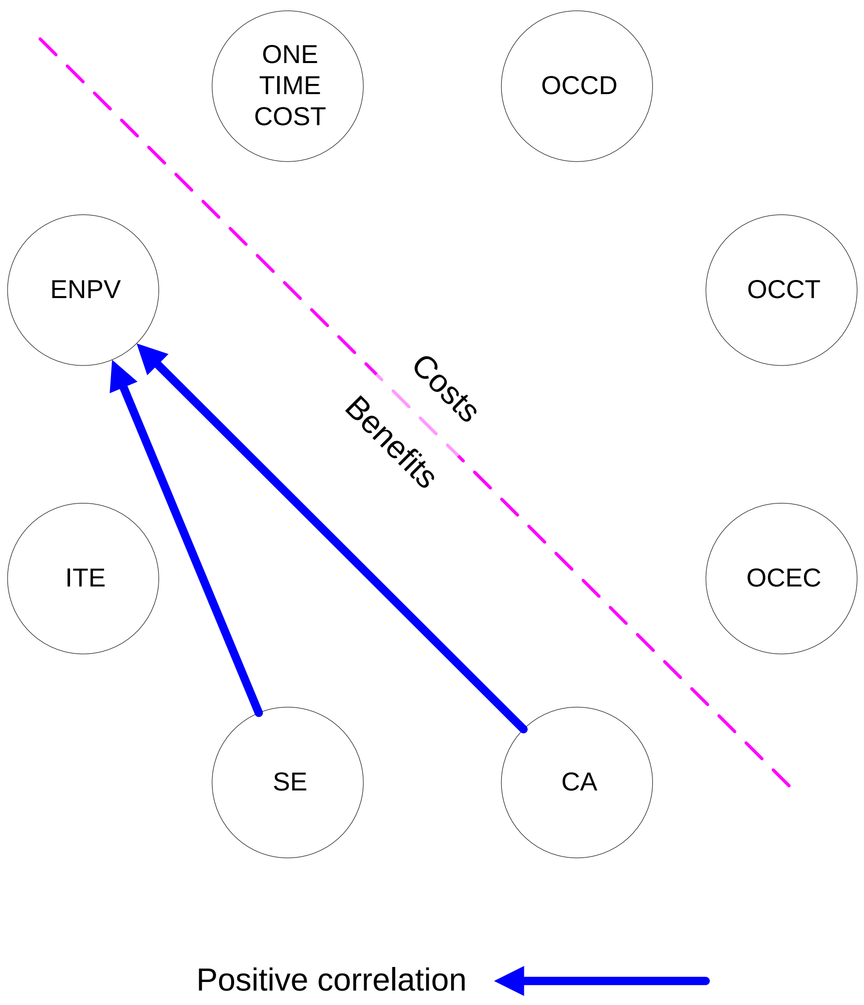

Figure 4: Interdependent relationship among the criteria

The first step of the proposed method shares the corresponding elements of the AHP method outlined above:

- Construction of a memo
- Compare each of their Criteria and score based on the memo
- Compare each of the Alternatives and score on the basis of the memo
- The results of the two comparisons are plotted in pairwise comparison matrices
- Construct normalized tables, where the data has a total sum equal to one
- Finding weights for each Criterion
- Finding weights for each Alternative

These steps do not involve the interdependence between criteria nor between alternatives. The results of the above comparisons are depicted in pairwise comparison matrices. Tables in Annex 1 provide the analysis as well as the resulting weights and consistency ratios for the intangible factors of the proposed model. The greater the value of a factor has, a relatively larger effect is considered in the selection process for this factor. The matrix tables and their relative priorities are computed with Microsoft Excel Spreadsheets tool.

The weight matrix of criteria as W_{1B} and W_{1C} result accordingly:

Table 2: "W_{1C}" weight matrix of benefits factors - criteria

One time cost C	0,080
OCCD	0,038
OCCT	0,251
OCEC	0,131

Table 3: "W_{1B}" weight matrix of costs factors - criteria

ENPV	0,068
ITE	0,038
SE	0,272
CA	0,122

Table 4: Project weight matrix for each criteria without interdependence

	One time cost C	OCCD	OCCT	OCEC	ENPV	ITE	SE	CA
Project($P_{1,1)}$)	0,168	0,554	0,221	0,501	0,060	0,360	0,409	0,158
Project($P_{1,2)}$)	0,218	0,087	0,064	0,264	0,330	0,143	0,094	0,215
Project($P_{1,3)}$)	0,287	0,314	0,652	0,106	0,090	0,407	0,384	0,068
Project($P_{1,4)}$)	0,327	0,045	0,064	0,129	0,520	0,090	0,112	0,559
	W_{21}	W_{22}	W_{23}	W_{24}	W_{25}	W_{26}	W_{27}	W_{28}

In order to determine the degree of influence between the criteria, Saaty's nine scales [34,35], as well as the Saaty and Takizawa's concept [21] will be used in place of Saaty's supermatrix [34,35]. When a network consists of only two clusters apart from the goal, namely criteria and alternatives, the matrix manipulation approach proposed by Saaty and Takizawa (1986) [21] can be employed to deal with dependence of the elements of a system. The network diagram of the specific problem, can be drawn as a linear hierarchy (Fig. 5) with inner and outer dependences and no feedback.

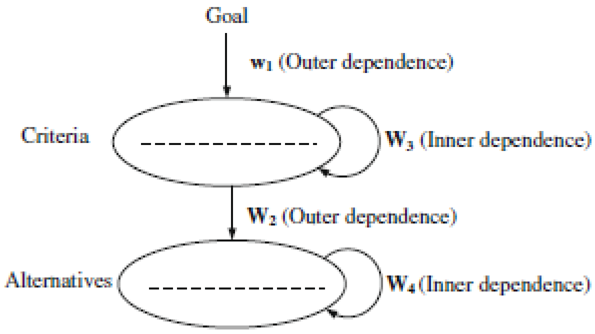

Figure 5: Network diagram representation for a three-component decision problem.

Fig. 5 shows that outer dependence exists in both goal-criteria and criteria-alternatives. It also shows that both criteria and alternatives have their own inner dependence. The supermatrix for this linear hierarchy can be represented as:

$$\mathbf{W} = \begin{array}{l} \text{Goal (G)} \\ \text{Criteria (C)} \\ \text{Alternatives (A)} \end{array} \overset{\begin{array}{ccc} \text{G} & \text{C} & \text{A} \end{array}}{\begin{bmatrix} 0 & 0 & 0 \\ \mathbf{w}_1 & \mathbf{W}_3 & 0 \\ 0 & \mathbf{W}_2 & \mathbf{W}_4 \end{bmatrix}},$$

Figure 6: Supermatrix for a linear hierarchy

where w_1 is a vector that indicates the impact level of the goal on the criteria, W_2 is a matrix that indicates the impact level of the criteria on each of the alternatives. W_3 and W_4 are the matrices that indicate the inner dependence of criteria and alternatives, respectively.

4.1 Criteria Interependencies

After structuring the decision problem, the next step is to examine the influence among criteria. When selecting the ICT project, the criteria should not be considered alone. Therefore, the impact of the criteria on each other needs to be examined by using pairwise comparisons.

In the following table the sets of weights are obtained. The data in this table show the degree of relative impact of the eight criteria between them. Based on the hypothesis depicted in figure 4 above, the "SE" degree of relative impact for "ENPV" is 0,417 and the "CA" degree of relative impact for ENPV is 0,083. They were obtained from decision maker by Saaty's nine scales, which means the degree of interdependence among the criteria with respect to each project.

Table 5: Interdependence weight matrix of benefits factors-criteria

W_{3C}	One time cost C	OCCD	OCCT	OCEC
One time cost C	1,000	0,000	0,000	0,000
OCCD	0,000	1,000	0,000	0,000
OCCT	0,000	0,000	1,000	0,000
OCEC	0,000	0,000	0,000	1,000

Table 6: Interdependence weight matrix of costs factors-criteria

W_{3B}	ENPV	ITE	SE	CA
ENPV	0,500	0,000	0,000	0,000
ITE	0,000	1,000	0,000	0,000
SE	0,417	0,000	1,000	0,000
CA	0,083	0,000	0,000	1,000

Next, the interdependence among the alternatives with respect to each criterion is treated. An illustration of the question to which one must respond is: with respect to the satisfaction of the criteria, criteria 1 (One time cost C), with project, which project contributes more to the action of project 1 to criteria 1 and how much more? In this way, the data are shown in Tables 26-33.

It is mentioned that this example does not consider interdependencies between the four projects, therefore the tables are repeated equally. The data is repeated in the last rows to normalize and give a sum of one.

The interdependence priorities of the criteria are obtained by synthesizing the results from above steps as follows:

Table 7: Interdependence priorities of the benefits factors-criteria

$W_{CB}=W_{3B}*W_{1B}$	0,080
	0,038
	0,251
	0,131

Table 8: Interdependence priorities of the costs factors-criteria

$W_{CC}=W_{3C}*W_{1C}$	0,034
	0,038
	0,300
	0,128

The priorities of the Projects W_p with respect to each of the four criteria are given by synthesizing the above results, as follows:

Table 9: Project interdependence weight matrix for each criteria

	$W_{p1} = W_{41}*W_{21}$	$W_{p2} = W_{42}*W_{22}$	$W_{p3} = W_{43}*W_{23}$	$W_{p4} = W_{44}*W_{24}$	$W_{p5} = W_{45}*W_{25}$	$W_{p6} = W_{46}*W_{26}$	$W_{p7} = W_{47}*W_{27}$	$W_{p8} = W_{48}*W_{28}$
Project($P_{1,1)}$	0,168	0,554	0,221	0,501	0,060	0,360	0,409	0,158
Project($P_{1,2)}$	0,218	0,087	0,064	0,264	0,330	0,143	0,094	0,215
Project($P_{1,3)}$	0,287	0,314	0,652	0,106	0,090	0,407	0,384	0,068
Project($P_{1,4)}$	0,327	0,045	0,064	0,129	0,520	0,090	0,112	0,559

Finally, the overall priorities for the candidate projects are calculated by multiplying W_p by W_c.

Table 10: Overall priorities for the candidate projects

Project($P_{1,1)}$	0,315
Project($P_{1,2)}$	0,144
Project($P_{1,3)}$	0,355
Project($P_{1,4)}$	0,187

These ANP final results are interpreted as follows. The highest weight project in this ICT project selection example is $P_{1,3}$. Next is project $P_{1,1}$. In the end there are projects $P_{1,4}$ and $P_{1,2}$.

Although the ANP and AHP results show no great disparity, there are some different points in deviation variables and the weight of ICT projects priorities differ. The comparison of results based on the AHP and ANP approach is presented in the following table.

Table 11: AHP and ANP solution comparison

	ANP Solution	AHP Solution
Project($P_{1,1)}$	0,315	0,306
Project($P_{1,2)}$	0,144	0,149
Project($P_{1,3)}$	0,355	0,349
Project($P_{1,4)}$	0,187	0,196

It can be seen that the existence of interdependencies further strengthens the position of Project 3 and Project 1. This, apart from the fact that these projects present higher weights values on the criteria "SE" and "CA" in the relative rankings, is also due to the further impact of the last two criteria in the "ENPV" which is considered as input in the specific example configuration. It should be noted, however, that this example has, on the one hand, minimal interrelationships between the criteria and, on the other hand, independent alternatives. This is why the results between the two methods do not show significant variations.

4.2 Impact of interdependencies

As mentioned above, the criteria "SE" and "CA" are related to "ENPV". In order to subsequently determine how much the project priorities change as the interaction between the criteria changes, a sensitivity analysis has been carried out.

Once again the sets of weight were obtained from decision maker by Saaty's nine scales as follows:

Table 12: Sets of weights obtained from decision maker by Saaty's nine scales

1	2	3	4	5	6	7	8	9
0,450	0,438	0,417	0,375	0,250	0,125	0,083	0,063	0,050
0,050	0,063	0,083	0,125	0,250	0,375	0,417	0,438	0,450

If the relative "degrees of interaction" values are changed based on these sets in the above-mentioned "Interdependence weight matrix of costs factors-criteria", then the following chart of weights priorities for each project will emerge.

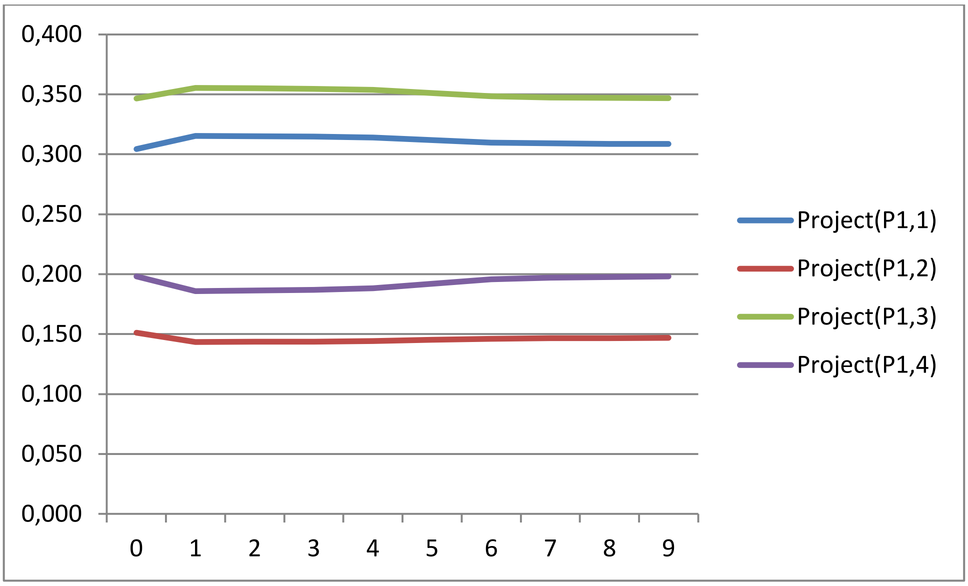

Figure 7: Diagram of project weights variation for different values of interaction between criteria

In the specific case, it was found that only the weights of the alternatives were changed without the further change of their ranking.

4.3 Project Interependencies

In order to demonstrate the possible effect of cross-correlations between projects in the final classification, a base case scenario change is required. In particular, it is assumed that projects $P_{1,2}$ and $P_{1,4}$ are interconnected with respect to the criterion "SE" according to the following table. The data were obtained from the decision maker by Saaty's nine-point scale, which means the degree of interdependence among the alternatives with respect to criteria "SE". The data is repeated in the last rows to normalize and give a sum of one.

Table 13: Project satisfaction interdependence weight matrix for criteria "SE"

w_{47}	Project($P_{1,1}$)	Project($P_{1,2}$)	Project($P_{1,3}$)	Project($P_{1,4}$)
Project($P_{1,1}$)	1	0	0	0
Project($P_{1,2}$)	0	1	0	5
Project($P_{1,3}$)	0	0	1	0
Project($P_{1,4}$)	0	1/5	0	1

1,000	0,000	0,000	0,000
0,000	0,833	0,000	0,833
0,000	0,000	1,000	0,000
0,000	0,167	0,000	0,167

The new priorities of the Projects W_p with respect to each of the four criteria and the overall priorities for the candidate projects are given as follows:

Table 14: Project interdependence weight matrix for each criteria

	$W_{p1} = W_{41} * W_{21}$	$W_{p2} = W_{42} * W_{22}$	$W_{p3} = W_{43} * W_{23}$	$W_{p4} = W_{44} * W_{24}$	$W_{p5} = W_{45} * W_{25}$	$W_{p6} = W_{46} * W_{26}$	$W_{p7} = W_{47} * W_{27}$	$W_{p8} = W_{48} * W_{28}$
Project($P_{1,1}$)	0,168	0,554	0,221	0,501	0,060	0,360	0,409	0,158
Project($P_{1,2}$)	0,218	0,087	0,064	0,264	0,330	0,143	0,172	0,215
Project($P_{1,3}$)	0,287	0,314	0,652	0,106	0,090	0,407	0,384	0,068
Project($P_{1,4}$)	0,327	0,045	0,064	0,129	0,520	0,090	0,034	0,559

Table 15: Overall priorities for the candidate projects

		ranking position		
	w_p*w_c	new	previous	w_p*w_c
Project($P_{1,1}$)	0,315	2	2	0,315
Project($P_{1,2}$)	0,167	3	4	0,144
Project($P_{1,3}$)	0,355	1	1	0,355
Project($P_{1,4}$)	0,164	4	3	0,187

According to this classification, apart from the numerical variations, there is also a reversal of the classification for projects $P_{1,2}$ and $P_{1,4}$. This is due to the gravity of the SE criterion combined with the significant interaction of the two projects.

5. CONCLUSION

This study contributes to the prior literature by providing a new methodology for ICT project portfolio selection. A number of papers have suggested different methodologies to evaluate portfolios of projects with interdependencies, while others have taken project uncertainty into consideration. However, there is a lack of portfolio selection methods that concurrently incorporates project uncertainty and interdependencies. Hence, a key contribution of this work is the construction of a methodology for selecting portfolios of projects that responds to uncertainty conditions and deals with project interdependencies in terms of resource, outcome and success probability.

For developing the new decision model, a framework approach called ROAHP was used as the basis. The use of real options theory is considered to overcome the relative uncertainty of ICT projects and therefore extends to this study. In addition, in order to integrate the intangible characteristics of these investments and the interdependencies between the plans and the evaluation criteria, which are a key feature of ICT investment, the ANP method is proposed. The ANP is a multi-criteria approach for decision-making, able to deal with all kinds of interactions among elements, and has the competence to transform qualitative judgments into quantitative values. The new model that came up, called ROANP, can easily handle multi-stage ICT projects, managerial flexibility options, and project interdependencies. It is the first time that an ICT project selection model takes account of intratemporal and intertemporal interdependencies combined with risk at the portfolio level.

The example case of ROAHP model with the necessary configurations was used to highlight the effect of the interrelations on the project prioritization through the results of the new proposed method. Firstly, based on the performed analysis, it is actually shown that the problem has inner dependences among the elements, which requires the ANP network form to model the selection process. By comparing the results of the proposed method with those of the previous model as outlined above, there is a similarity in projects priorities although there are variations in numerical weights results. This is due to the specificity of this example; on the one hand there are minimal interrelationships between the criteria and on the other hand the independence of the alternative projects between them. In addition, with regard to the effect of the interrelationship between the criteria of the example, the sensitivity analysis carried out showed changes in the weights of the alternatives without alteration of the alternatives ranking. However, it is worth noting, that although in the example of the study the alternative projects are considered independent, an assumed interrelationship resulted in changing their final ranking.

This study has shown that recognizing and exploiting interdependencies a step ahead of development, namely during selection would be beneficial to the organization. In addition, the cost of difficulty in data gathering for modeling is not so critical as the risk in selecting the wrong project without considering the interdependencies. The power of the new model is much more striking when applied to a real portfolio selection scenario with inner and outer dependences and feedback between the elements.

Additions to the proposed methodology may involve the compilation of a list of experts to provide judgements for the decision making process and the design of a questionnaire to collect input data through pairwise comparison. Moreover, the model's content of evaluation criteria may be enriched. The latter may result in a quite large number of evaluation criteria, thus requiring dedicated software tools, such as SuperDecisions [8], for obtaining a solution.

Finally, this work can be developed further by extending the proposed algorithm into a mathematical programming model etc. combined to zero-one goal programming for portfolio optimization subject to budget constraints. Hence, the problem can be solved as a dynamic programming model, where the optimal prioritization represents the solution that maximizes value across all potential combinations of projects.

TABLE OF TERMINOLOGY

Ξενόγλωσσος όρος	**Ελληνικός Όρος**
Analytic Network Process	Διαδικασία Δικτυακής Ανάλυσης
Goal Programming Method	Μέθοδος Προγραμματισμού Στόχων
Information Communication Technology	Τεχνολογία Πληροφορικής & Επικοινωνιών
Multi-Criteria Decision Making	Πολυκριτηριακή Ανάλυση Λήψης Αποφάσεων
Real Options	Δικαιώματα Προαίρεσης
Real Options Theory	Θεωρία των Δικαιωμάτων Προαίρεσης

ABBREVIATIONS - ACRONYMS

AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
BSC	Balanced Scorecard
CI	Consistency Index
CR	Consistency Ratio
DEA	Data Envelopment Analysis
ENPV	Expanded NPV
ICT	Information Communication Technology
IS	Information System
MCDM	Multi Criteria Decision Making
NPV	Net Present Value
NSFC	National Natural Science Foundation of China
RI	Random Consistency Index
ROAHP	Real Options Analytic Hierarchy Process
ROs	Real Options
R&D	Research and Development
ΕΚΠΑ	Εθνικό και Καποδιστριακό Πανεπιστήμιο Αθηνών
ΤΠΕ	Τεχνολογία Πληροφορικής & Επικοινωνιών

ANNEX I

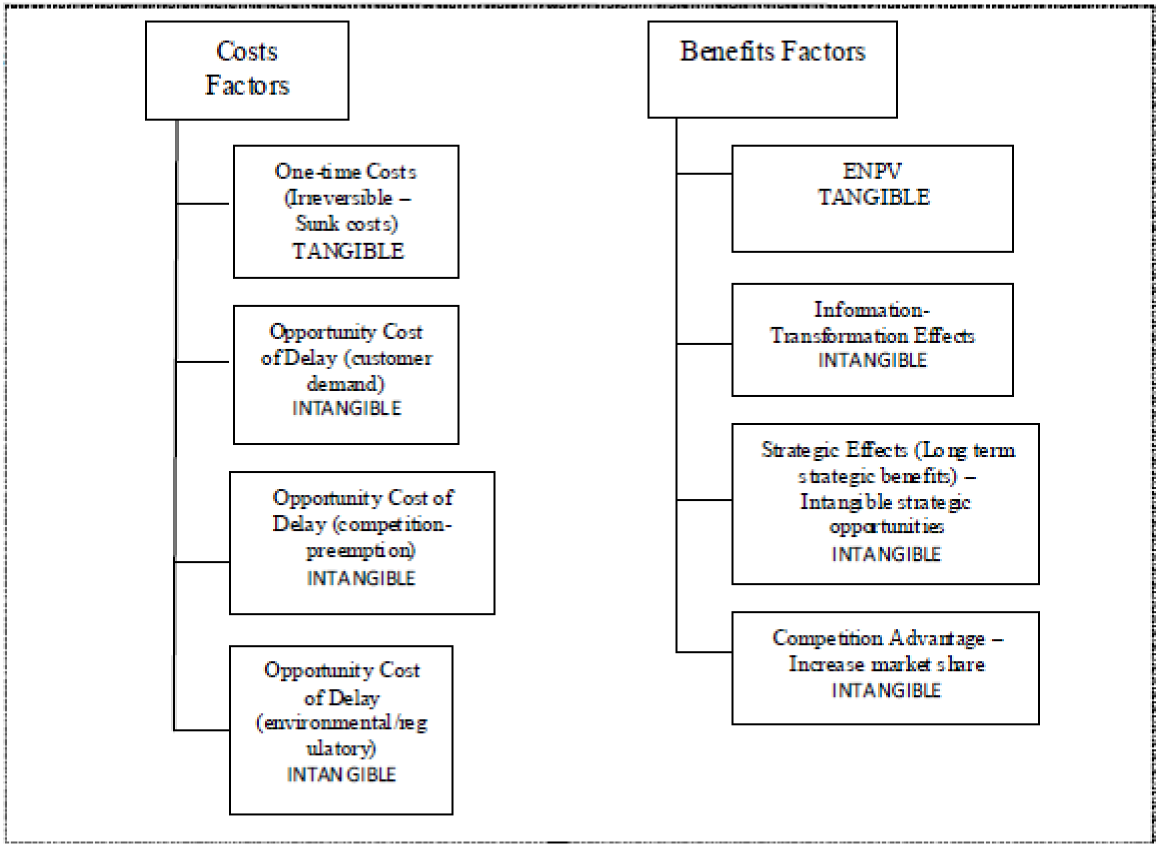

Figure 8: Network diagram representation for a three-component decision problem.

Table 16: Pair wise matrices and weights for cost factor "One time cost C"

	Project($P_{1,1}$)	Project($P_{1,2}$)	Project($P_{1,3}$)	Project($P_{1,4}$)	
Project($P_{1,1}$)	1,00	0,77	0,59	0,52	
Project($P_{1,2}$)	1,29	1,00	0,76	0,67	
Project($P_{1,3}$)	1,71	1,32	1,00	0,88	
Project($P_{1,4}$)	1,94	1,50	1,14	1,00	
Sum	5,94	4,59	3,48	3,06	
STANDARDIZED MATRIX					
					Weight
	0,17	0,17	0,17	0,17	16,8%
	0,22	0,22	0,22	0,22	21,8%
	0,29	0,29	0,29	0,29	28,7%
	0,33	0,33	0,33	0,33	32,7%

Table 17: Pair wise matrices and weights for cost factor "OCCD (Option Cost due to high Customer Demand)"

	Project($P_{1,1}$)	Project($P_{1,2}$)	Project($P_{1,3}$)	Project($P_{1,4}$)	
Project($P_{1,1}$)	1,00	7,00	3,00	8,00	
Project($P_{1,2}$)	0,14	1,00	0,17	3,00	
Project($P_{1,3}$)	0,33	5,88	1,00	8,00	
Project($P_{1,4}$)	0,13	0,33	0,13	1,00	
Sum	1,60	14,22	4,30	20,00	
STANDARDIZED MATRIX					
					Weight
	0,62	0,49	0,70	0,40	55,4%
	0,09	0,07	0,04	0,15	8,7%
	0,21	0,41	0,23	0,40	31,4%
	0,08	0,02	0,03	0,05	4,5%

Table 18: Pair wise matrices and weights for cost factor "OCCT (Option Cost due to Competition Threat-Preemption)"

	Project($P_{1,1}$)	Project($P_{1,2}$)	Project($P_{1,3}$)	Project($P_{1,4}$)	
Project($P_{1,1}$)	1,00	4,00	0,25	4,00	
Project($P_{1,2}$)	0,25	1,00	0,11	1,00	
Project($P_{1,3}$)	4,00	9,00	1,00	9,00	
Project($P_{1,4}$)	0,25	1,00	0,11	1,00	
Sum	5,50	15,00	1,47	15,00	
STANDARDIZED MATRIX					
					Weight
	0,18	0,27	0,17	0,27	22,1%
	0,05	0,07	0,08	0,07	6,4%
	0,73	0,60	0,68	0,60	65,2%
	0,05	0,07	0,08	0,07	6,4%

Table 19: Pair wise matrices and weights for cost factor "OCEC (Option Cost due to Environmental Changes)"

	Project($P_{1,1}$)	Project($P_{1,2}$)	Project($P_{1,3}$)	Project($P_{1,4}$)	
Project($P_{1,1}$)	1,00	2,00	4,00	5,00	
Project($P_{1,2}$)	0,50	1,00	2,00	3,00	
Project($P_{1,3}$)	0,25	0,50	1,00	0,50	
Project($P_{1,4}$)	0,20	0,33	2,00	1,00	
Sum	1,95	3,83	9,00	9,50	
STANDARDIZED MATRIX					
					Weight
	0,51	0,52	0,44	0,53	50,1%
	0,26	0,26	0,22	0,32	26,4%
	0,13	0,13	0,11	0,05	10,6%
	0,10	0,09	0,22	0,11	12,9%

Table 20: Pair wise matrices and weights for benefit factor "ENPV"

	Project($P_{1,1}$)	Project($P_{1,2}$)	Project($P_{1,3}$)	Project($P_{1,4}$)	
Project($P_{1,1}$)	1,00	0,18	0,67	0,12	
Project($P_{1,2}$)	5,50	1,00	3,67	0,63	
Project($P_{1,3}$)	1,50	0,27	1,00	0,17	
Project($P_{1,4}$)	8,67	1,58	5,78	1,00	
Sum	16,67	3,03	11,11	1,92	
STANDARDIZED MATRIX					
					Weight
	0,06	0,06	0,06	0,06	6,0%
	0,33	0,33	0,33	0,33	33,0%
	0,09	0,09	0,09	0,09	9,0%
	0,52	0,52	0,52	0,52	52,0%

Table 21: Pair wise matrices and weights for benefit factor "ITE (Information & Transformation Effects)"

	Project($P_{1,1}$)	Project($P_{1,2}$)	Project($P_{1,3}$)	Project($P_{1,4}$)	
Project($P_{1,1}$)	1,00	3,00	1,00	3,00	
Project($P_{1,2}$)	0,33	1,00	0,33	2,00	
Project($P_{1,3}$)	1,00	3,03	1,00	5,00	
Project($P_{1,4}$)	0,33	0,50	0,20	1,00	
Sum	2,67	7,53	2,53	11,00	
STANDARDIZED MATRIX					
					Weight
	0,38	0,40	0,40	0,27	36,0%
	0,13	0,13	0,13	0,18	14,3%
	0,38	0,40	0,40	0,45	40,7%
	0,13	0,07	0,08	0,09	9,0%

Table 22: Pair wise matrices and weights for benefit factor "SE (Strategic Effects)"

	Project($P_{1,1}$)	Project($P_{1,2}$)	Project($P_{1,3}$)	Project($P_{1,4}$)	
Project($P_{1,1}$)	1,00	4,00	1,00	5,00	
Project($P_{1,2}$)	0,25	1,00	0,33	0,50	
Project($P_{1,3}$)	1,00	3,00	1,00	5,00	
Project($P_{1,4}$)	0,20	2,00	0,20	1,00	
Sum	2,45	10,00	2,53	11,50	
STANDARDIZED MATRIX					
					Weight
	0,41	0,40	0,39	0,43	40,9%
	0,10	0,10	0,13	0,04	9,4%
	0,41	0,30	0,39	0,43	38,4%
	0,08	0,20	0,08	0,09	11,2%

Table 23: Pair wise matrices and weights for benefit factor "CA (Competitive Advantage)"

	Project($P_{1,1}$)	Project($P_{1,2}$)	Project($P_{1,3}$)	Project($P_{1,4}$)	
Project($P_{1,1}$)	1,00	0,50	4,00	0,20	
Project($P_{1,2}$)	2,00	1,00	3,00	0,33	
Project($P_{1,3}$)	0,25	0,33	1,00	0,17	
Project($P_{1,4}$)	5,00	3,00	5,88	1,00	
Sum	8,25	4,83	13,88	1,70	
STANDARDIZED MATRIX					
					Weight
	0,12	0,10	0,29	0,12	15,8%
	0,24	0,21	0,22	0,20	21,5%
	0,03	0,07	0,07	0,10	6,8%
	0,61	0,62	0,42	0,59	55,9%

Table 24: Criteria pair-wise matrice and weights for tangible and intangible cost factors

	One time cost C	OCCD	OCCT	OCEC	
One time cost C	1,00	3,00	0,33	0,33	
OCCD	0,33	1,00	0,20	0,33	
OCCT	3,00	5,00	1,00	3,00	
OCEC	3,00	3,00	0,33	1,00	
Sum	7,33	12,00	1,87	4,67	
STANDARDIZED MATRIX					
					Weight
	0,14	0,25	0,18	0,07	15,9%
	0,05	0,08	0,11	0,07	7,7%
	0,41	0,42	0,54	0,64	50,1%
	0,41	0,25	0,18	0,21	26,3%

Table 25: Criteria pair-wise matrice and weights for tangible and intangible benefit factors

	ENPV	ITE	SE	CA	
ENPV	1,00	3,00	0,20	0,33	
ITE	0,33	1,00	0,20	0,33	
SE	5,00	5,00	1,00	3,00	
CA	3,00	3,00	0,33	1,00	
Sum	9,33	12,00	1,73	4,67	
STANDARDIZED MATRIX					
					Weight
	0,11	0,25	0,12	0,07	13,6%
	0,04	0,08	0,12	0,07	7,6%
	0,54	0,42	0,58	0,64	54,3%
	0,32	0,25	0,19	0,21	24,5%

ANNEX II

Table 26: Project satisfaction interdependence weight matrix for criteria "One time cost C"

w_{41}	Project($P_{1,1}$)	Project($P_{1,2}$)	Project($P_{1,3}$)	Project($P_{1,4}$)
Project($P_{1,1}$)	1	0	0	0
Project($P_{1,2}$)	0	1	0	0
Project($P_{1,3}$)	0	0	1	0
Project($P_{1,4}$)	0	0	0	1

1	0	0	0
0	1	0	0
0	0	1	0
0	0	0	1

Table 27: Project satisfaction interdependence weight matrix for criteria "OCCD"

w_{42}	Project($P_{1,1}$)	Project($P_{1,2}$)	Project($P_{1,3}$)	Project($P_{1,4}$)
Project($P_{1,1}$)	1	0	0	0
Project($P_{1,2}$)	0	1	0	0
Project($P_{1,3}$)	0	0	1	0
Project($P_{1,4}$)	0	0	0	1

1	0	0	0
0	1	0	0
0	0	1	0
0	0	0	1

Table 28: Project satisfaction interdependence weight matrix for criteria "OCCT"

w_{43}	Project($P_{1,1}$)	Project($P_{1,2}$)	Project($P_{1,3}$)	Project($P_{1,4}$)
Project($P_{1,1}$)	1	0	0	0
Project($P_{1,2}$)	0	1	0	0
Project($P_{1,3}$)	0	0	1	0
Project($P_{1,4}$)	0	0	0	1

1	0	0	0
0	1	0	0
0	0	1	0
0	0	0	1

Table 29: Project satisfaction interdependence weight matrix for criteria "OCEC"

W_{44}	Project($P_{1,1}$)	Project($P_{1,2}$)	Project($P_{1,3}$)	Project($P_{1,4}$)
Project($P_{1,1}$)	1	0	0	0
Project($P_{1,2}$)	0	1	0	0
Project($P_{1,3}$)	0	0	1	0
Project($P_{1,4}$)	0	0	0	1

1	0	0	0
0	1	0	0
0	0	1	0
0	0	0	1

Table 30: Project satisfaction interdependence weight matrix for criteria "ENPV"

W_{45}	Project($P_{1,1}$)	Project($P_{1,2}$)	Project($P_{1,3}$)	Project($P_{1,4}$)
Project($P_{1,1}$)	1	0	0	0
Project($P_{1,2}$)	0	1	0	0
Project($P_{1,3}$)	0	0	1	0
Project($P_{1,4}$)	0	0	0	1

1	0	0	0
0	1	0	0
0	0	1	0
0	0	0	1

Table 31: Project satisfaction interdependence weight matrix for criteria "ITE"

W_{46}	Project($P_{1,1}$)	Project($P_{1,2}$)	Project($P_{1,3}$)	Project($P_{1,4}$)
Project($P_{1,1}$)	1	0	0	0
Project($P_{1,2}$)	0	1	0	0
Project($P_{1,3}$)	0	0	1	0
Project($P_{1,4}$)	0	0	0	1

1	0	0	0
0	1	0	0
0	0	1	0
0	0	0	1

Table 32: Project satisfaction interdependence weight matrix for criteria "SE"

w_{47}	Project($P_{1,1}$)	Project($P_{1,2}$)	Project($P_{1,3}$)	Project($P_{1,4}$)
Project($P_{1,1}$)	1	0	0	0
Project($P_{1,2}$)	0	1	0	0
Project($P_{1,3}$)	0	0	1	0
Project($P_{1,4}$)	0	0	0	1

1	0	0	0
0	1	0	0
0	0	1	0
0	0	0	1

Table 33: Project satisfaction interdependence weight matrix for criteria "CA"

w_{48}	Project($P_{1,1}$)	Project($P_{1,2}$)	Project($P_{1,3}$)	Project($P_{1,4}$)
Project($P_{1,1}$)	1	0	0	0
Project($P_{1,2}$)	0	1	0	0
Project($P_{1,3}$)	0	0	1	0
Project($P_{1,4}$)	0	0	0	1

1	0	0	0
0	1	0	0
0	0	1	0
0	0	0	1

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