Integrating Real Options with AHP and GP for prioritizing ICT infrastructure projects

Dr. Georgios N. Angelou
Thessaloniki, Greece
gangelou@eyath.gr

Dr. Anastasios A. Economides
Professor of Information Systems Dept.
University of Macedonia
Thessaloniki, Greece
economid@uom.gr

Abstract—**In this paper we combine Real Options (ROs), Analytic Hierarchy Process (AHP) and zero-one Goal Programming (ZOGP) in an integrated decision analysis framework for valuing and prioritizing a portfolio of ICT infrastructure investments. It is the first time that ROs are integrated with AHP and ZOGP providing a single multi-objective multi-criteria model, called GROAHP. Finally, a case illustration is provided showing how the GROAHP can be formulated and solved.**

Keywords-component; Real Options, AHP, Zero-one Goal Programming, Information Communication Technology, Portfolio Prioritization

I. Introduction

The valuation of Information Communication Technologies (ICT) investments is a challenging task. It is characterized by rapidly changing business and technology conditions but mainly by intangible benefits, costs and risk factors, which cannot be quantified in monetary terms. In addition to intangible attributes there are also other attributes that are difficult to quantify as well. Traditional finance theory suggests that firms should use a Discounted Cash Flow (DCF) methodology to analyze capital allocation requests. However, this approach does not properly account for the flexibility inherent in most ICT investment decisions. For example, an ICT infrastructure project may have a negative Net Present Value (NPV) 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 [14].

Research on ROs for justifying ICT investments has mainly focused on valuation decisions for a single project. For instance, [13] uses an options model to quantify the benefits of switching from SAP R/2 to SAP R/3. Similarly, [10] develops options that consider the effect of uncertainty in costs and benefits associated with ICT investment opportunities, using data on the deployment of point-of-sale debit services as reported in [3]. Reference [5] examines ROs applicability in an actual broadband investment case study.

However, ROs models are strictly quantitative, while ICT investments experience tangible and intangible factors and the latter can be mainly treated by qualitative analysis. In this work we integrate ROs, Analytic Hierarchy Process (AHP) and zero-one Goal Programming (ZOGP) for prioritizing ICT infrastructure projects. The integration of the three methodologies into a common decision analysis framework yields the proposed model, which we call it, GROAHP. We extent the work of [1] where ROs and AHP are integrated in one decision analysis model called ROAHP providing a multicriteria analysis for prioritizing portfolio of ICT projects. It is the first time that ROs are integrated with AHP and Goal Programming (GP) providing a single multi-objective multi criteria model. GROAHP provides a better understanding of projects' financial tangible and intangible factors and various goals and constraints enabling these projects to be valued and prioritized with higher accuracy.

Problem definition

We consider a portfolio of M ICT projects. They are grouped into $i=1,\ldots,n$ phases (Figure 1). Let at phase 1 there are K infrastructure projects $P_{1,k}$, $k=1, 2, \ldots, K$. Infrastructure projects do not have any prerequisites and may serve as building blocks for future investment opportunities $P_{i,m}$, $(i=2,3\ldots,n,\ m=1, 2, \ldots, M\text{-}K)$. Alternatively, each of them provides a platform for launching other applications by enabling follow-on projects in future periods. We treat the launching of these applications as ROs. Typical infrastructure projects include telecommunication networks, ICT platforms, management of shared customer databases and ICT expertise development. Our aim is to prioritize the phase 1 infrastructure projects.

The first challenge is to include intangible factors related to the ROs analysis and combine them with the tangible factors given by the typical ROs models.

The second challenge is to enhance the proposed methodology and model, by taking into account various business goals and constraints such as specific budget constraint that a portfolio's project can experience.

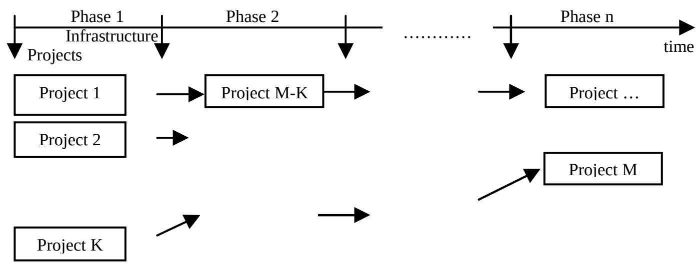

Figure 1. ICT portfolio's projects deployed in n phases

The paper is organized as follows. In Section 2, we integrate the ROs and AHP and focus on the investments factors applied to the ICT business field. In Section 3, we further introduce GP and provide a new model called GROAHP. In Section 4, we apply the proposed model in a real life case study. Finally, in Section 5, we conclude and suggest possible future research.

II. An AHP structure for ROs analysis

AHP is a multi-criteria decision analysis technique. It aims at choosing from a number of alternatives based on how well these alternatives rate against a chosen set of qualitative as well as quantitative criteria [9]. The main advantage of the AHP approach is that different criteria with different measures can be easily transformed into a single utility measure. The adopted criteria are divided into costs and benefits.

Costs-Benefits level 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. We consider the following costs and benefits factors:

Costs Factors Analysis

- One time cost (Tangible).

It corresponds to the sunk, irreversible cost to exercise option and implement project.

- Opportunity cost that is the cost of delay to invest coming from revenues losses due to high customers demand (Intangible).
- Opportunity cost that is the cost of delay to invest coming from competition threat (Intangible).
- Opportunity cost of delay to invest due to environmental or regulatory changes (Intangible).

Naturally, by waiting the firm will lose some revenues. L*earning-by-waiting* helps to resolve market, competition, and organizational risks. However, competitors may preempt the RO owner. In addition, the customers' demand may be high enough to overcome uncertainty "clearness". If customers demand is significantly high during waiting period indicating high level of revenue losses, it may be better of proceeding in the implementation of the investment instead of deferring to invest. More importantly, waiting too long could lead to market share gains by competitors who had no prior presence in the market. Competition opportunity cost is taken into account very seriously in the ICT industry especially after early 90's where competition in ICT industry has increased dramatically. The same applies for regulatory or other environmental issues, which may also eliminate investment opportunity during waiting period.

Benefits Factors Analysis

- ENPV (Tangible).

It contains the option(s) contribution of future investment opportunities. Without loss of perspective we put this factor in benefits though it integrates both tangible benefits (revenues) and costs.

- Information Effects-Transformation Effects (Intangible).

These benefits apply especially in cases where project is focusing more on internal use and exploitation, having the goal to reengineer the firm.

- Strategic-Long Term benefits (investment opportunities modeled as growth options) (Intangible).

They are created by the initial project and its predefined options cannot be clearly quantified.

- Competition Effects-Increase Market Share (Intangible).

The firm can gain competitive advantage by the project implementation, which can be translated to increase the market share.

Information Effects emerge primarily from ICT technology's capacity to collect, store, process and disseminate information. Following these effects, business value comes from improved decision quality, employee empowerment and enhanced organizational effectiveness. Transformation Effects refer to the value of ICT technology's ability to facilitate and support process innovation and transformation such as business process reengineering. The business value related to these effects concern reduced cycle times, improved responsiveness and product enhancement as a result of these reengineered processes [7].

Strategic-Long Term benefits (investment opportunities) that are born by the initial projects and their predefined options, usually, cannot be initially quantified. In particular, beyond the operational benefits that company is going to have from phase 1 projects, there are certain long-term strategic goals that can be achieved (e.g. the entrance of more value added advanced telecommunication services). In ROs literature, investment opportunities, known in advance, based on initial infrastructure projects are treated as growth options, while for the estimation of their values compound option models are utilized [14]. However, growth investment opportunities in reality can be hardly defined during decision phase. For this reason, we model qualitatively the existence of growth investment opportunities, which are based on projects in previous phases and cannot be defined quantitatively in advance.

As seen, in our case we use 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. In order to achieve homogeneity between various types of objectives, as we will show next, we have to normalize the quantitative values into the range of [0,1]. For the AHP we use the commercial software system called Expert Choice [4].

Integration of ROs and AHP

The structure of the decision analysis framework contains three levels: 1) Portfolio level, 2) Options level, and 3) Costs-Benefits level (Figure 2 in Appendix). In the first level, the portfolio's *M* distinct projects are recognized. Our target is to prioritize the initial *K* infrastructure projects on which the rest *M-K* projects are based. In the second level, we consider that the initial infrastructure projects posses a number of future investment opportunities, (i.e. *M-K*), which can be treated as ROs. We assume various types of ROs, such as option to defer the project, option to expand scale of the existing infrastructure project, option to implement investment in stages in order to mitigate risks and option to growth concerning future investment opportunities. Although, in our analysis, we are mainly focusing on the option to growth and option to defer, other option types may be easily incorporated in our model. Finally, in the third level, we have the AHP structure of the adopted factors. The overall utility factor of AHP structure is divided into costs and benefits factors. These factors may by further decomposed into their applicable sub-criteria, which are closely related to the ROs and the investment issues coming from this analysis. We apply the pair-wise comparisons for the intangible factors. For the ENPV estimation of the initial *K* infrastructure projects we use a nested binomial option-pricing model provided by [14]. The final result of the analysis, at the top, is the prioritization of the ICT projects according to the overall utility factor. The number and types (tangible and intangible) of the factors can be further increased in a future work in order to consider more practical business issues. Unfortunately, the prioritization of the ICT projects using the ROs and AHP methodologies does not take into consideration some other issues of the problem. Particularly, sufficient resources may not exist to support the investment's deployment strategy. Also, applying the combination of ROs and AHP for prioritizing the ICT projects can result to a non-optimum ranking, since possible limiting or constraining resources as well as keeping desire goal levels are not directly considered in the evaluation process so far.

In the following, we enhance the proposed ROs and AHP integration by adopting a mathematical programming approach for portfolio optimization subject to projects' goals and constraints. We present a new model called GROAHP, for finding the optimum deployment strategy. GROAHP is the result of the integration of the ROs, AHP and zero-one GP (ZOGP) into a single multiple objective, multi-criteria model.

III. GROAHP DECISION ANALYSIS FRAMEWORK

Goal Programming (GP) is a technique for handling multiple-objective situations using linear programming. Each objective is viewed as a goal. Then, given the usual resource limitations or other constraints, the decision maker attempts to develop decisions that provide the "best" solution in terms of coming as close as possible to reaching all goals. When the decision variables take only the integer values, 0 and 1, then the procedure is called zero-one GP (ZOGP). Reference [11] provides a comprehensive presentation of GP. GP has been used to model problems in all the functional areas of business such as economics, management and marketing [11].

We use the ZOGP methodology to set specific constraints and goals targets values. We combine ROs with AHP in order to structure the evaluation process providing pair wise comparison mechanisms to quantify subjective, non-monetary, intangible costs and benefits factors and combine them with the monetary, tangible ones. ROs and AHP combination derives the hierarchy and provides data for the GROAHP model. The relevant scores of these factors are formulated in a ZOGP model to generate the final ranking of the ICT projects. The ZOGP does not require translation of multiple and conflicting goals into one-dimensional (i.e. non-preemptive) objective criterion [12].

The GROAHP allows the decision makers to establish priority levels for the criteria, and to assign weights to the intangible criteria using the AHP. In addition, for each criterion we consider an aspiration level or a goal-target associated with the desirable or acceptable level of achievement of an objective.

Formulating the GROAHP model

The purpose of the decision model is to identify the most appropriate initial infrastructure project of phase 1. We define the following decision variables:

$X_k = 1$, *if project* P_{1k} *is accepted for implementation*

$X_k=0$, *otherwise.*

We also define the variables that measure the deviation from the goal target values in a similar way as in [12].

D^+_f : the positive slack deviation from goal f (indicates the amount of over achievement).

D^-_f : the negative slack deviation from goal f (indicates the amount of underachievement).

Benefits Factors

n_b: the number of the components of the tangible and intangible benefits included in the model.

B_{fk}: the amount of the tangible or intangible benefit f in choosing project $P_{1,k}$,

($k = 1,2,\ldots,K$; $f = 1,2,\ldots,n_b$).

TBf: the target (goal) level (aspiration level) for the tangible or intangible benefit factor f, given by the decision maker.

<u>Costs Factors</u>

n_c: the number of the components of the tangible and intangible costs included in the model.

Cfk: the amount of the tangible or intangible cost f in choosing project $P_{1,k}$,

($k = 1,2,\ldots,K$; $f = 1,2,\ldots,n_c$).

TCf : the target (goal) level (aspiration level) for the tangible or intangible cost factor f, given by the decision maker.

The purpose of the proposed model is to choose the most appropriate infrastructure project taking into account the goal levels reflected in the right hand of the following equations (1) to (4). The objective function of this ZOGP problem seeks to minimize the sum of the undesired absolute deviations from the stated goals. We model the objective function according to the decision maker's preference.

We have three options in defining the objective function: (1) to put both deviation variables in the objective function, (2) to put only positive deviation variable in the objective function, or (3) to put only the negative deviation variable in the objective function. If the goal should be ensured exactly then both deviation variables should be included. While if the goal is the minimum or maximum accepted threshold then the negative and positive deviations should be included respectively [11].

The GROAHP is the following:

$$Min\left[\sum_{f=1}^{n_b} WTB_f^+ \times DTB_f^+ + WTB_f^- \times DTB_f^-, \sum_{f=1}^{n_c} WTC_f^+ \times DTC_f^+ + WTC_f^- \times DTC_f^-,\right] \quad (1)$$

subject to the following constraints:

- at most one infrastructure project in phase 1 should be selected

$$X_1 + X_2 + ... + X_K - D_i^+ + D_i^- = 1 \quad (2)$$

- for factors of benefits

$$\sum_{k=1}^{K} B_{fk} \times X_k - DTB_f^+ - DTB_f^- = \mathrm{TB}_f \text{ , for f } = 1,2,..., \mathrm{n_b} \quad (3)$$

- for factors of costs

$$\sum_{k=1}^{K} C_{fk} \times X_k - DTC_f^+ - DTC_f^- = \mathrm{TC}_f \text{ , for f } = 1,2,..., \mathrm{n_c} \quad (4)$$

In addition, the decision variables X_k as well as the positive and negative slack deviation variables $D_i^+, D_i^-, DTB_f^+, DTB_f^-, DTC_f^+, DTC_f^-$ of the various goals are considered to be non-negative.

The objective coefficients $WTB_f^+, WTB_f^-, WTC_f^+, WTC_f^-$ are weights indicating priorities for the goals given by the decision maker through the ROs and AHP methodology. The superscript plus indicates the positive deviation above the goal, while the superscript minus indicates the amount of deviation below the goal. Finally, the terms B_{fk}, C_{fk} are also derived by the combination of ROs and AHP.

The model's solution will give the decision variables X_k as well as the deviation variables

$D_i^+, D_i^-, DTB_f^+, DTB_f^-, DTC_f^+, DTC_f^-$, where the former will indicate which project to be selected.

The proposed GROAHP decision analysis framework follows the following steps:

1. Identify portfolio's projects as well as options presence and type for all projects.
2. Estimate the overall ENPV values for the initial infrastructure projects including the follow on investment opportunities, treated as ROs.
3. Apply the AHP methodology in order to integrate the tangible factors as estimated by typical ROs model with the intangible ones as mentioned before and estimate the overall priority of the initial infrastructure projects.
4. Formulate the GROAHP model taking into account the tangible and intangible factors as indicated by the ROs and AHP structure.

The first two steps concern the pure ROs analysis, while the last two steps concern the AHP and GP integration, in the options field.

For the estimation of the ENPV values of the infrastructure projects we adopt a typical compound and particularly a 50-step Log Transform Binomial (LTB) model [14].

IV. A CASE ILLUSTRATION

To illustrate the proposed model we apply it to an ICT portfolio investment decision for a growing Water Supply & Sewerage Company, which we refer to as WSSC to protect its identity and its projects. The company's principal business is the supply of water and sewerage services to over 1.5 million people. WSSC is interested in prioritizing four ICT infrastructure projects. 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. Table I in appendix provides a brief description of the portfolio's projects. while, figure 3 represents the portfolio's structure.

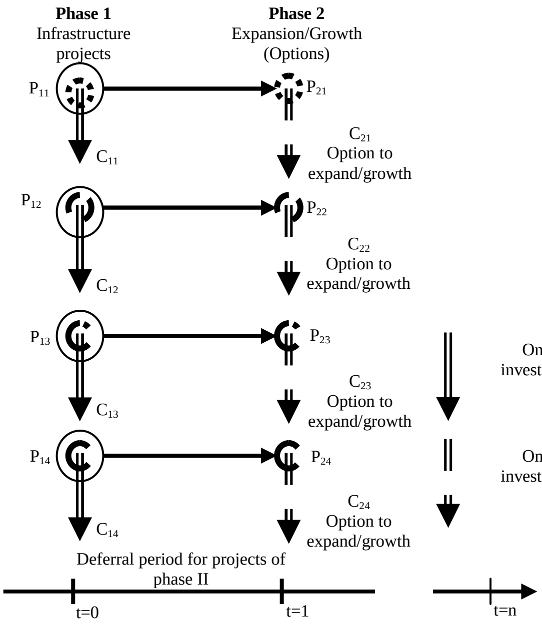

Figure 3. Eight ICT projects for WSSC

Tables II and IV in appendix present the ROs values for phase 2 projects and ENPV for phase 1 infrastructure projects respectively.

A. Application of the ROs and AHP model

We first apply the ROs and AHP model in order to compare the ranking results with these extracted by the GROAHP model. Applying the proposed ROs and AHP structure, the pair wise comparison matrices are derived and the relative performance measures are computed for both tangible and intangible factors.

Our example is for intuition purpose only and hence we implement the pair wise comparisons ourselves. In addition, [8] comments that since it is sometimes difficult to find technical people who can compare options it is necessary for the analyst to learn in detail about each option and do the scoring alone. We play here the analyst role. We take into account the consistency ratio level, as according to AHP method a consistency ratio must be less than 0.10 to be acceptable [9].

Table IV and V in appendix provide the analysis as well as the resulting weights and consistency ratios for the intangible factors of the proposed model. The tangible data for the ENPV and One-Time costs are also normalized for comparison purposes as seen in Table VI of appendix. In order to introduce them into the AHP analysis, we use their relative tangible values between each other for their pair wise comparisons. Since tangible factors are by definition measurable in quantitative units we normalize them in order to maintain parity among all tangible factors included in the evaluation. In particular, we use the notation tf_{lk} that indicates the normalized TF_{lk} in project k *for* $k=1,2,3,4$ and is given by

$$tf_{lk} = TF_{lk} / \sum_{k=1}^{4} TF_{lk} \qquad (5)$$

TF_{lk} indicates the value of tangible factor l $(l=1,\ldots L)$ in project k, (in our model L=1: ENPV).

It is used to ensure that any tangible benefit and cost factor will be compatible with others in the evaluation. The greater value a tangible factor has, a relatively larger effect is considered in the selection process for this factor.

Finally, Table VII in appendix presents the criteria pair wise matrices and their relative priorities weights.

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, we compute with the Expert Choice tool the total priorities for the alternatives. Figure 4 gives the prioritization result for the phase 1 projects.

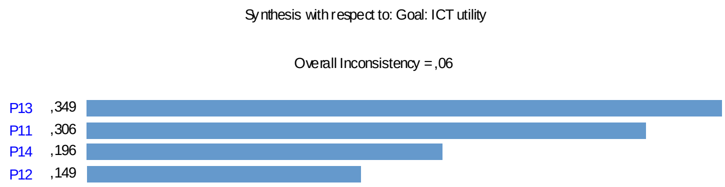

Figure 4. Projects prioritization performed with Expert Choice tool

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 (last column of Table III in appendix).

B. Application of the GROAHP model

We analyze further the case study by adopting the proposed ZOGP methodology. The purpose of the ZOGP is to choose the most appropriate ICT candidate for phase 1, which closely meets the goals defined by the management of the firm. Tables IV, V and VI in appendix present the target values (i.e. aspiration levels), which are defined by the management of the firm. For some factors the goal is the upper threshold to be met. While for some other factors the goal is the lower threshold to be exceeded. Hence, we indicate with H and L that higher and lower values are more preferable respectively.

The GROAHP model formulation, which is based on the eight decision factors using the data seen in Tables IV, V and VI is given below. The objective function includes three expressions of criteria, as we include the objective of selecting one project at the end. In particular, the first expression ensures that only one alternative ICT cluster of projects is selected. The second and third expression ensures that the tangible and intangible benefits and costs respectively are included. As mentioned before the coefficients seen in these expressions are derived from the pair wise matrixes for the factors of the AHP structure. Finally, we consider no specific priorities for each level of these three expressions of criteria.

$$Min\begin{bmatrix}\{D_1^+ + D_1^-\},\{0{,}219*D_2^- + 0{,}074*D_3^- + 0{,}549*D_4^- + 0{,}248*D_5^-\}, \\ \{0{,}151*D_6^+ + 0{,}075*D_7^+ + 0{,}508*D_8^+ + 0{,}265*D_9^+\}\end{bmatrix}$$

subject to:

$$X_1 + X_2 + X_3 + X_4 - D_1^+ + D_1^- = 1$$
$$0{,}06X_1 + 0{,}33X_2 + 0{,}09X_3 + 0{,}52X_4 - D_2^+ + D_2^- = 0{,}10 \quad \text{(ENPV)}$$
$$0{,}385X_1 + 0{,}131X_2 + 0{,}396X_3 + 0{,}088X_4 - D_3^+ + D_3^- = 0{,}40 \quad \text{(ITE)}$$
$$0{,}411X_1 + 0{,}091X_2 + 0{,}389X_3 + 0{,}109X_4 - D_4^+ + D_4^- = 0{,}30 \quad \text{(SE)}$$
$$0{,}152X_1 + 0{,}217X_2 + 0{,}065X_3 + 0{,}567X_4 - D_5^+ + D_5^- = 0{,}10 \quad \text{(SE)}$$
$$0{,}17X_1 + 0{,}22X_2 + 0{,}29X_3 + 0{,}33X_4 - D_6^+ + D_6^- = 0{,}30 \quad \text{(Cost)}$$
$$0{,}566X_1 + 0{,}080X_2 + 0{,}311X_3 + 0{,}042X_4 - D_7^+ + D_7^- = 0{,}50 \quad \text{(OCCD)}$$
$$0{,}218X_1 + 0{,}062X_2 + 0{,}657X_3 + 0{,}062X_4 - D_8^+ + D_8^- = 0{,}30 \quad \text{(OCCT)}$$
$$0{,}504X_1 + 0{,}267X_2 + 0{,}103X_3 + 0{,}126X_4 - D_9^+ + D_9^- = 0{,}50 \quad \text{(OCEC)}$$
$$X_1, X_2, X_3, X_4 = (0{,}1)$$

All the deviation variables should be non-negative.

The first constraint ensures that only one cluster of ICT project is selected. The remaining of the constraints takes into account the aspiration levels (goals) for the tangible and intangible costs and benefits factors as presented in the AHP structure.

We use the LINDO software package to solve the model, which is a well-known commercial software tool for solving linear optimization problems. We consider that all the goals have the same priorities concerning the order in which the program will try to achieve the goals fulfillment. When no priorities are considered the program considers the fulfillment of all the goals simultaneously.

Hence, taking into account the various goals and constraints levels as defined before, the results of the model show that the first priority project to be implemented is project P_{11} since $X_1=1$ and $X_2 = X_3 = X_4 = 0$.

The application of the ROs and AHP model shows that project P_{13} is considered as the first choice, while with the GROAHP model P_{11} project takes the leadership. In addition, when we consider 2 projects to be selected then projects P_{11} and P_{14} are qualified. Finally, when three projects are accepted then project P_{12} is also included in the selection list. However, as the number of projects to be accepted is increasing the deviations from the goals-targets values is increasing. Table VIII presents the ranking of phase 1 cluster of projects as extracted firstly by ROs and AHP and secondly by GROAHP methodologies and relative models. As seen, the ranking can change when specific goal and constraints levels are considered.

V. CONCLUSION

In this work we integrate ROs, AHP and GP, for the first time in the literature, providing a decision analysis framework for prioritizing a portfolio of ICT infrastructure projects. We analyze the projects on strategic, non-financial enterprise goals and incorporate these considerations with the financial, tangible goals using ROs. Finally, we provide a case illustration showing how GROAHP can be formulated and solved. We show that ranking results can change, when tangible and intangible factors are combined, compared to the pure tangible factors' analysis provided by a typical ROs model. The ranking results may change further when specific goals and constraints for investments are included in the analysis making the whole process more efficient.

The main forthcoming of the GROAHP is the assumption that infrastructure 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. In addition, growth investment opportunities are often difficult to be clearly identified and quantified in advance, as in real-world settings emerging technologies and standards change rapidly. In this work, we model qualitatively the possible existence of growth investment opportunities, which are based on projects in previous phases and cannot be defined quantitatively in advance. An extension of our work would be to take into account the qualitative interactions between current projects and follow on ones that are mainly coming in a long-term basis and cannot be modeled in advance. We take into account a relatively small number of intangible factors. In a future work more detail intangible factors can be included in the proposed model. The model can be used for finding the optimum deployment strategy for a cluster of projects. In particular, instead of considering a portfolio of ICT projects to be optimized, we can consider only one cluster or a single mega project and examine the various alternatives of its deployment strategy. As alternatives, here we are considering the various deployment scenarios for the same project. Finally, the model can be enhanced by the introduction of game theory for modeling competitive interactions between players in the ICT market.

APPENDIX

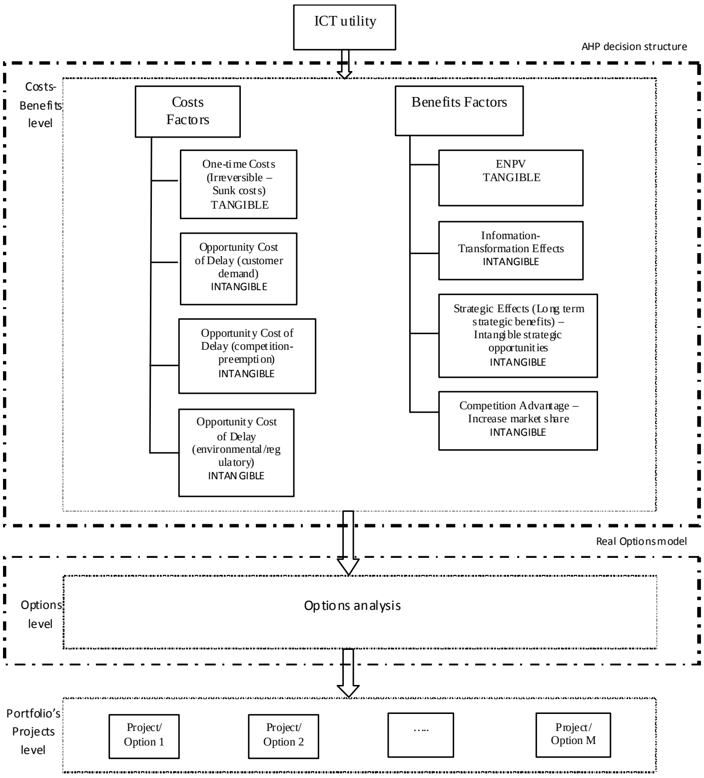

Figure 2. Portfolio optimization framework – Analytical view of the ROs-AHP structure

TABLE I. PORTFOLIO OF 8 ICT PROJECTS FOR WSSC

Project	**Description**
P_{11}	StruMap - 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. Revenues from the project are related to more efficient network analysis and decrease of operation and maintenance cost.
P_{12}	GIS Platform - a Geographical Information System (GIS) that allows users to create, view, access and analyze map (geo-referenced) data. The development of such system increases the efficiency in organization's overall operation.
P_{13}	Siebel/Asset Management – An ICT application that provides capabilities for efficient asset management and customers services support. This application will decrease the cost of assets operation and maintenance.
P_{14}	ICAT-Telemetry – Information Communication and Automation Technology Infrastructure to enable WSSC to perform more efficiently water network management. It is the main telemetry and supervising system which it will ensure the decrease of operation costs, mainly the personnel costs.
P_{21}	StruMap - Extension of StruMap on Internal (distribution network) optimization
P_{22}	Extension of GIS platform application to Equipment Management providing an information portal for factors affecting customers demand and support.
P_{23}	Extension of Siebel to information portal for customers support providing also on line question and answer service to WSSC customers.
P_{24}	Expand Operation Capability of the Existing ICAT platform

TABLE II. REAL OPTIONS ANALYSIS FOR PHASE II PORTFOLIO'S PROJECTS/OPTIONS (VALUES IN K€).

Projects volatilities (σ) as well as correlation level (ρ) between benefits and costs are given in the first column.

Investment Opportunity and risk level	One-time cost $C_{\text{expand}}^{\text{option to}}$ at t = 1 (PV at t=0)	V (revenues – operating costs) at t=0	**ENPV/OV (NPN with option value) - Only Revenues uncertainty (LTB model 50 steps)**
Project/Option 21 (P_{21}), σ_v = 30%, σ_C = 30%, ρ_{vC} = -0,5	900 (855)	1000	**197**

Project/Option 22 (P_{22}), σ_v = 20%, σ_C = 20%, ρ_{vC} = -0,5	2000 (1900)	2000	**209**
Project/Option 23 (P_{23}), σ_v = 30%, σ_C = 20%, ρ_{vC} = -0,5	1200 (1140)	1100	**114**
Project/Option 24 (P_{24}), σ_v = 40%, σ_C = 30%, ρ_{vC} = -0,5	2500 (2375)	1900	**155**

TABLE III. REAL OPTIONS ANALYSIS FOR PHASE 1 PORTFOLIO'S PROJECTS (VALUES IN K€).

Investment Opportunity	One-time cost C $_{initial}$ infrastructure cost at t = 0	V (revenues – operating costs) for phase 1 only at t=0	PNPV (no option value) for phase 1 projects	Overall PNPV with all future investment phases (for comparison purposes)	**Overall ENPV (NPN with nested option value) - Only Revenues uncertainty**
Project (P_{11})	1000	850	-150	-5	**47**
Project (P_{12})	1500	1400	-100	0	**254**
Project (P_{13})	2000	2100	100	60	**69**
Project (P_{14})	1200	950	250	-225	**405**

TABLE IV. PAIR WISE MATRICES AND WEIGHTS FOR COSTS INTANGIBLE FACTORS

OCCD (Opportunity Cost due to high Customers' Demand) – **Target: 0.5 L**

	Project (P_{11})	Project (P_{12})	Project (P_{13})	Project (P_{14})	Weight
Project (P_{11})	1	7	3	8	0.566
Project (P_{12})		1	1/6	3	0.080
Project (P_{13})			1	8	0.311
Project (P_{14})				1	0.042

Inconsistency 0,08

OCCT (Opportunity Cost due to Competition Threat-Preemption) – **Target: 0.3 L**

	Project (P_{11})	Project (P_{12})	Project (P_{13})	Project (P_{14})	Weight
Project (P_{11})	1	4	¼	4	0.218
Project (P_{12})		1	1/9	1	0.062
Project (P_{13})			1	9	0.657
Project (P_{14})				1	0.062

Inconsistency 0,02

OCEC (Opportunity Cost due to Environmental Changes) – **Target: 0.5 L**

	Project (P_{11})	Project (P_{12})	Project (P_{13})	Project (P_{14})	Weight
Project (P_{11})	1	2	4	5	0.504
Project (P_{12})		1	2	3	0.267
Project (P_{13})			1	½	0.103
Project (P_{14})				1	0.126

Inconsistency 0,05

TABLE V. PAIR WISE MATRICES AND WEIGHTS FOR BENEFITS INTANGIBLE FACTORS

ITE (Information & Transformation Effects) – **Target: 0.4 H**

	Project (P_{11})	Project (P_{12})	Project (P_{13})	Project (P_{14})	Weight
Project (P_{11})	1	3	1	3	0.385
Project (P_{12})		1	1/3	2	0.131
Project (P_{13})			1	5	0.396
Project (P_{14})				1	0.088

Inconsistency 0,03

SE (Strategic Effects) – **Target: 0.3 H**

	Project (P_{11})	Project (P_{12})	Project (P_{13})	Project (P_{14})	Weight
Project (P_{11})	1	4	1	5	0.411
Project (P_{12})		1	1/3	½	0.091
Project (P_{13})			1	5	0.389
Project (P_{14})				1	0.109

Inconsistency 0,06

CA (Competitive Advantage) – **Target: 0.1 H**

	Project (P_{11})	Project (P_{12})	Project (P_{13})	Project (P_{14})	Weight
Project (P_{11})	1	½	4	1/5	0.152
Project (P_{12})		1	3	1/3	0.217
Project (P_{13})			1	1/6	0.065
Project (P_{14})				1	0.567

Inconsistency 0,06

TABLE VI. WEIGHTS FOR COSTS AND BENEFITS TANGIBLE FACTORS – TARGET COST: 0,30 L, TARGET BENEFITS: 0,10 H

	PV Phase I+II One time cost C normalized	Overall – ENPV normalized
Project (P_{11})	0.17	0.06
Project (P_{12})	0.22	0.33
Project (P_{13})	0.29	0.09
Project (P_{14})	0.33	0.52

TABLE VII. CRITERIA PAIR-WISE MATRIXES AND WEIGHTS

Weights for tangible and intangible cost factors (inconsistency 0.07)

Investment Opportunity	One time cost C	OCCD	OCCT	OCEC	Priority
C	1	3	1/3	1/3	0.151
OCCD	1/3	1	1/5	1/3	0.075
OCCT	3	5	1	3	0.508
OCEC	3	3	1/3	1	0.265

Weights for tangible and intangible benefit factors (inconsistency 0.07)

Investment Opportunity	ENPV	ITE	SE	CA	Priority
ENPV	1	3	1/5	1/3	0.129
ITE	1/3	1	1/5	1/3	0.074
SE	5	5	1	3	0.549
CA	3	3	1/3	1	0.248

TABLE VIII. FINAL ICT PORTFOLIO'S PROJECTS RANKING

ROs-AHP	**GROAHP – when one project to be selected**	**GROAHP – when two projects to be selected**	**GROAHP – when three projects to be selected**
Project (P_{13})	Project (P_{11})	Project (P_{11})	Project (P_{11})
Project (P_{11})		Project (P_{14})	Project (P_{14})
Project (P_{14})			Project (P_{12})
Project (P_{12})			

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