A Robust Data Envelopment Analysis Method for Business and IT Alignment of Enterprise Architecture Scenarios

Mehdi Fasanghari*
Industrial Engineering, University of Tehran
fasanghari@gmail.com
Mohsen Sadegh Amalnick
Industrial Engineering, University of Tehran
amalnick@ut.ac.ir
Reza Taghipour Anvari
Malek Ashtar University of Technology
taghipour@cra.ir
Jafar Razmi
Industrial Engineering, University of Tehran
jrazmi@ut.ac.ir

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Abstract

Information Technology is recognized as a competitive enabler in today's dynamic business environment. Therefore, alliance of business and Information Technology process is critical, which is mostly emphasized in Information Technology governance frameworks. On the other hand, Enterprise Architectures are deployed to steer organizations for achieving their objectives while being responsive to changes. Thus, it is proposed to align the business and Information Technology through investigating the suitability of Enterprise Architecture scenarios. In view of this fact, investigating a flexible decision making method for business and information technology alignment analysis is necessary, but it is not sufficient since the subjective analysis is always perturbed by some degree of uncertainty. Therefore, we have developed a new robust Data Envelopment Analysis technique designed for Enterprise Architecture scenario analysis. Several numerical experiments and a sensitivity analysis are designed to show the performance, significance, and flexibility of the proposed method in a real case.

Keywords: Group Data Envelopment Analysis, Enterprise Architecture, IT Governance, COBIT, Robust Optimization.

1. Introduction

Due to the ever increasing struggle to persist in changing environment of today's market, Information Technology (IT) is recognized as one of the best enablers and strategic partner of business capturing the most capital investments in many enterprises [1]. IT governance frameworks define the mechanism of IT-related responsibilities and decision-making structure and are mostly recognized as a series of processes by which business and IT are aligned. However, effective implementation of an IT governance framework is a rather difficult and costly task, since it requires the acquirement of current status of organizations and an understanding of the desired to-be structure of the organization to find the gaps therein and set for improvements. Increasingly, mangers figure out the great contribution of such governance architectures for depicting the right overview of the organization mission, business objective, information systems, and their relationship. For this, managers in charges with their consultants may propose different IT architecture or scenarios to set the roadmap for the requested business strategies which ensures long-term success and cost-efficiency according to the available budget and resource. Enterprise Architecture (EA) is one of the most effective approaches offering these benefits in an integrated and efficient information system by presenting distinctive architectures for the four key areas of business, data, application, and infrastructure [2-4]. Therefore, planning the EA scenarios or IT master plans can show the systematic approach for transforming the enterprise IT infrastructure for achieving the business strategies and goals. Evaluating the EA scenarios is vital as an EA scenario is really expensive and time-consuming for implementation [5, 6]. IT and business alignment is the most important aspect of EA scenario analysis, which was out of consideration for many years. To this

* Corresponding Author

aim, we have used the COBIT framework for EA scenarios analysis. Data Envelopment Analysis (DEA) is a well-known decision making tool to evaluate a set of decision making units (DMUs) based on the multi input-output performance measures [7]. In some real applications of DEA, the respected performance criteria are collected based on the expert opinions. However, when several experts with different knowledge and experiences are to submit their points of view, finding the most proper DMU is not an easy task. In addition, experts' opinions data are mostly perturbed by uncertainty due to several reasons. In this paper, we intend to analyze the EA scenarios by introducing a new expert-based decision-making technique that embraces distinct preferences' weights of experts contaminated by a bounded degree of hesitancy. More specifically, we introduce a novel DEA technique by incorporating the robust optimization concept. In summary, developing a new robust DEA method for EA scenario analysis in view of the IT and business alignment is the primitive contribution in this paper. Analyzing a real case study in Iran Telecommunication Research Center (ITRC) is done to show the reliability and applicability of our proposed idea.

For this, the paper structure is as follows. First, we take a look at the works deemed to our study. Then, we lay the background of our works with introduction of the models and specific related works, namely DEA and robust optimization technique. Our models, both deterministic and its robust counterpart, is also explained in this section. After that, introducing the case study for the numerical experiments will be presented. The performance evaluation follows next, which include empirical results of the deterministic and robust version of the proposed DEA model. Finally, we conclude in the last Section.

2. Related Works

In this Section, we review some of the literature around EA analysis domain, and then take a look at IT governance frameworks, especially COBIT framework.

2.1 EA analysis review

According to [8], some of the researches focus on the complexity of EA systems. This category can be divided into three dimensions of structure, behavior statistics, and dynamic behavior. It means that some analysis such as Niemann [4] model notices on the complexity and dependency of EA components and their influence on the organization. Yu model [9] extends this structural analysis and describes the transition phase to achieve to the desired status of the organization. Now, if the experts' opinions are considered in the analysis, the behavior sub-category works such as [10] emerges. Considering the pathological effects and the behavior of the organization in the time, gives rise to the dynamic analysis of EA scenarios [11]. Time reference is another dimension of the comparison. Some analyses deal with existing established EA and some evaluate the to-be structure of the future EA in the organization. Jacob et el. [10] provides a dynamic model which is able to analyze the current and desired status of EA and detects the conditions leading to the target status. Another category considers whether the EAs under study are already implemented [9-12] or the scenarios based on that EA are being investigated [4,13]. The analysis technique used for evaluation is another important dimension in three sub categories of expert-based [4,9,13], rule-based [11] and indicator-based [4,5,10,14,15] methods. Analysis using experts' opinions are the most flexible approach [8], but time-consuming. A more formal method is the rule based approach, but it can just recognize presence or absence of a pattern in structure. Indicator based approaches can capture better properties such as convergence, and interoperability, though it is very dependent on the assumption and interpretation of the architecture under analysis.

More generally, Multi Criteria Decision Making (MCDM) techniques are tailored for finding an optimum solution among a set of alternatives which are judged on multiple attributes. Such techniques can be used in investigating various quality attributes of software architecture or project selections [13,16-20]. Among the methods of MCDM, Analytical Hierarchical Process (AHP) [21] has been used to judge and select the best architecture candidate or project [13,16,18,22]. Specifically, Razavi et el. [13] have proposed an AHP-based approach for analysis and selection of EA scenarios. Further, Data Envelopment Analysis (DEA) is recognized as a very efficient approach in the decision making domain with easy implementation. A large body of researches and applications has been proposed for DEA [7] pivoted on efficacy measurement in various domains. DEA techniques are used for assessing IT impact on firm performance [23] and using IT as a tool for selection of projects among various proposals [24]. Such analysis of DEA helps to find the source of efficacy and inefficacy and establishes the roadmap for improvement in the organization.

Group-decision making based on AHP approach has gained popularity in the decision-making domain [25,26]. However, AHP has some limitations in confronting the uncertainty. Specifically, it can just handle uncertainty of fuzzy type. Overall, EA scenarios selection problems are usually treated without considering uncertainty of experts [27].

2.2 IT Governance background

There are several IT governance standards available as governmental draft or industry standards (e.g., CMMI, COBIT, ITIL, MOF, ISPL1, ASL2, ISO, Six Sigma, DSDM3) which support the governance of IT in a way that is aligned with the business. One of the most effective frameworks proposed is the Control Objectives for IT and related Technology (COBIT) created by the Information Systems Audit and Control Association (ISACA) and the IT Governance Institute (ITGI) in 1992 [28]. This framework provides managers and auditors with a set of measures and processes which help them to maximize their benefit through the responsible use of resources, appropriate management of risk and alignment of business and IT.

Acting as an integrator of different aspects of both IT and business, COBIT presents its structure and metrics in a manageable and logical structure of four domains namely: 1) plan and organize, 2) acquire and implement, 3) deliver and support and 4) monitor and evaluate. Each of these domains is described through a set of control objectives or measures. A short description of the main domains is summarized as follows [29-33]:

- Plan and organize: This domain presents the strategy and tactics of the way IT can assist to business goals. These visions should be contributed to different people throughout the organization.
- Acquire and implement: For achieving the IT strategies and tactics, IT solutions should be acquired and implemented and finally be integrated into the business process. Further, if there are preexisting systems available, ensuring the continuity of their functionality is handled in this domain.
- Deliver and support: The required service should be delivered and all other processes regarding the management of data and security concerns in addition to supportive activities are dealt with in this domain.
- Monitor and evaluate: all IT processes should be regularly evaluated to meet their quality requirement. So internal controls and regulatory compliance are addressed in this domain.

Robust optimization models can be used as a good approach for encountering the uncertainty in decision making, especially it is useful in the following situations [34]:

- Some parameters are estimates and carry estimation risk.
- There are constraints with uncertain parameters to be satisfied regardless of their values of these parameters.
- The objective functions/optimal solutions are particularly sensitive to perturbations.
- The decision-maker cannot afford low-probability high-magnitude risks.

It is necessary for a decision-making process to reduce the sensitiveness of its results regarding to the input parameters and data. Thus, in this paper, we propose a group DEA model with uncertain data. Experts present their judgment with interval data (lower bound, nominal bound, and upper bound for expressing their opinion).

3. The proposed robust group decision making method based on DEA

In this section, we elaborate the proposed robust decision making method, which is developed based on a robust DEA model. The proposed robust DEA model has the capability to incorporate the opinions of a group of decision makers to evaluate a set of homogeneous decision making units or alternatives (here EA scenarios). The robust DEA model is inspired from the classical CCR DEA model. Therefore, we first briefly review the classical CCR DEA model. After that, the robust DEA model is introduced. To cope with uncertainty of experts' judgment, we use a technique based on the robust optimization. Hence, in the subsequent sub-section, we explain this model and then introduce our robust counterpart of the DEA model provided to handle the uncertainty existed in the input data gathered from experts' opinions.

3.1 The classical CCR DEA model

Data Envelopment Analysis is a non-parametric mathematical programming for measuring the relative efficiency and ranking of various productive units, termed decision making units (DMUs) [35]. It does not require any production or the cost function and measures the performance DMUs based on their multiple inputs and outputs. The relative efficiency measures of DMUs is obtained through determining a piecewise linear efficiency frontier along the most efficient DMU, and the least efficient DMU is recognized by comparison with its frontier curve. The original input oriented DEA model is written as follows:

$$P(I): E_{so}^{*}: \max \sum_{r=1}^{k} u_r y_{ro}^{s}$$

subject to:

$$\sum_{r=1}^{k} u_r y_{rj}^{s} - \sum_{i=1}^{m} v_i x_{ij}^{s} \leq 0$$

$$\sum_{i=1}^{m} v_i x_{io}^{s} = 1$$

$$u_r, v_i \geq 0. \qquad (1)$$

In this model, a set of n homogenous decision making unit ($j = 1,...,n$) with m inputs ($i = 1,...,m$) and k outputs ($r = 1,...,k$) is assessed where x_{ij}^{s} denotes the ith input data of the jth DMU obtained from the sth expert's opinion. Similarly, y_{rj}^{s} denotes the rth output data of the jth DMU obtained from the sth expert's opinion. Furthermore, E_{so}^{*} denotes the efficiency of oth DMU when the input and output data are obtained from the sth expert's opinion. We also call E_{so}^{*} the ideal efficiency score of oth DMU from sth expert view. Model (1) is repeatedly solved for each DMU to obtain its efficiency score.

In the aforementioned model, it is assumed that inputs and outputs are explicitly defined. However, there are many real cases that data are used without inputs (such as index data or pure output data). In this case, the original DEA model converts to a DEA model with k outputs and one dummy input of 1 for all DMUs [36]. In this situation, the original DEA model (1) cannot evaluate DMUs. Hence, to fill the gap of this area, we propose a new Group Decision Making Method which is inspired by classical DEA model (1) to evaluate DMUs based on several matrix input-output data that each of which is collected according to one expert' opinions.

3.2 Robust Optimization

The classical DEA model has no mechanism to deal with uncertainty in input or output data. Several methods such as Chance Constraint Programming (CCP) [37] and Stochastic Programming (SP) are introduced to handle such uncertainty. For some of the representative works related to these models, Sengupta [38-40] and Cooper [41-43] can be considered. In these models, uncertain data are estimated with probabilities, and an error distribution should be determined. These issues limit the real world applications of these models.

As an alternative approach for dealing with uncertainty, robust optimization versions of DEA have recently been raised which covers the decision making process when data are of the form of interval data. Robust optimization can handle the uncertainty in the form of box, ellipsoidal, and polyhedral uncertainty sets [44]. The concept was first introduced by [45] who discussed uncertainty in column vector of the constraint matrix. Subsequently, Ben-tal and Nemirovski [44,46,47] and more recently Bertsimas et el. [48,49] have proposed methods to deal with ellipsoidal and polyhedral uncertainty types. These methods are usually named as BT and BN approach and have some distinguishing differences in terms of preserving the class of the problem after applying the robust approach or the number of variables and constraints [34]. Various works have been suggested according to these techniques. For example, Sadjadi and Omrani [34] applied robust optimization approach to DEA and utilized their model to evaluate the performance of Iranian electricity distribution companies. They suppose uncertainty of ellipsoidal uncertainty to demonstrate the efficiency of robust approaches for ranking strategies of their application. Furthermore, Wang and Wei [50] proposed a non-linear programming for robust data envelopment analysis. In another work, Sadjadi [51] combined the idea of robust optimization with traditional bootstrapped DEA [52,53] to propose a general model for performance assessment and ranking of DMUs with case study of telecommunication companies. The input and output data in [51] can be changed in an interval, and the results overcomes the incurrent bias. Shokouhi [54] used the combination of super-efficiency DEA and robust BA approach for handling uncertainty in both inputs and output which is considered to be of ellipsoidal type for efficiency assessment of gas companies.

Next, we explain the robust optimization of Ben-Tal et el. [55] with the box uncertainty sets to set the background for elaborating the robust counterpart of our proposed robust DEA model. The main advantage of Ben-Tal et el. approach [55] using the box uncertainty set is that the resulted robust counterpart model becomes a linear programming model whereas applying this approach with ellipsoidal uncertainty leads to obtain a nonlinear robust counterpart model, which increases the time complexity. Therefore, we utilize box uncertainty sets to develop the robust counterpart of our proposed model. For this, consider the following linear optimization model:

$$\min cx,$$
$$\text{subject to: } Ax \geq b \quad (2)$$

where x is the vector of decision variables and A is the matrix of constraints with elements a_{ij}. In this model, c, A, b are constant. Now, if these parameters are uncertain in a specific range of U, which is called the uncertainty set, and we wish our solution yet stays in an immune range while addressing the uncertainty of those parameters, we use the robust optimization approach.

$$\min \ cx,$$
$$\text{subject to:}$$
$$Ax \geq b,$$
$$c, A, b \in U \quad (3)$$

The robust approach for addressing the box uncertainty of entry $\tilde{a} = \{\tilde{a}_{ij}\}_{i=1,...,m, j=1,...,n}$ is as follows:

$$U = \{\tilde{a}_{ij} \in R^n : |\tilde{a}_{ij} - \bar{a}_{ij}| \leq G_{ij}, i = 1,...,m, j = 1,...,n\} \quad (4)$$

Here, we take uncertainty in row i of constraint matrix. Similarly, uncertainty can be focused in the objective coefficients. In this set, $\bar{a}_{ij}$ is the mean value of $\tilde{a}_{ij}$ and G_{ij} is the uncertainty scale of a given entry. Hence, the robust counterpart model can be written as:

$$\left\{\min_{\tilde{a} \in U} \ \{\sum_{j=1}^{n} \tilde{a}_{ij} x_j\}\right\} \geq b_i \quad or$$
$$\left\{\min_{\tilde{a}_{ij} \in R^n : |\tilde{a}_{ij} - \bar{a}_{ij}| \leq G_{ij}} \ \{\sum_{j=1}^{n} \tilde{a}_{ij} x_j\}\right\} \geq b_i \quad (5)$$

According to uncertainty set U presented in (6), and since the scale uncertainty G_{ij} is a positive number, the minimum value of $\sum_{j=1}^{n} \tilde{a}_{ij} x_j$ on the box uncertainty set U is occurred for the lower bound of $\tilde{a}_{ij}$, which become $\bar{a}_{ij} - G_{ij}$.

$$U = \{\tilde{a}_{ij} \in R : \bar{a}_{ij} - G_{ij} \leq \tilde{a}_{ij} \leq \bar{a}_{ij} + G_{ij},$$
$$i = 1,...,m, j = 1,...,n\} \quad (6)$$

Therefore, inequality (5) is reformulated as follows:

$$\sum_{j=1}^{n} \bar{a}_{ij} x_j - \sum_{j=1}^{n} G_{ij} x_j \geq b_i \quad (7)$$

which is the robust counterpart of constraint $Ax \geq b$ of model (2) and thus the robust LP model is solvable.

3.3 Robust counterpart of the proposed DEA model

In our application, due to the expert based nature of data, experts cannot express an exact value for input and output data and therefore, uncertainties are inherent in experts' opinions. We, therefore, represent the robust version of our model to handle this kind of uncertainty. If we suppose that output data obtained from experts' opinions (y_{rj}^s) are defined as the box uncertainty sets, the robust counterpart of the robust DEA can be expressed as:

$$P(II): \max z$$
$$\text{subject to:}$$
$$\left\{\min_{\tilde{y}_{ro}^s \in u^B} \{\sum_{s=1}^{S} w_s \sum_{r=1}^{k} u_r \tilde{y}_{ro}^s\}\right\} \geq z,$$
$$\sum_{i=1}^{m} v_i x_{io}^s = 1, \quad \forall s$$
$$\left\{\max_{\tilde{y}_{rj}^s \in u^B} \{\sum_{r=1}^{k} u_r \tilde{y}_{rj}^s\}\right\} - \sum_{i=1}^{m} v_i x_{ij}^s \leq 0, \quad \forall j,s$$
$$\left\{\min_{\tilde{y}_{ro}^s \in u^B} \{\sum_{r=1}^{k} u_r \tilde{y}_{ro}^s\}\right\} \geq E_{so}^*, \quad \forall s$$
$$u_r, v_i \geq 0. \quad (8)$$

It is worthy to mention that we first move the objective function into constraints by introducing new decision variable z, and then provide the robust equivalence of all constraints of the robust DEA model. As a result, the first constraint of the above model is equivalent to the objective function of the robust DEA model. Similarly, the two last constraints of model P(II) are the robust counterpart of the DEA model.

The uncertainty set of model P(II) is defined as follows:

$$U^B = [\bar{y}_{rj}^s - G_{rj}^s, \bar{y}_{rj}^s + G_{rj}^s] \quad (9)$$

where $\bar{y}_{rj}^s$ is the nominal data assigned to rth output (here benefit-type criteria) in jth DMU whose value determined according to the sth expert opinion.

It is noted that the minimum and maximum value of $\tilde{y}_{rj}^s$ on the box uncertainty set U^B, are occurred for the lower and upper bounds of $\tilde{y}_{rj}^s$, which are $\bar{y}_{rj}^s - G_{rj}^s$ and $\bar{y}_{rj}^s + G_{rj}^s$ respectively. Therefore, when minimizing the left-hand of the first constraint on the box uncertainty of U^B, it became equal to $\sum_{s=1}^{S} w_s \sum_{r=1}^{R} u_r [\bar{y}_{ro}^s - G_{ro}^s]$, since $\tilde{y}_{ro}^s \geq 0$. A similar method can be used for maximizing the two last constraints of model P(II). Finally, the robust counterpart model can be written as:

$P(III)$: max z

subject to:

$$\sum_{s=1}^{S} w_s \sum_{r=1}^{k} u_r [\bar{y}_{ro}^{s} - G_{ro}^{s}] \geq z$$

$$\sum_{i=1}^{m} v_i x_{io}^{s} = 1, \quad \forall s$$

$$\sum_{r=1}^{k} u_r [\bar{y}_{rj}^{s} + G_{rj}^{s}] - \sum_{i=1}^{m} v_i x_{ij}^{s} \leq 0, \quad \forall j,s$$

$$\sum_{r=1}^{k} u_r [\bar{y}_{ro}^{s} - G_{ro}^{s}] \geq E_{so}^{*}, \quad \forall s$$

$$u_r, v_i \geq 0. \qquad (10)$$

In this model, $\bar{y}_{rj}^{s}$ and G_{rj}^{s} are the nominal data and scale uncertainty of data obtained from sth expert on rth output of jth DMU.

The existing robust DEA models which take benefit of BT approach are non-linear programming model due to usage of ellipsoidal uncertainty form [34,50]. However, our technique uses box uncertainty which leads to a linear programming model. Linear models have the benefit of simplicity and also the higher accuracy of the computational result in comparison to nonlinear programming models.

4. The application of proposed robust DEA for EA scenario evaluations

Our case study is studied for the ITRC in Iran as the greatest organizations handling ICT projects with a variant degree of importance and complexity. Having four faculties of IT, CT, security, and strategic planning, the center considers transformations of its process for approaching e-organizations objectives. To fulfill his vision, ITRC considers developing some practical scenarios for successful accomplishment of its task. EA has been accepted as a tool for planning and managing the process. Therefore, a group of IT experts designed 12 EA scenarios stated in Table 1 which correspond to 12 DMUs for our model. In fact, there are four distinct scenarios including planning for ERP implementation, web service implementation, portal implementation, and the process integration of ITRC and each can be implemented via in-sourcing (using the ITRC's own resources and employees), out-sourcing (a recovery-oriented proposal for downsizing and cost reduction), and co-sourcing (combining the in-source and out-source capability through contracting an out-sourced firm to provide part of IT solutions) [56].

Table 1. The 12 EA scenarios (ICT master plan) for ITRC migration to e-organization

DMU No.	EA scenario	Explanation
DMU1	In-source ERP	Implementing an ERP by in-sourcing
DMU2	Out-source ERP	Out-sourcing an ERP for implementation
DMU3	co-sourcing ERP	Implementing an ERP through co-sourcing
DMU4	In-source web services	Delivering the web services by in-sourcing
DMU5	Out-source web services	Delivering the web services through out-sourcing
DMU6	co-sourcing web services	Delivering the web services through co-sourcing
DMU7	In-source portal	Integration of ITRC departments through in-source portal implementation
DMU8	Out-source portal	Integration of ITRC departments through out-source portal implementation
DMU9	co-sourcing portal	Integration of ITRC departments through co-sourcing portal implementation
DMU10	In-source process integration	Integration the process of ITRC by in-sourcing
DMU11	Out-source process integration	Integration the process of ITRC by out-sourcing
DMU12	co-sourcing process integration	Integration the process of ITRC through co-sourcing

Executing each of these plans, demands high investments with high risks and hidden costs and it is safer to scrutinize the selection of EA against a robust analytical tool. To satisfy business objectives, information needs correspondence to certain several control objectives such as: efficiency, effectiveness, confidentiality, integrity, accessibility, availability, compliance, and reliability. These metrics correspond to the criteria covered in COBIT's framework which are utilized for evaluating the proposed EA scenarios before implementation by experts and our method. In fact, four experts are asked to submit their view on the suitability of each scenario in regard to every process of COBIT framework and then the proposed robust PRS-DEA method is deployed for obtaining the overall efficacy score of these EA according to all experts' preferences. The objective of this evaluation is to signify the maturity level of COBIT in the EA proposals and then selecting the best balanced improvement plan considering the IT processes of COBIT framework which meets almost all of the ICT ministries' objectives. So, the scenario which covers all or most of COBIT processes with high maturity is more likely to gain higher overall ranking and is expected to provide business and IT alignments efficiently.

Tables A-1 to A-4 present each expert's opinions regarding the estimated maturity of each process for the scenario under judgment. The range of maturity levels is from 0 to 10 which indicate the degree of realization of a specific process under a given scenario. Therefore, lower value of maturity level is an indication of weak realization and the higher value is an indication of high realization of that process when a specific scenario is implemented. Further, as data are inexact, experts present their estimated maturity in an interval of lower and higher bound. Further, the nominal value denoted by $\bar{y}_{rj}^{s}$ reflects the average estimated maturity of rth process under implementation of jth scenario from sth expert's viewpoint which is obtained by averaging the lower and upper bound values. For example, the reported data in Appendix

Table A-1 presents the lower, nominal and upper bound for the estimated maturity levels of COBIT processes through the implementation of different proposed EA scenarios from the first expert's viewpoint.

The information in these tables can be used to identify IT processes which are estimated to be affected at most or at least when implementing a given EA scenario. This information can be used to reflect the strengths and weaknesses of implementing that specific EA scenario which is then can be a source of value for recognizing the activities for reaching the desired status for processes.

The output parameters of the model are equal to 34 processes of COBIT and for the input parameter, a dummy input of 1 is considered [36]. The evaluation results are presented in the next section.

5. Performance Evaluation

We utilize several numerical experiments to validate the applicability and significance of the robust counterpart of our proposed method. As mentioned before, four experts' opinions are used in this experiment and scoring to the 34 processes of COBIT are regarded as the closed box uncertainty due to inherent imprecise nature of experts' opinion. In fact, the data for COBIT processes are considered as the interval of $[\bar{y}_{rj}^{s} - G_{rj}^{s}, \bar{y}_{rj}^{s} + G_{rj}^{s}]$ with G_{rj}^{s} as the scale uncertainty associated with sth expert' opinion about rth COBIT process in jth EA scenario.

To compute the ideal efficiency score (E_{so}^{*}) from each expert's point of view, we solve model P(I) with nominal data $(\bar{y}_{rj}^{s})$. It is worthy to mention that the best efficiency scores from each expert's point of view can be provided when uncertainty is not considered in model P(I). If we solve model P(I) with uncertain data to obtain ideal efficiency scores, the objective function (E_{so}^{*}) does not function as expected. For this reason, the resulted efficiency scores cannot be considered as ideal efficiency scores. Therefore, it is logical to provide ideal efficiency scores by solving model P(II) with nominal data $(\bar{y}_{rj}^{s})$. The respected results are reported in Table 2. For example, the second column of Table 2 reports the ideal efficiency scores according to data gathered from the first expert. According to the results, DMU1, 4, 5, 6 and 8 attain the efficiency score of one.

Further, we set $w_1 = w_2 = w_3 = w_4 = 0.25$. Please note that the proposed robust model turns into a deterministic model when the uncertainties are not considered in the model parameters.

Table 2. Ideal efficiency scores according to the experts' opinion

DMU No.	Expert 1	Expert 2	Expert 3	Expert 4
DMU1	1	1	1	1
DMU2	0.818	0.733	0.818	0.747
DMU3	0.750	0.724	0.857	0.714
DMU4	1	1	1	1
DMU5	1	1	1	1
DMU6	1	1	1	1
DMU7	0.955	1	0.875	1
DMU8	1	1	1	1
DMU9	0.875	1	1	1
DMU10	0.857	0.750	0.857	0.808
DMU11	0.750	0.750	0.714	0.750
DMU12	0.750	0.724	0.828	0.857

For the analysis, first, we solve the deterministic model $P(II)$ using the nominal data and calculate the performance of each DMU. The second column of Table 3 reports the corresponding results. As indicated, DMU4 and DMU5 acquire the maximum efficiency score of 1 and DMU3 holds the least efficiency score (0.546). Then, the robust counterpart model is solved. As it was expected, the deterministic model generates the higher efficiency score when it compares to the robust counterpart model. On the other hand, the efficiency scores generated by the deterministic model are greater than those produced by the robust counterpart model, since it protects decision making model against uncertainty. Furthermore, the efficiency score of each DMU is decreased by increasing the uncertainty level. This is the expected trend, since the efficiency of DMUs is predicted with a higher degree of uncertainty. The resulted efficiency scores are also graphically depicted in Figure 1. Moreover, the proposed robust DEA model, provide more discriminative results, which are more suitable for DMU ranking purpose.

Table 3. Efficiency scores obtained by the deterministic and robust Model

DMU number	Deterministic model	Robust model
DMU1	0.908	0.650
DMU2	0.615	0.394
DMU3	0.546	0.345
DMU4	1	0.713
DMU5	1	0.847
DMU6	0.833	0.639
DMU7	0.694	0.5
DMU8	0.859	0.708
DMU9	0.735	0.564
DMU10	0.553	0.403
DMU11	0.611	0.451
DMU12	0.601	0.461

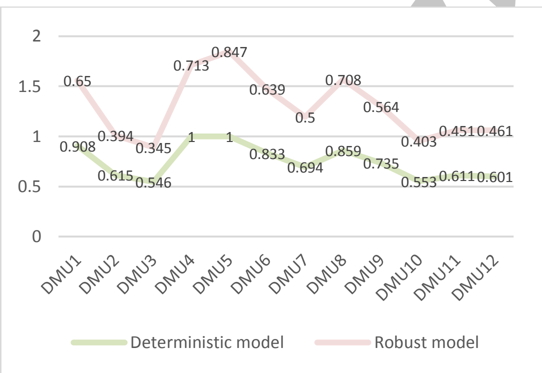

Figure 1. Efficiency scores under the proposed deterministic and robust optimization models

Based on achieved results, one can easily derive ranking of EA scenario according to the uncertainty level in mind. For example, if a manager wants to have its decision-making process with the highest protection and reliability level, then he should select the fifth EA scenario (i.e., "Out-source web services" scenario), which gains the highest efficiency score and is selected as the most preferred scenario for making ITRC objectives for alignments of IT and business realized.

6. Conclusion

In this paper, we have developed a robust DEA approach which embraces the effects of bounded uncertainties in experts' opinions using the robust optimization technique. This method is tested for a case study of EA scenario analysis, which determines the best scenario for implementation in a governmental institute of Iran (ITRC). The flexibility of the proposed robust DEA model with the integration of bounded uncertainty of experts' data in the proposed decision-making technique makes it a very reliable and efficient approach. Extensive experiments are carried out to prove the feasibility of the model with various degrees of uncertainty. The results show a promising research perspective in the field of both IT (IT Governance and EA evaluation problem) and MCDM domains. Through the presented method for business and IT alignment assessment, the variation of experts' opinion has no effect on final results. In fact, our analysis model is protected against the input data variation, and the output results are robust against the uncertainty. Specifically, the proposed analytical tool is intrinsically able to deal with different uncertainty in input data of decision making processes without any constraints. Therefore, as a future work, one may endeavor to try other types of uncertainty in EA evaluation scenarios.

7. Appendix

Table A-1. The input and output data for IT research projects of ITRC including summary statistics expressed by expert 1 (E1)

	DMU1			DMU2			DMU3			DMU4			DMU5			DMU6			DMU7			DMU8			DMU9			DMU10			DMU11			DMU12			Min	Max	Mean
	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U			
PO1	7	8	9	4	5	6	0	1	2	7	8	9	7	8	9	5	6	7	2	3	4	8	9	10	5.5	6	6.5	4.5	5	5.5	4.5	5	5.5	2.5	3	3.5	1	9	5.58
PO2	5	6	7	2	3	4	0	1	2	6	7	8	6	7	8	5	6	7	1	2	3	6	7	8	4.5	5	5.5	5.5	4.5	6.5	2.5	3	3.5	4.5	2	5.5	1	7	4.46
PO3	6	7	8	3	4	5	5	6	7	5	6	7	7	8	9	5	6	7	5	6	7	3	4	5	5.5	6	6.5	0.5	2.5	1.5	3.5	4	4.5	3.5	6	4.5	2.5	8	5.46
PO4	5	6	7	4	5	6	4	5	6	5	6	7	8	9	10	6	7	8	5	6	7	8	9	10	4.5	5	5.5	5.5	6	6.5	5.5	6	6.5	3.5	6	4.5	5	9	6.33
PO5	7	8	9	2	3	4	0	1	2	5	6	7	7	8	9	5	6	7	5	6	7	6	7	8	5.5	6	6.5	3.5	3.5	4.5	2.5	3	3.5	1.5	6	2.5	1	8	5.29
PO6	7	8	9	2	3	4	3	4	5	5	6	7	8	9	10	3	4	5	2	3	4	5	6	7	4.5	5	5.5	1.5	3	2.5	3.5	4	4.5	5.5	3	6.5	3	9	4.83
PO7	5	6	7	2	3	4	1	2	3	6	7	8	7	8	9	7	8	9	3	4	5	5	6	7	2.5	3	3.5	3.5	4	4.5	3.5	4	4.5	5.5	4	6.5	2	8	4.92
PO8	6	7	8	3	4	5	3	4	5	8	9	10	7	8	9	7	8	9	4	5	6	2	3	4	4.5	5	5.5	3.5	4	4.5	3.5	4	4.5	2.5	5	3.5	3	9	5.50
PO9	5	6	7	4	5	6	2	3	4	4	5	6	7	8	9	6	7	8	1	2	3	6	7	8	4.5	5	5.5	4.5	4.5	5.5	3.5	4	4.5	4.5	2	5.5	2	8	4.88
PO10	7	8	9	5	6	7	2	3	4	7	8	9	8	9	10	6	7	8	4	5	6	2	3	4	3.5	4	4.5	2.5	4	3.5	4.5	5	5.5	5.5	5	6.5	3	9	5.58
AI1	6	7	8	4	5	6	3	4	5	7	8	9	9	9.5	10	4	5	6	6	7	8	5	6	7	2.5	3	3.5	0.5	3.5	1.5	5.5	6	6.5	2.5	7	3.5	3	9.5	5.92
AI2	6	7	8	2	3	4	4	5	6	9	9.5	10	9	9.5	10	5	6	7	3	4	5	7	8	9	4.5	5	5.5	4.5	5	5.5	4.5	5	5.5	3.5	4	4.5	3	9.5	5.92
AI3	6	7	8	4	5	6	5	6	7	5	6	7	7	8	9	6	7	8	4	5	6	2	3	4	5.5	6	6.5	4.5	5	5.5	4.5	5	5.5	2.5	5	3.5	3	8	5.67
AI4	7	8	9	2	3	4	1	2	3	5	6	7	9	9.5	10	6	7	8	1	2	3	3	4	5	3.5	4	4.5	4.5	4.5	5.5	3.5	4	4.5	2.5	2	3.5	2	9.5	4.67
AI5	6	7	8	4	5	6	1	2	3	6	7	8	9	9.5	10	5	6	7	2	3	4	7	8	9	4.5	5	5.5	2.5	3.5	3.5	3.5	4	4.5	2.5	3	3.5	2	9.5	5.25
AI6	7	8	9	5	6	7	5	6	7	5	6	7	7	8	9	5	6	7	2	3	4	8	9	10	5.5	6	6.5	3.5	3.5	4.5	2.5	3	3.5	5.5	3	6.5	3	9	5.63
AI7	7	8	9	4	5	6	2	3	4	6	7	8	9	9.5	10	5	6	7	1	2	3	6	7	8	5.5	6	6.5	4.5	5.5	5.5	5.5	6	6.5	2.5	2	3.5	2	9.5	5.58
DS1	6	7	8	4	5	6	1	2	3	8	9	10	8	9	10	3	4	5	4	5	6	4	5	6	5.5	6	6.5	3.5	4.5	4.5	4.5	5	5.5	3.5	5	4.5	2	9	5.54
DS2	5	6	7	1	2	3	2	3	4	9	9.5	10	9	9.5	10	5	6	7	5	6	7	5	6	7	5.5	6	6.5	5.5	5.5	6.5	4.5	5	5.5	1.5	6	2.5	2	9.5	5.88
DS3	7	8	9	5	6	7	4	5	6	6	7	8	6	7	8	4	5	6	2	3	4	4	5	6	4.5	5	5.5	4.5	5	5.5	4.5	5	5.5	2.5	3	3.5	3	8	5.33
DS4	5	6	7	4	5	6	1	2	3	6	7	8	7	8	9	4	5	6	5	6	7	4	5	6	4.5	5	5.5	5.5	5	6.5	3.5	4	4.5	3.5	6	4.5	2	8	5.33
DS5	7	8	9	2	3	4	3	4	5	5	6	7	6	7	8	6	7	8	6	7	8	3	4	5	3.5	4	4.5	1.5	3	2.5	3.5	4	4.5	4.5	7	5.5	3	8	5.33
DS6	6	7	8	5	6	7	4	5	6	5	6	7	7	8	9	4	5	6	0	1	2	3	4	5	5.5	6	6.5	4.5	5	5.5	4.5	5	5.5	2.5	1	3.5	1	8	4.92
DS7	6	7	8	3	4	5	3	4	5	4	5	6	9	9.5	10	5	6	7	4	5	6	6	7	8	5.5	6	6.5	4.5	5	5.5	4.5	5	5.5	4.5	5	5.5	4	9.5	5.71
DS8	5	6	7	4	5	6	3	4	5	8	9	10	9	9.5	10	6	7	8	4	5	6	7	8	9	2.5	3	3.5	3.5	4.5	4.5	4.5	5	5.5	4.5	5	5.5	3	9.5	5.92
DS9	5	6	7	3	4	5	1	2	3	8	9	10	7	8	9	3	4	5	6	7	8	4	5	6	4.5	5	5.5	1.5	3.5	2.5	4.5	5	5.5	1.5	7	2.5	2	9	5.46
DS10	7	8	9	4	5	6	5	6	7	5	6	7	7	8	9	7	8	9	6	7	8	7	8	9	2.5	3	3.5	2.5	4.5	3.5	5.5	6	6.5	4.5	7	5.5	3	8	6.38
DS11	5	6	7	5	6	7	1	2	3	5	6	7	7	8	9	6	7	8	5	6	7	3	4	5	6.5	7	7.5	3.5	3.5	4.5	2.5	3	3.5	5.5	6	6.5	2	8	5.38
DS12	5	6	7	5	6	7	2	3	4	7	8	9	7	8	9	5	6	7	2	3	4	4	5	6	5.5	6	6.5	1.5	3.5	2.5	4.5	5	5.5	1.5	3	2.5	3	8	5.21
DS13	6	7	8	4	5	6	5	6	7	8	9	10	7	8	9	4	5	6	2	3	4	3	4	5	3.5	4	4.5	4.5	4	5.5	2.5	3	3.5	4.5	3	5.5	3	9	5.08
ME1	5	6	7	4	5	6	1	2	3	8	9	10	7	8	9	3	4	5	6	7	8	3	4	5	5.5	6	6.5	3.5	4	4.5	3.5	4	4.5	1.5	7	2.5	2	9	5.50
ME2	6	7	8	3	4	5	1	2	3	6	7	8	8	9	10	7	8	9	4	5	6	7	8	9	5.5	6	6.5	3.5	4	4.5	3.5	4	4.5	4.5	5	5.5	2	9	5.75
ME3	5	6	7	5	6	7	1	2	3	6	7	8	9	9.5	10	6	7	8	4	5	6	7	8	9	3.5	4	4.5	4.5	4	5.5	2.5	3	3.5	5.5	5	6.5	2	9.5	5.54
ME4	7	8	9	5	6	7	4	5	6	9	9.5	10	9	9.5	10	3	4	5	1	2	3	4	5	6	4.5	5	5.5	1.5	3.5	2.5	4.5	5	5.5	4.5	2	5.5	2	9.5	5.38

L=Lower bound value $(\bar{y}_{ij}^{1} - G_{ij}^{1})$

N=Nominal value $(\bar{y}_{ij}^{1})$

U=Upper bound vale $(\bar{y}_{ij}^{1} + G_{ij}^{1})$

Table A-2. The input and output data for IT research projects of ITRC including summary statistics expressed by expert 2 (E2)

	DMU1			DMU2			DMU3			DMU4			DMU5			DMU6			DMU7			DMU8			DMU9			DMU10			DMU11			DMU12			Min	Max	Mean
	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U			
PO1	4	6	8	3	5	7	4	6	8	4	6	8	9.5	9.75	10	7.5	8	8.5	3.5	4	4.5	7.5	8	8.5	4	5	6	3	5	5	5	6	7	5	4	7	4	9.75	6.06
PO2	4	6	8	2	4	6	0	2	4	5	7	9	9.5	9.75	10	3.5	4	4.5	5.5	6	6.5	4.5	5	5.5	5	6	7	2	4	4	4	5	6	3	6	5	2	9.75	5.40
PO3	4	6	8	3	5	7	2	4	6	5	7	9	6.5	7	7.5	5.5	6	6.5	6.5	7	7.5	3.5	4	4.5	5	6	7	4	4	6	2	3	4	1	7	3	3	7	5.50
PO4	6	8	10	3	5	7	0	1	3	6	8	10	9.5	9.75	10	4.5	5	5.5	2.5	3	3.5	3.5	4	4.5	5	6	7	4	5.5	6	5	6	7	3	3	5	1	9.75	5.35
PO5	6	8	10	2	4	6	2	4	6	8	9	10	9.5	9.75	10	5.5	6	6.5	1.5	2	2.5	4.5	5	5.5	5	6	7	4	5	6	4	5	6	2	2	4	2	9.75	5.48
PO6	5	7	9	3	5	7	0	2	4	4	6	8	8.5	9	9.5	5.5	6	6.5	3.5	4	4.5	3.5	4	4.5	3	4	5	4	4	6	2	3	4	1	4	3	2	9	4.83
PO7	4	6	8	3	5	7	3	5	7	5	7	9	8.5	9	9.5	4.5	5	5.5	3.5	4	4.5	4.5	5	5.5	3	4	5	3	4.5	5	4	5	6	3	4	5	4	9	5.29
PO8	5	7	9	2	4	6	0	2	4	7	8.5	10	8.5	9	9.5	7.5	8	8.5	6.5	7	7.5	6.5	7	7.5	4	5	6	1	4	3	5	6	7	5	7	7	2	9	6.21
PO9	6	8	10	3	5	7	0	2	4	6	8	10	7.5	8	8.5	3.5	4	4.5	4.5	5	5.5	4.5	5	5.5	6	7	8	1	3.5	3	4	5	6	4	5	6	2	8	5.46
PO10	6	8	10	4	6	8	1	3	5	7	8.5	10	7.5	8	8.5	4.5	5	5.5	6.5	7	7.5	6.5	7	7.5	2	3	4	3	5	5	5	6	7	4	7	6	3	8.5	6.13
AI1	4	6	8	2	4	6	4	6	8	8	9	10	6.5	7	7.5	4.5	5	5.5	1.5	2	2.5	3.5	4	4.5	2	3	4	1	2.5	3	2	3	4	5	2	7	2	9	4.46
AI2	5	7	9	2	4	6	3	5	7	6	8	10	8.5	9	9.5	6.5	7	7.5	4.5	5	5.5	7.5	8	8.5	4	5	6	3	4	5	3	4	5	2	5	4	4	9	5.92
AI3	5	7	9	0	2	4	0	2	4	8	9	10	8.5	9	9.5	6.5	7	7.5	5.5	6	6.5	5.5	6	6.5	4	5	6	2	4	4	4	5	6	4	6	6	2	9	5.67
AI4	6	8	10	1	3	5	0	2	4	8	9	10	8.5	9	9.5	4.5	5	5.5	3.5	4	4.5	7.5	8	8.5	4	5	6	2	3.5	4	3	4	5	3	4	5	2	9	5.38
AI5	5	7	9	3	5	7	1	3	5	5	7	9	7.5	8	8.5	7.5	8	8.5	0.5	1	1.5	6.5	7	7.5	5	6	7	3	4.5	5	4	5	6	4	1	6	1	8	5.21
AI6	5	7	9	1	3	5	0	2	4	5	7	9	8.5	9	9.5	5.5	6	6.5	6.5	7	7.5	4.5	5	5.5	3	4	5	1	4	3	5	6	7	3	7	5	2	9	5.58
AI7	4	6	8	0	2	4	0	2	4	6	8	10	8.5	9	9.5	4.5	5	5.5	1.5	2	2.5	7.5	8	8.5	2	3	4	1	3	3	3	4	5	4	2	6	2	9	4.50
DS1	4	6	8	1	3	5	0	2	4	4	6	8	7.5	8	8.5	6.5	7	7.5	5.5	6	6.5	7.5	8	8.5	3	4	5	4	4.5	6	3	4	5	4	6	6	2	8	5.38
DS2	5	7	9	2	4	6	3	5	7	6	8	10	9.5	9.75	10	3.5	4	4.5	3.5	4	4.5	5.5	6	6.5	6	7	8	3	4.5	5	4	5	6	2	4	4	4	9.75	5.69
DS3	4	6	8	4	6	8	2	4	6	7	8.5	10	8.5	9	9.5	7.5	8	8.5	5.5	6	6.5	4.5	5	5.5	4	5	6	3	4	5	3	4	5	4	6	6	4	9	5.96
DS4	4	6	8	1	3	5	3	5	7	3	5	7	8.5	9	9.5	6.5	7	7.5	5.5	6	6.5	4.5	5	5.5	3	4	5	0	2	2	2	3	4	2	6	4	2	9	5.08
DS5	4	6	8	0	2	4	1	3	5	7	8.5	10	6.5	7	7.5	5.5	6	6.5	5.5	6	6.5	4.5	5	5.5	3	4	5	4	4.5	6	3	4	5	1	6	3	2	8.5	5.17
DS6	5	7	9	3	5	7	2	4	6	6	8	10	6.5	7	7.5	6.5	7	7.5	1.5	2	2.5	8.5	9	9.5	5	6	7	1	2.5	3	2	3	4	4	2	6	2	9	5.21
DS7	5	7	9	3	5	7	0	1	3	4	6	8	7.5	8	8.5	7.5	8	8.5	0.5	1	1.5	4.5	5	5.5	6	7	8	4	5.5	6	5	6	7	4	1	6	1	8	5.04
DS8	4	6	8	2	4	6	3	5	7	6	8	10	7.5	8	8.5	5.5	6	6.5	3.5	4	4.5	6.5	7	7.5	5	6	7	5	5.5	7	4	5	6	3	4	5	4	8	5.71
DS9	5	7	9	3	5	7	0	2	4	4	6	8	6.5	7	7.5	3.5	4	4.5	4.5	5	5.5	4.5	5	5.5	6	7	8	3	4	5	3	4	5	1	5	3	2	7	5.08
DS10	6	8	10	0	2	4	2	4	6	8	9	10	6.5	7	7.5	3.5	4	4.5	2.5	3	3.5	8.5	9	9.5	6	7	8	1	3.5	3	4	5	6	4	3	6	2	9	5.38
DS11	5	7	9	2	4	6	3	5	7	7	8.5	10	8.5	9	9.5	3.5	4	4.5	5.5	6	6.5	5.5	6	6.5	4	5	6	0	2.5	2	3	4	5	3	6	5	2.5	9	5.58
DS12	5	7	9	1	3	5	0	2	4	6	8	10	9.5	9.75	10	5.5	6	6.5	1.5	2	2.5	3.5	4	4.5	5	6	7	2	3.5	4	3	4	5	3	2	5	2	9.75	4.77
DS13	6	8	10	3	5	7	0	2	4	6	8	10	6.5	7	7.5	7.5	8	8.5	6.5	7	7.5	2.5	3	3.5	4	5	6	4	4.5	6	3	4	5	3	7	5	2	8	5.71
ME1	5	7	9	3	5	7	0	1	3	5	7	9	7.5	8	8.5	5.5	6	6.5	6.5	7	7.5	7.5	8	8.5	5	6	7	2	4.5	4	5	6	7	4	7	6	1	8	6.04
ME2	4	6	8	2	4	6	2	4	6	5	7	9	9.5	9.75	10	4.5	5	5.5	4.5	5	5.5	5.5	6	6.5	6	7	8	0	3	2	4	5	6	3	5	5	3	9.75	5.56
ME3	5	7	9	0	2	4	0	2	4	8	9	10	7.5	8	8.5	5.5	6	6.5	5.5	6	6.5	7.5	8	8.5	2	3	4	2	4	4	4	5	6	5	6	7	2	9	5.50
ME4	5	7	9	2	4	6	0	2	4	7	8.5	10	8.5	9	9.5	4.5	5	5.5	3.5	4	4.5	5.5	6	6.5	3	4	5	5	4.5	7	2	3	4	5	4	7	2	9	5.08

L=Lower bound value $(\bar{y}_{rj}^2 - G_{rj}^2)$

N=Nominal value $(\bar{y}_{rj}^2)$

U=Upper bound vale $(\bar{y}_{rj}^2 + G_{rj}^2)$

Table A-3. The input and output data for IT research projects of ITRC including summary statistics expressed by expert 3 (E3)

	DMU1			DMU2			DMU3			DMU4			DMU5			DMU6			DMU7			DMU8			DMU9			DMU10			DMU11			DMU12			Min	Max	Mean
	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U			
PO1	4	6	8	1	3	5	0	2	4	6	8	10	6.5	7	7.5	4.5	5	5.5	5.5	6	6.5	5.5	6	6.5	3	4	5	0	2.5	2	3	4	5	5	6	7	2	8	4.96
PO2	4	6	8	2	4	6	0	1	3	4	6	8	8.5	9	9.5	5.5	6	6.5	1.5	2	2.5	6.5	7	7.5	3	4	5	1	3	3	3	4	5	5	2	7	1	9	4.50
PO3	4	6	8	3	5	7	3	5	7	8	9	10	6.5	7	7.5	6.5	7	7.5	4.5	5	5.5	2.5	3	3.5	4	5	6	0	2.5	2	3	4	5	4	5	6	2.5	9	5.29
PO4	6	8	10	3	5	7	0	2	4	6	8	10	7.5	8	8.5	6.5	7	7.5	5.5	6	6.5	5.5	6	6.5	5	6	7	4	4.5	6	3	4	5	1	6	3	2	8	5.88
PO5	6	8	10	4	6	8	0	2	4	4	6	8	7.5	8	8.5	6.5	7	7.5	1.5	2	2.5	7.5	8	8.5	3	4	5	3	4.5	5	4	5	6	5	2	7	2	8	5.21
PO6	5	7	9	1	3	5	0	2	4	4	6	8	7.5	8	8.5	6.5	7	7.5	3.5	4	4.5	6.5	7	7.5	3	4	5	0	3	2	4	5	6	5	4	7	2	8	5.00
PO7	5	7	9	3	5	7	1	3	5	7	8.5	10	8.5	9	9.5	6.5	7	7.5	4.5	5	5.5	5.5	6	6.5	5	6	7	4	4.5	6	3	4	5	5	5	7	3	9	5.83
PO8	6	8	10	0	2	4	1	3	5	7	8.5	10	8.5	9	9.5	5.5	6	6.5	1.5	2	2.5	4.5	5	5.5	5	6	7	3	3.5	5	2	3	4	3	2	5	2	9	4.83
PO9	6	8	10	3	5	7	0	2	4	3	5	7	8.5	9	9.5	6.5	7	7.5	0.5	1	1.5	5.5	6	6.5	5	6	7	0	2	2	2	3	4	2	1	4	1	9	4.58
PO10	4	6	8	3	5	7	3	5	7	4	6	8	8.5	9	9.5	6.5	7	7.5	0.5	1	1.5	6.5	7	7.5	3	4	5	3	5	5	5	6	7	3	1	5	1	9	5.17
AI1	5	7	9	2	4	6	0	2	4	7	8.5	10	8.5	9	9.5	6.5	7	7.5	2.5	3	3.5	8.5	9	9.5	5	6	7	0	3	2	4	5	6	3	3	5	2	9	5.54
AI2	5	7	9	3	5	7	3	5	7	6	8	10	8.5	9	9.5	7.5	8	8.5	5.5	6	6.5	5.5	6	6.5	4	5	6	4	4.5	6	3	4	5	4	6	6	4	9	6.13
AI3	5	7	9	2	4	6	0	2	4	3	5	7	7.5	8	8.5	4.5	5	5.5	3.5	4	4.5	7.5	8	8.5	3	4	5	2	4	4	4	5	6	5	4	7	2	8	5.00
AI4	4	6	8	1	3	5	1	3	5	3	5	7	8.5	9	9.5	6.5	7	7.5	5.5	6	6.5	3.5	4	4.5	4	5	6	3	4.5	5	4	5	6	1	6	3	3	9	5.29
AI5	5	7	9	1	3	5	0	1	3	4	6	8	9.5	9.75	10	4.5	5	5.5	1.5	2	2.5	8.5	9	9.5	3	4	5	1	3	3	3	4	5	2	2	4	1	9.75	4.65
AI6	6	8	10	3	5	7	3	5	7	8	9	10	8.5	9	9.5	7.5	8	8.5	2.5	3	3.5	2.5	3	3.5	5	6	7	2	3	4	2	3	4	4	3	6	3	9	5.42
AI7	4	6	8	1	3	5	2	4	6	5	7	9	7.5	8	8.5	3.5	4	4.5	2.5	3	3.5	2.5	3	3.5	2	3	4	2	3	4	2	3	4	2	3	4	3	8	4.17
DS1	4	6	8	3	5	7	3	5	7	5	7	9	7.5	8	8.5	6.5	7	7.5	4.5	5	5.5	4.5	5	5.5	2	3	4	5	5	7	3	4	5	2	5	4	3	8	5.42
DS2	4	6	8	4	6	8	3	5	7	7	8.5	10	7.5	8	8.5	4.5	5	5.5	6.5	7	7.5	7.5	8	8.5	5	6	7	0	2	2	2	3	4	1	7	3	2	8.5	5.96
DS3	5	7	9	1	3	5	0	2	4	3	5	7	7.5	8	8.5	4.5	5	5.5	6.5	7	7.5	6.5	7	7.5	3	4	5	4	4	6	2	3	4	3	7	5	2	8	5.17
DS4	5	7	9	4	6	8	0	1	3	6	8	10	8.5	9	9.5	4.5	5	5.5	4.5	5	5.5	6.5	7	7.5	3	4	5	1	3	3	3	4	5	4	5	6	1	9	5.33
DS5	6	8	10	1	3	5	0	2	4	6	8	10	7.5	8	8.5	6.5	7	7.5	6.5	7	7.5	8.5	9	9.5	4	5	6	1	3	3	3	4	5	5	7	7	2	9	5.92
DS6	4	6	8	3	5	7	4	6	8	4	6	8	9.5	9.75	10	6.5	7	7.5	4.5	5	5.5	6.5	7	7.5	3	4	5	4	4	6	2	3	4	3	5	5	3	9.75	5.65

	DMU1			DMU2			DMU3			DMU4			DMU5			DMU6			DMU7			DMU8			DMU9			DMU10			DMU11			DMU12			Min	Max	Mean
	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U			
DS7	5	7	9	4	6	8	1	3	5	6	8	10	6.5	7	7.5	5.5	6	6.5	2.5	3	3.5	5.5	6	6.5	4	5	6	2	4	4	4	5	6	4	3	6	3	8	5.25
DS8	5	7	9	0	2	4	4	6	8	4	6	8	9.5	9.75	10	4.5	5	5.5	3.5	4	4.5	8.5	9	9.5	6	7	8	2	3.5	4	3	4	5	4	4	6	2	9.75	5.60
DS9	6	8	10	0	2	4	1	3	5	6	8	10	7.5	8	8.5	6.5	7	7.5	3.5	4	4.5	3.5	4	4.5	2	3	4	1	3	3	3	4	5	3	4	5	2	8	4.83
DS10	5	7	9	3	5	7	1	3	5	4	6	8	7.5	8	8.5	4.5	5	5.5	0.5	1	1.5	2.5	3	3.5	4	5	6	2	3	4	2	3	4	2	1	4	1	8	4.17
DS11	5	7	9	3	5	7	3	5	7	6	8	10	8.5	9	9.5	7.5	8	8.5	6.5	7	7.5	7.5	8	8.5	3	4	5	2	3.5	4	3	4	5	2	7	4	3.5	9	6.29
DS12	5	7	9	4	6	8	2	4	6	4	6	8	8.5	9	9.5	4.5	5	5.5	5.5	6	6.5	4.5	5	5.5	5	6	7	2	3	4	2	3	4	3	6	5	3	9	5.50
DS13	4	6	8	2	4	6	1	3	5	5	7	9	6.5	7	7.5	7.5	8	8.5	3.5	4	4.5	3.5	4	4.5	3	4	5	0	3	2	4	5	6	1	4	3	3	8	4.92
ME1	6	8	10	3	5	7	3	5	7	6	8	10	8.5	9	9.5	5.5	6	6.5	4.5	5	5.5	5.5	6	6.5	5	6	7	5	4.5	7	2	3	4	2	5	4	3	9	5.88
ME2	4	6	8	3	5	7	4	6	8	5	7	9	6.5	7	7.5	3.5	4	4.5	2.5	3	3.5	3.5	4	4.5	6	7	8	5	5.5	7	4	5	6	3	3	5	3	7	5.21
ME3	5	7	9	3	5	7	0	1	3	5	7	9	7.5	8	8.5	7.5	8	8.5	2.5	3	3.5	7.5	8	8.5	3	4	5	3	4	5	3	4	5	4	3	6	1	8	5.17
ME4	5	7	9	3	5	7	2	4	6	4	6	8	8.5	9	9.5	3.5	4	4.5	5.5	6	6.5	7.5	8	8.5	2	3	4	1	4	3	5	6	7	5	6	7	3	9	5.67

L=Lower bound value $(\bar{y}_{rj}^{3} - G_{rj}^{3})$

N=Nominal value $(\bar{y}_{rj}^{3})$

U=Upper bound vale $(\bar{y}_{rj}^{3} + G_{rj}^{3})$

Table A-4. The input and output data for IT research projects of ITRC including summary statistics expressed by expert 4 (E4)

	DMU1			DMU2			DMU3			DMU4			DMU5			DMU6			DMU7			DMU8			DMU9			DMU10			DMU11			DMU12			Min	Max	Mean
	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U	L	*N*	U			
PO1	6.5	7	7.5	3.5	4	4.5	1.5	2	2.5	9.5	9.75	10	7	8	9	7	8	9	4	5	6	7	8	9	3	4	5	5	4.5	7	2	3	4	2	5	4	2	9.75	5.69
PO2	5.5	6	6.5	3.5	4	4.5	0.5	1	1.5	5.5	6	6.5	7	8	9	7	8	9	5	6	7	5	6	7	2	3	4	1	3	3	3	4	5	5	6	7	1	8	5.08
PO3	6.5	7	7.5	4.5	5	5.5	2.5	3	3.5	8.5	9	9.5	7	8	9	7	8	9	3	4	5	8	9	10	6	7	8	2	3.5	4	3	4	5	3	4	5	3	9	5.96
PO4	5.5	6	6.5	4.5	5	5.5	5.5	6	6.5	8.5	9	9.5	7	8	9	7	8	9	0	1	2	3	4	5	5	6	7	3	4.5	5	4	5	6	3	1	5	1	9	5.29
PO5	5.5	6	6.5	3.5	4	4.5	4.5	5	5.5	7.5	8	8.5	7	8	9	4	5	6	2	3	4	7	8	9	4	5	6	0	2	2	2	3	4	1	3	3	2	8	5.00
PO6	7.5	8	8.5	2.5	3	3.5	5.5	6	6.5	8.5	9	9.5	8	9	10	6	7	8	5	6	7	4	5	6	4	5	6	1	3.5	3	4	5	6	4	6	6	3	9	6.04
PO7	7.5	8	8.5	4.5	5	5.5	1.5	2	2.5	8.5	9	9.5	8	9	10	4	5	6	3	4	5	3	4	5	3	4	5	3	3.5	5	2	3	4	2	4	4	2	9	5.04
PO8	6.5	7	7.5	3.5	4	4.5	4.5	5	5.5	6.5	7	7.5	6	7	8	5	6	7	0	1	2	6	7	8	3	4	5	4	4.5	6	3	4	5	3	1	5	1	7	4.79
PO9	6.5	7	7.5	2.5	3	3.5	1.5	2	2.5	7.5	8	8.5	7	8	9	5	6	7	2	3	4	4	5	6	4	5	6	0	3.5	2	5	6	7	3	3	5	2	8	4.96
PO10	6.5	7	7.5	2.5	3	3.5	2.5	3	3.5	8.5	9	9.5	7	8	9	4	5	6	4	5	6	7	8	9	3	4	5	4	5	6	4	5	6	4	5	6	3	9	5.58
AI1	5.5	6	6.5	4.5	5	5.5	2.5	3	3.5	8.5	9	9.5	7	8	9	5	6	7	0	1	2	3	4	5	4	5	6	1	3	3	3	4	5	3	1	5	1	9	4.58
AI2	7.5	8	8.5	5.5	6	6.5	5.5	6	6.5	5.5	6	6.5	9	9.5	10	6	7	8	5	6	7	5	6	7	6	7	8	3	4	5	3	4	5	2	6	4	4	9.5	6.29
AI3	5.5	6	6.5	5.5	6	6.5	1.5	2	2.5	9.5	9.75	10	6	7	8	7	8	9	1	2	3	5	6	7	4	5	6	3	4.5	5	4	5	6	5	2	7	2	9.75	5.27
AI4	5.5	6	6.5	5.5	6	6.5	3.5	4	4.5	9.5	9.75	10	6	7	8	4	5	6	4	5	6	5	6	7	4	5	6	3	5	5	5	6	7	3	5	5	4	9.75	5.81
AI5	6.5	7	7.5	3.5	4	4.5	0.5	1	1.5	5.5	6	6.5	6	7	8	4	5	6	1	2	3	2	3	4	6	7	8	0	2.5	2	3	4	5	5	2	7	1	7	4.21
AI6	7.5	8	8.5	2.5	3	3.5	3.5	4	4.5	8.5	9	9.5	9	9.5	10	3	4	5	5	6	7	3	4	5	5	6	7	5	4.5	7	2	3	4	1	6	3	3	9.5	5.58
AI7	6.5	7	7.5	4.5	5	5.5	0.5	1	1.5	4.5	5	5.5	7	8	9	5	6	7	5	6	7	3	4	5	5	6	7	1	3.5	3	4	5	6	2	6	4	1	8	5.21
DS1	7.5	8	8.5	2.5	3	3.5	2.5	3	3.5	9.5	9.75	10	8	9	10	5	6	7	3	4	5	4	5	6	4	5	6	2	4	4	4	5	6	1	4	3	3	9.75	5.48
DS2	7.5	8	8.5	2.5	3	3.5	3.5	4	4.5	5.5	6	6.5	8	9	10	5	6	7	2	3	4	5	6	7	5	6	7	1	3.5	3	4	5	6	3	3	5	3	9	5.21
DS3	7.5	8	8.5	1.5	2	2.5	3.5	4	4.5	7.5	8	8.5	6	7	8	3	4	5	0	1	2	5	6	7	4	5	6	2	3.5	4	3	4	5	2	1	4	1	8	4.46
DS4	6.5	7	7.5	2.5	3	3.5	1.5	2	2.5	7.5	8	8.5	8	9	10	6	7	8	4	5	6	2	3	4	5	6	7	3	4	5	3	4	5	1	5	3	2	9	5.25
DS5	5.5	6	6.5	2.5	3	3.5	2.5	3	3.5	8.5	9	9.5	9	9.5	10	5	6	7	1	2	3	8	9	10	2	3	4	2	4	4	4	5	6	2	2	4	2	9.5	5.13
DS6	5.5	6	6.5	3.5	4	4.5	0.5	1	1.5	6.5	7	7.5	8	9	10	3	4	5	4	5	6	4	5	6	6	7	8	3	4.5	5	4	5	6	4	5	6	1	9	5.21
DS7	6.5	7	7.5	3.5	4	4.5	4.5	5	5.5	5.5	6	6.5	8	9	10	6	7	8	1	2	3	7	8	9	2	3	4	4	5.5	6	5	6	7	5	2	7	2	9	5.38
DS8	5.5	6	6.5	3.5	4	4.5	2.5	3	3.5	9.5	9.75	10	7	8	9	7	8	9	5	6	7	6	7	8	6	7	8	1	3	3	3	4	5	3	6	5	3	9.75	5.98
DS9	5.5	6	6.5	2.5	3	3.5	4.5	5	5.5	5.5	6	6.5	7	8	9	4	5	6	6	7	8	6	7	8	5	6	7	5	5	7	3	4	5	3	7	5	3	8	5.75
DS10	5.5	6	6.5	4.5	5	5.5	2.5	3	3.5	6.5	7	7.5	6	7	8	3	4	5	6	7	8	5	6	7	2	3	4	2	4	4	4	5	6	4	7	6	3	7	5.33
DS11	6.5	7	7.5	1.5	2	2.5	4.5	5	5.5	4.5	5	5.5	8	9	10	5	6	7	2	3	4	6	7	8	4	5	6	2	3	4	2	3	4	2	3	4	2	9	4.83
DS12	7.5	8	8.5	5.5	6	6.5	3.5	4	4.5	8.5	9	9.5	9	9.5	10	4	5	6	3	4	5	8	9	10	5	6	7	1	3.5	3	4	5	6	1	4	3	3.5	9.5	6.08
DS13	5.5	6	6.5	4.5	5	5.5	3.5	4	4.5	5.5	6	6.5	6	7	8	3	4	5	4	5	6	7	8	9	5	6	7	5	5.5	7	4	5	6	3	5	5	4	8	5.54
ME1	6.5	7	7.5	5.5	6	6.5	3.5	4	4.5	7.5	8	8.5	8	9	10	6	7	8	2	3	4	7	8	9	2	3	4	4	5	6	4	5	6	2	3	4	3	9	5.67
ME2	6.5	7	7.5	4.5	5	5.5	4.5	5	5.5	7.5	8	8.5	7	8	9	6	7	8	6	7	8	4	5	6	5	6	7	2	3.5	4	3	4	5	2	7	4	3.5	8	6.04
ME3	5.5	6	6.5	5.5	6	6.5	1.5	2	2.5	8.5	9	9.5	8	9	10	4	5	6	1	2	3	6	7	8	5	6	7	4	4.5	6	3	4	5	3	2	5	2	9	5.21
ME4	6.5	7	7.5	3.5	4	4.5	2.5	3	3.5	6.5	7	7.5	7	8	9	6	7	8	3	4	5	7	8	9	5	6	7	1	3	3	3	4	5	4	4	6	3	8	5.42

L=Lower bound value $(\bar{y}_{rj}^{4} - G_{rj}^{4})$

N=Nominal value $(\bar{y}_{rj}^{4})$

U=Upper bound vale $(\bar{y}_{rj}^{4} + G_{rj}^{4})$

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