A P-Robust Stochastic DEA Model for Enterprise Architecture Scenario Selection

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Abstract-**Enterprise Architecture (EA) is the most suitable approaches intended to assist companies in achieving their long-term objective. Meanwhile, establishing EA in an organization is a costly and time-consuming task. We can analyze the EA scenarios using famous IT governance frameworks to achieve IT and business alignment. In this paper, we propose a new analytical approach for selecting and ranking EA scenarios according to the criteria of a well-established IT governance framework, namely COBIT. We propose a new group-based analytical approach based on a novel DEA model combined with p-robust technique.**

Keyword-Enterprise Architecture; COBIT; Data Envelopment Analysis; Group Decision Making; P-robustness.

I. INTRODUCTION

Today's dynamic environment of organizations, considers IT as an enabler in keeping them in the competitive edge of the market, and extensive investments are expended on this domain. However, to gain advantage of such investments and reduce the risks, the strategic unification of business and IT domain should be realized. Attaining such alliance is the primary target of IT governance (Haes and Grembergen 2008). Investment on IT governance deployment is a critical priority in organizations since it increase the profitability (Weill 2004). For effective execution of IT governance, organizations need to evaluate their current status and determine where the

deficiency exists and how the planned improvement should be realized. Numerous IT proposals or IT master plans may be suggested for IT development in an organization. These roadmaps should take into account the organization's missions and information systems to be aligned with the business strategies from the viewpoint of IT governance requirements.

Enterprise Architectures (EAs) are promised to give such a general view and offer tangible benefits to the enterprise to achieve the optimal performance of the business process within an efficient IT environment. EA performs this task by targeting four architectural domains of business, application, data, and infrastructure (Niemann 2006, Davoudi and Shams Aliee 2009, Davoudi and Shams Aliee 2009). Business

architecture defines the functions and end-to-end processes in addition to their relationship to realize the organization's mission. Application architecture concerns about the structure of the systems according to the technology defined. The data architecture, deals with the structure of information and its compatibility with the organizational needs; and lastly, the technical architecture, defines the technology and infrastructure of the IT systems in the organization. IT governance frameworks help to select the optimum scenario for an organization through the correspondence of EA dimensions to that of IT governance measures. However, the perspective of evaluating EA candidates from the IT governance framework viewpoint is missing in the literature. A few works investigate the relationship between performance and corporate governance (Mashayekhi and Bazaz 2008, Yeh, Wang et al. 2010, Wang, Lu et al. 2011, Jackowicz and Kowalewski 2012), but these research studies ignore the strategic business and IT alignment. In this paper, we have focused on business and IT alignment of EA scenarios considering the IT processes presented in COBIT framework, the most famous IT governance framework for business and IT alignment analysis.

Evaluating the performance of EA scenarios can be managed by simulating the proposed scenarios in real condition, but this idea is really expensive and time consuming. Thus, the IT processes presented in COBIT framework is proposed in this paper to be used as the criteria for evaluating the EA scenarios; since through maturity of these COBIT processes, comprehensive alignment of business and IT will be assured. Owing to this fact, for EA evaluation purpose according to IT governance best practices, it is much desired to use analytical engineering-based tools in a companion to surveying domain experts' preferences. We follow this approach throughout the rest of the paper with proposing a new application for Data Envelopment Analysis (DEA) technique, which is widely accepted as a very efficient tool for assessing the performance of units under study. The proposed contribution of proposed DEA in this paper is covering the flexible group-decision making through the p-robust concept. In proposed DEA method, the experts' idea is considered in final ranking of EA scenarios according to the proficiency of the experts, and the sensitive analysis is possible for aggregating the group analysis in the decision-making process.

Then, we test our method to a case study of a governmental research institute in Iran to determine the applicability of our model. Therefore, our contributions have duality both in EA analysis domain and decision making methods which can be summarized as below:

- The first application of DEA for EA scenarios evaluation purpose and establishing benchmarks which can enlighten the improvement path for the organization;
- The first use of the indicators of an IT governance framework for EA scenario evaluation which is an orchestration of IT governance and EA for the higher efficiency of organizations;
- Proposing a new group-based decision making technique which to capture several experts' judgments;

- Incorporating p-robustness measure in the proposed technique to produce the final EA ranking results within a flexible margin of experts' preferences.

To reach this aim, the structure of the paper is set out as follows: In section 2, we review the literature of EA analysis models. Section 3 is the main body of the paper introducing our model. Section 4 contextualizes a case study for our proposed approach and the results of some numerical experiments for our case study. Finally, we conclude at section 5.

II. LITERATURE REVIEW

There are some famous EA frameworks such as Zachman (Zachman 1987, Zachman 2009), DODAF (Group 2004), and TOGAF(Harrison 2007). Subsequently, there is a stream of works dedicated to assessment of EA frameworks (Tang, Han et al. 2004, Ohren 2005, Abdallah and Galal-Edeen 2006, Leist and Zellner 2006, Urbaczewski and Mrdalj 2006, Odongo, Kang et al. 2010, Magoulas, Hadzic et al. 2012). EA analysis approaches consider EA analysis in terms of satisfying attributes. This trend is more executed in software quality management context and multi criteria decision making techniques can be deployed for that.

Yu (Yu, Strohmaier et al. 2006) evaluated EA from structural dimension and guides the designer of EA to achieve a desired architecture using the expert opinions. It encompasses both functional and non-functional characteristics of EA. Niemann (Niemann 2006) model is also an expert-based model which presents the complexity and dependency of EA components, and the extend of its correspondence to standards. Jacob (Jacob and Jonkers 2006) presents a dynamic model which can analyze the current status of EA and characterize the behavior to get to the desired status. It uses a computational model using some input indicators and the results are some guideline statistics. Boer et el. (Boer, Bonsangue et al. 2005) present a more general structure to evaluate both functional and non-functional requirement of an organization using XML modeling of current and desired status of the organization. Some of the assessment frameworks in the literature are dependent on a specific framework and some of them are not. Further, some of the frameworks focus on the analysis of the EA master plans that are implemented (Närman, Johnson et al. 2007, Närman, Schönherr et al. 2008) and yet some other focus on not-yet implemented plans, since there may be EA plans for the stage of a proposal that needs a scrutinized analysis before selection for the success of the organization. Since current status of the enterprise organization is used as a basic architecture and the desired architecture is designed from this preliminary architecture in the planning phase, EA maturity is one of the methods used in the literature. Assessment of existing EA architecture is studied in (Javanbakht, Rezaie et al. 2008) that gives a quantitative measure of the potential of the current architecture. Then, with this input, an analysis of the plans for improving the architecture would be feasible. An evaluation of plans that takes into account organization's missions, opportunities, and threats is studied in (Javanbakht, Pourkamali et al. 2009). In

(Davoudi and Shams Aliee 2009) some quality attributes for assessing the EA framework is presented and the same authors presented AHP decision-making model to evaluate their proposal in (Davoudi and Shams Aliee 2009). Jahani (Jahani, Javadein et al. 2010) presents a model to measure the readiness of an organization to implement EA considering different dimensions of organization strategy, resource accessibility, organization culture and other management criteria but the model is too general to assess the specific EA plans designed for the organization. It emphasizes the role of senior managers and resource availability to initiate EA implementation. Kang et el. (Kang, Lee et al. 2010) uses alignment of strategy and business architecture to determine the requirement for achieving the organization's strategies. They use a matrix using balanced score card measures to describe this alignment.

Notice that in a smaller scale, software architecture analysis frameworks concentrate just on information systems of the organization such as SAAM(Dolan 2001), ALMA(Bengtsson, Lassing et al. 2004), ATAM(Kazman, Klein et al. 1998) and CBAM(Kazman, Asundi et al. 2001). Some research also such as Yoon (Yoon 2011) model specifies some index to measure the performance of IT section of an organization. There are also some models and standards such as ISO/IEC(ISO/IEC 1991), Kazman(Bass, Clements et al. 2003), and Dromey(Dromey 1995) which are proposed for software quality assessment.

Investigation of quality attributes of software architecture using Multi Criteria Decision Making (MCDM) models has been the subject of some researches (Svahnberg, Wohlin et al. 2003, Zhu, Aurum et al. 2005, Lee, Choi et al. 2006, Reddy, Naidu et al. 2007, Büyüközkan and Ruan 2008, Razavi, Shams Aliee et al. 2011). In these kinds of problems, optimum solution was found among a set of alternatives which are judged against multiple attributes. As EA has multi-dimensional characteristics, EA scenario analysis can be done with a proper MCDM model. Among the MCDM models, Analytical Hierarchical Process (AHP)(Saaty 1980) and its fuzzy version has been applied to judge and select the best architecture candidate or project (Davidsson, Johansson et al. 2006, Reddy, Naidu et al. 2007, Büyüközkan and Ruan 2008, Razavi, Shams Aliee et al. 2011). Moreover, Data Envelopment Analysis (DEA) is recognized as an alternative approach for measuring a set of homogenous DMUs, which has the advantages of MCDM methods but requires less exogenous information (Sarkis 2000). Several papers also have leveraged this method for selecting IT projects to meet their long-term commitments (Wang, Gopal et al. 1997, Asosheh, Nalchigar et al. 2010) and also for assessing the effect of IT on the performance of a firm but application of DEA in EA scenario selection is void.

In many practical applications, performance measurement should be performed according to the opinions of a group of experts. Likewise, a concrete EA scenario should aggregate the opinions of a group of experts. Group decision making methods extended based on AHP methodology are the most common toolset proposed in the literature for ranking decision making units (DMUs) based on the experts' opinions

(Huang, Liao et al. 2009). Further, the final results should not have much divergence to each expert's opinion.

Notice that DEA method is never used for the EA scenarios evaluation. One reason behind this may lies in the fact that the output of basic DEA optimization incorporates the idea of one expert. If we keep having a consolidation of the ideas, we may run each time a DEA data matrix according to one expert's opinion. This model will be time-consuming and also the result may diverge from a confidence level that we desire because of the condition of a group decision-making.

III. PROPOSED P-ROBUST STOCHASTIC DEA MODEL

In many practical applications, performance measurement should be performed according to the opinions of a group of experts. Likewise, a concrete EA scenario should aggregate the opinions of a group of experts. Group decision making methods extended based on AHP methodology are the most common toolset proposed in the literature for ranking units based on the experts' opinions (Huang, Liao et al. 2009). However, intelligent decision support techniques such as DEA offer much more benefits compared to AHP technique such as: 1) DEA can handle very large problems in MCDM with no constraints; 2) DEA can present a distributed evaluation which provides decision-maker with a comprehensive view of the performance of units under study and hence help the DM to recognize the improvement domains; 3) Further, DEA produce the optimal weights of experts automatically in contrast to AHP. In this section, we propose our group-based technique by a short overview of basic DEA model.

DEA is an efficient methodology developed based on the powerful mathematical programing concepts, for measuring the efficiency and ranking of productive units, termed DMUs (decision making units) (Charnes, Cooper et al. 1978). The method is classified as a non-parametric model introduced based on the concept of pareto optimality. It determines a piecewise linear efficiency frontier along the most efficient DMU to derive the relative efficiency measures of all other DMUs and scoring the least efficient DMU by comparison with its frontier curve. The model assesses a set of homogenous decision making units with m inputs and k outputs. The original CCR input-oriented DEA model can be written as follows:

$$E_s^*: \max e_o = \sum_{r=1}^{k} u_r y_{ro}^s$$

subject to:

$$\sum_{r=1}^{k} u_r y_{rj}^s - \sum_{i=1}^{m} v_i x_{ij}^s \leq 0, \quad \forall j \qquad (1)$$

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

$$u_r, v_i \geq 0.$$

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_s

demonstrates the efficiency of oth DMU from the viewpoint of the *s*th expert's opinion. Also, e_o denotes the efficiency of the *o*th DMU when it is under evaluation. The efficiency of all DMUs is provided by solving model (1) repeatedly for each DMU.

In the aforementioned model, it is assumed that inputs and outputs are explicitly defined for performance evaluation. However, there are many real cases that data are used without inputs (such as index data or pure output data). Liu et al. (Liu, Zhang et al. 2011) proposed various types of DEA models with explicit inputs. In our case, since we have *k* benefit type criteria, we consider a DEA model with *k* output and one dummy input of 1 for all DMUs. The model (1) measures the efficiency of DMUs based on the *s*th expert's opinion. In the next section, we extend model (1) so that we can assess the efficiency of DMUs based on all experts' opinions. The proposed model can be considered as a group decision making method, since it utilizes the all experts' opinions for performance measurement purpose.

Robustness is associated with the difference in objective function value. A decision-making model whose objective function value does not deteriorate is robust. In fact, the performance of a DEA model in different realization of a problem is more important than the right estimation or prediction of its result for the same problem in uncertain situations. Let us suppose there are several scenarios with different objective function value for a DEA model in different realization of uncertain parameters for decision-making. There are two approaches for defining robustness measures. A class of robustness measures focuses on achieving some efficiency scores for DMUs which scenarios have the best performance in different realization of uncertain parameters; while, the other class tries to have a results whose performance is not bad regarding the best performance (Sabuncuoglu and Goren 2009). The second class of robustness measures achieve robustness through minimizing the regret.

Kouvelis, Kurawarwala et al. (1992) introduced the notion of p-robustness for the first time. The facility location and international sourcing problems was solved using this technique for achieving robustness against the existing uncertainty. Suppose there are several scenarios for an optimization problem. Thus, there is a difference between the cost of a scenario solution and the optimal solution. This difference means regret. The most common measures applied for robustness are minimax cost and minimax regret which can be used for minimizing the maximum cost and minimizing the maximum regret across a set of scenarios respectively (Snyder and Daskin 2006).

Minimax regret, minimax cost, and expected cost models are customary approaches for solving linear programing models where there are several scenarios (here, experts' opinions). In our typical problem, these models can be reformulated as minimax regret, maximin efficiency, and expected efficiency models. The two former models protect against the worst-case scenario, which may be occur with very small probability in real-world applications. Therefore, protecting against the worst case is impractical, complex, and time consuming. To tackle this problem,

a new DEA model is proposed whose objective is maximizing the expected efficiency or average weighted efficiency and controlling the relative regret among experts' opinions. The relative regret indicates the relative difference between the efficiency scores generated by the model and ideal efficiency scores obtained based on the experts' opinions. In order to control the relative regret, novel constraints called p-robust constraints are incorporated in the proposed DEA model.

In this paper, p-robust constraints are constructed based on the relative regret concept. The p-robustness concept coined by (Mo and Harrison 2005) was first used in a supply-chain network design to indicate that relative regret of each scenario should not be more than constant *p*. In the following, we use the definition of "p-robust" as defined by (Snyder 2006, Snyder and Daskin 2006):

Definition: For a given set S of scenarios (in our model, it means the experts' opinion about the performance criteria), let P_s be the deterministic minimization problem for scenario s (*s*th expert's opinion) and let E_s^* be the optimal efficiency score for P_s. Let (u,v) be a feasible vector of the input and outputs' weights, and $E_s(u,v)$ be the efficiency score of (u,v) in scenario *s*. Then (u,v) is called *p*-robust if for all $s \in S$,

$$\frac{E_s^* - E_s(u,v)}{E_s^*} \le p \qquad (1)$$

The left-hand side denotes the relative regret for *s*th expert's opinion. The equation can be reformulated as follows:

$$E_s(u,v) \ge (1-p)E_s^* \qquad (2)$$

where $p \ge 0$ is a parameter and denote the robustness level among scenarios. Upper bound on the maximum allowable relative regret for each scenario is limited by this parameter.

In order to elaborate the proposed p-robust stochastic DEA model, the expected efficiency scores based on the experts' opinions is repeatedly maximized for each DMU in the context of the objective function. Furthermore, the p-robust constraints are incorporated to the model to control the relative regret associated with experts' opinions when evaluating each DMU. Finally, according to the definitions and discussions, the proposed p-robust stochastic DEA model is written as follows:

$$\max \sum_{s=1}^{S} w_s \sum_{r=1}^{k} u_r y_{ro}^s$$

subject to:

$$\sum_{r=1}^{k} u_r y_{ro}^s \ge (1-p)E_s^*, \quad s=1,...,S,$$

$$\sum_{r=1}^{k} u_r y_{rj}^s - \sum_{i=1}^{m} v_i x_{ij}^s \le 0, \quad j=1,...,n, \ s=1,...,S,$$

$$\sum_{i=1}^{m} v_i x_{ij}^s = 1, \quad j=1,...,n, \ s=1,...,S.$$

$$u_r, v_i \ge 0.$$

(3)

where w_s denotes the weight of sth expert's opinion. The objective function of model (4) is maximizing the weighted efficiency score of oth DMU when it is under evaluation according to the expert' opinions data for output criteria. The first set of constraints imposes the p-robust criterion associated with all experts' opinion. This set of constraints may not allow the scenario efficiency taking a value more than $100(1-p)\%$ of the ideal efficiency score obtained based on the expert' opinion. The parameter p can flexibly control the relative regret among all experts' opinions. Notice that if $p=\infty$ the p-robust constraints become inactive and if p is very small, and model (3) may become infeasible. The second to fourth set of constraints are the conventional DEA constraints which must be hold for all $s \in S$.

IV. P-ROBUST STOCHASTIC DEA APPLICATION

E-government development is the primary goal for countries to decrease the service cost and increase the citizen satisfaction. For a governmental organization, several EA scenarios can be proposed to realize the objective of an e-government plan. In view of this fact, 12 EA scenarios can be proposed for e-government realization shown in Table 1. Obviously, each EA scenario encompass a large body of professional experts and extensive investment. It is necessary to analyze the efficiency of these scenarios to have a better insight for e-government development and economize the IT development using the best EA scenarios.

TABLE 1. THE PROPOSED 12 POTENTIAL EA SCENARIOS (ICT MASTER PLANS) FOR E-GOVERNMENT DEVELOPMENT IN A GOVERNMENTAL ORGANIZATION

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

Among the plethora of IT governance standards and frameworks (e.g., CMMI, COBIT, ITIL, MOF, ISPL1, ASL2, ISO, Six Sigma, DSDM3), Control Objectives for IT and related Technology (COBIT) is one of the most successful internationally recognized IT governance and control framework which does not address any specific aspect of IT but gives a set of best practices (Hardy 2006, Žvanut and Bajec 2010, Bernroider and Ivanov 2011). This framework is a set of best practices created by the Information Systems Audit and Control Association (ISACA), and the IT Governance Institute (ITGI) in 1992 (ISACA 2010). ITGI states that COBIT presents an extensive set of IT activities in 34 high level processes for fulfilling business requirements from IT perspective shown in Table 2 (Hardy 2006, Žvanut and Bajec 2010, Bernroider and Ivanov 2011). This framework can be used by different users from executive, business and IT managers to every other stakeholder and help them to maximize their benefits of using information technology and ensuring that the enterprise's IT supports business objectives.

TABLE 2: COBIT PROCESSES AS THE OUTPUT VARIABLES OF P-ROBUST STOCHASTIC DEA MODEL

Code	COBIT Processes
PO1	Define a strategic IT plan.
PO2	Define the information architecture.
PO3	Determine technological direction.
PO4	Define the IT processes, organization and relationships.
PO5	Manage the IT investment.
PO6	Communicate management aims and direction.
PO7	Manage IT human resources.
PO8	Manage quality.
PO9	Assess and manage IT risks.
PO10	Manage projects.
AI1	Identify automated solutions.
AI2	Acquire and maintain application software.
AI3	Acquire and maintain technology infrastructure.
AI4	Enable operation and use.
AI5	Procure IT resources.
AI6	Manage changes.
AI7	Install and accredit solutions and changes.
DS1	Define and manage service levels.
DS2	Manage third-party services.
DS3	Manage performance and capacity.
DS4	Ensure continuous service.
DS5	Ensure systems security.
DS6	Identify and allocate costs.
DS7	Educate and train users.
DS8	Manage service desk and incidents.
DS9	Manage the configuration.
DS10	Manage problems.
DS11	Manage data.
DS12	Manage the physical environment.
DS13	Manage operations.
ME1	Monitor and evaluate IT performance.
ME2	Monitor and evaluate internal control.
ME3	Ensure compliance with external requirements.
ME4	Provide IT governance.

The business requirements of a good governmental organization consisted of efficiency, effectiveness, confidentiality, integrity, accessibility, availability, compliance, and information reliability. These requirements lead us to choose COBIT framework as a reference model to analyze the EA scenarios. In fact, we should analyze the coverage of each scenario in relation to the COBIT processes. The scenario which considers and covers more than other the 34 COBIT processes is entirely appropriate for selection; since it realizes the business requirements with an efficient and effective use of IT resources. In this research, the proposed p-robust stochastic DEA method is applied to analyze the performance of each EA scenario related to each COBIT process.

A. Computational results

The most essential step of the proposed p-robust-stochastic DEA method is selecting the input-output variables. Since all of our criteria are of benefit type criteria, they are represented as output measures. Therefore, as already mentioned, our proposed model comprises of 34 outputs taken from IT processes illustrated in Table 2 and one dummy input. An expert team consisted of four experts was established to run the dicision-making process.

OUR DATA SET CONSISTS OF THE ESTIMATED MATURITY LEVEL OF THE ENTIRE 12 EA SCENARIOS WITH REGARD TO 34 PROCESSES OF COBIT IN VIEW OF EACH EXPERT ILLUSTRATED IN

Table 3. The sth expert's opinion on rth COBIT process (as output) in jth EA scenario (as DMU) is presented with $y_{rj}^s = (y_{rj}^1, y_{rj}^2, y_{rj}^3, y_{rj}^4)$ in this table. Maturity levels are considered from 0 to 10 stating increasing realization of a specific process for a given scenario.

TABLE 3: THE OUTPUT DATA FOR EA SCENARIOS EXPRESSED BY EXPERTS

Outputs	DMU U1	DMU U2	DMU U3	DMU U4	DMU U5	DMU U6	DMU U7	DMU U8	DMU U9	DMU U10	DMU U11	DMU U12
PO1	(8,6,6,7)	(5,5,3,4)	(1,6,2,2)	(8,6,8,10)	(8,10,7,8)	(6,8,5,8)	(3,4,6,5)	(9,8,6,8)	(6,5,4,4)	(5,4,1,6)	(5,6,4,3)	(3,6,6,3)
PO2	(6,6,6,6)	(3,4,4,4)	(1,2,1,1)	(7,7,6,6)	(7,10,9,8)	(6,4,6,8)	(2,6,2,6)	(7,5,7,6)	(5,6,4,3)	(6,3,2,2)	(3,5,4,4)	(5,4,6,6)
PO3	(7,6,6,7)	(4,5,5,5)	(6,4,5,3)	(6,7,10,9)	(8,7,7,8)	(6,6,7,8)	(6,7,5,4)	(4,4,3,9)	(6,6,5,7)	(1,5,1,3)	(4,3,4,4)	(4,2,5,4)
PO4	(6,8,8,6)	(5,5,5,5)	(5,1,2,6)	(6,8,8,9)	(9,10,8,8)	(7,5,7,8)	(6,3,6,1)	(9,4,6,4)	(5,6,6,6)	(6,5,5,4)	(6,6,4,5)	(4,4,2,4)
PO5	(8,8,8,6)	(3,4,6,4)	(1,4,2,5)	(6,10,6,8)	(8,10,8,8)	(6,6,7,5)	(6,2,2,3)	(7,5,8,8)	(6,6,4,5)	(4,5,4,1)	(3,5,5,3)	(2,3,6,2)
PO6	(8,7,7,8)	(3,5,3,3)	(4,2,2,6)	(6,6,6,9)	(9,9,8,9)	(4,6,7,7)	(3,4,4,6)	(6,4,7,5)	(5,4,4,5)	(2,5,1,2)	(4,3,5,5)	(6,2,6,5)
PO7	(6,6,7,8)	(3,5,5,5)	(2,5,3,2)	(7,7,9,9)	(8,9,9,9)	(8,5,7,5)	(4,4,5,4)	(6,5,6,4)	(3,4,6,4)	(4,4,5,4)	(4,5,4,3)	(6,4,6,3)
PO8	(7,7,8,7)	(4,4,2,4)	(4,2,3,5)	(9,9,9,7)	(8,9,9,7)	(8,8,6,6)	(5,7,2,1)	(3,7,5,7)	(5,5,6,4)	(4,2,4,5)	(4,6,3,4)	(3,6,4,4)
PO9	(6,8,8,7)	(5,5,5,3)	(3,2,2,2)	(5,8,5,8)	(8,8,9,8)	(7,4,7,6)	(2,5,1,3)	(7,5,6,5)	(5,7,6,5)	(5,2,1,1)	(4,5,3,6)	(5,5,3,4)
PO10	(8,8,6,7)	(6,6,5,3)	(3,3,5,3)	(8,9,6,9)	(9,8,9,8)	(7,5,7,5)	(5,7,1,5)	(3,7,7,8)	(4,3,4,4)	(3,4,4,5)	(5,6,6,5)	(6,5,4,5)
AI1	(7,6,7,6)	(5,4,4,5)	(4,6,2,3)	(8,10,9,9)	(10,7,9,8)	(5,5,7,6)	(7,2,3,1)	(6,4,9,4)	(3,3,6,5)	(1,2,1,2)	(6,3,5,4)	(3,6,4,4)
AI2	(7,7,7,8)	(3,4,5,6)	(5,5,5,6)	(10,8,8,6)	(10,9,9,10)	(6,7,8,7)	(4,5,6,6)	(8,8,6,6)	(5,5,5,7)	(5,4,5,4)	(5,4,4,4)	(4,3,5,3)
AI3	(7,7,7,6)	(5,2,4,6)	(6,2,2,2)	(6,10,5,10)	(8,9,8,7)	(7,7,5,8)	(5,6,4,2)	(3,6,8,6)	(6,5,4,5)	(5,3,3,4)	(5,5,5,5)	(3,5,6,6)
AI4	(8,8,6,6)	(3,3,3,6)	(2,2,3,4)	(6,10,5,10)	(10,9,9,7)	(7,5,7,5)	(2,4,6,5)	(4,8,4,6)	(4,5,5,5)	(5,3,4,4)	(4,4,5,6)	(3,4,2,4)
AI5	(7,7,7,7)	(5,5,3,4)	(2,3,1,1)	(7,7,6,6)	(10,8,10,7)	(6,8,5,5)	(3,1,2,2)	(8,7,9,3)	(5,6,4,7)	(3,4,2,1)	(4,5,4,4)	(3,5,3,6)
AI6	(8,7,8,8)	(6,3,5,3)	(6,2,5,4)	(6,7,10,9)	(8,9,9,10)	(6,6,8,4)	(3,7,3,6)	(9,5,3,4)	(6,4,6,6)	(4,2,3,6)	(3,6,3,3)	(6,4,5,2)
AI7	(8,6,6,7)	(5,2,3,5)	(3,2,4,1)	(7,8,7,5)	(10,9,8,8)	(6,5,4,6)	(2,2,3,6)	(7,8,3,4)	(6,3,3,6)	(5,2,3,2)	(6,4,3,5)	(3,5,3,3)
DS1	(7,6,6,8)	(5,3,5,3)	(2,2,5,3)	(9,6,7,10)	(9,8,8,9)	(4,7,7,6)	(5,6,5,4)	(5,8,5,5)	(6,4,3,5)	(4,5,6,3)	(5,4,4,5)	(4,5,3,2)
DS2	(6,7,6,8)	(2,4,6,3)	(3,5,5,4)	(10,8,9,6)	(10,10,8,9)	(6,4,5,6)	(6,4,7,3)	(6,6,8,6)	(6,7,6,6)	(6,4,1,2)	(5,5,3,5)	(2,3,2,4)
DS3	(8,6,7,8)	(6,6,3,2)	(5,4,2,4)	(7,9,5,8)	(7,9,8,7)	(5,8,5,4)	(3,6,7,1)	(5,5,7,6)	(5,5,4,5)	(5,4,5,3)	(5,4,3,4)	(3,5,4,3)
DS4	(6,6,7,7)	(5,3,6,3)	(2,5,1,2)	(7,5,8,8)	(8,9,9,9)	(5,7,5,7)	(6,6,5,5)	(5,5,7,3)	(5,4,4,6)	(6,1,2,4)	(4,3,4,4)	(4,3,5,2)
DS5	(8,6,8,6)	(3,2,3,3)	(4,3,2,3)	(6,9,8,9)	(7,7,8,10)	(7,6,7,6)	(7,6,7,2)	(4,5,9,9)	(4,4,5,3)	(2,5,2,3)	(4,4,4,5)	(5,2,6,3)
DS6	(7,7,6,6)	(6,5,5,4)	(5,4,6,1)	(6,8,6,7)	(8,7,10,9)	(5,7,7,4)	(1,2,5,5)	(4,9,7,5)	(6,6,4,7)	(5,2,5,4)	(5,3,3,5)	(3,5,4,5)
DS7	(7,7,7,7)	(4,5,6,4)	(4,1,3,5)	(5,6,8,6)	(10,8,7,9)	(6,8,6,7)	(5,1,3,2)	(7,5,6,8)	(6,7,5,3)	(5,5,3,5)	(5,6,5,6)	(5,5,5,6)
DS8	(6,6,7,6)	(5,4,2,4)	(4,5,6,3)	(9,8,6,10)	(10,8,10,8)	(7,6,5,8)	(5,4,4,6)	(8,7,9,7)	(3,6,7,7)	(4,6,3,2)	(5,5,4,4)	(5,4,5,4)
DS9	(6,7,8,6)	(4,5,2,3)	(2,2,3,5)	(9,6,8,6)	(8,7,8,8)	(4,4,7,5)	(7,5,4,7)	(5,5,4,7)	(5,7,3,6)	(2,4,2,6)	(5,4,4,4)	(2,2,4,4)
DS10	(8,8,7,6)	(5,2,5,5)	(6,4,3,3)	(6,10,6,7)	(8,7,8,7)	(8,4,5,4)	(7,3,1,7)	(8,9,3,6)	(3,7,5,3)	(3,2,3,3)	(6,5,3,5)	(5,5,3,5)
DS11	(6,7,7,7)	(6,4,5,2)	(2,5,5,5)	(6,9,8,5)	(8,9,9,9)	(7,4,8,6)	(6,6,7,3)	(4,6,8,7)	(7,5,4,5)	(4,1,3,3)	(3,4,4,3)	(6,4,3,3)
DS12	(6,7,7,8)	(6,3,6,6)	(3,2,4,4)	(8,8,6,9)	(8,10,9,10)	(6,6,5,5)	(3,2,6,4)	(5,4,5,9)	(6,6,6,6)	(2,3,3,2)	(5,4,3,5)	(2,4,4,2)
DS13	(7,8,6,6)	(5,5,4,5)	(6,2,3,4)	(9,8,7,6)	(8,7,7,7)	(5,8,8,4)	(3,7,4,5)	(4,3,4,8)	(4,5,4,6)	(5,5,1,6)	(3,4,5,5)	(5,4,2,4)
ME1	(6,7,8,7)	(5,5,5,6)	(2,1,5,4)	(9,7,8,8)	(8,8,9,9)	(4,6,6,7)	(7,7,5,3)	(4,8,6,8)	(6,6,6,3)	(4,3,6,5)	(4,6,3,5)	(2,5,3,3)
ME2	(7,6,6,7)	(4,4,5,5)	(2,4,6,5)	(7,7,7,8)	(9,10,7,8)	(8,5,4,7)	(5,5,3,7)	(8,6,4,5)	(6,7,7,6)	(4,1,6,3)	(4,5,5,4)	(5,4,4,3)
ME3	(6,7,7,6)	(6,2,5,6)	(2,2,1,2)	(7,10,7,9)	(10,8,8,9)	(7,6,8,5)	(5,6,3,2)	(8,8,8,7)	(4,3,4,6)	(5,3,4,5)	(3,5,4,4)	(6,6,5,4)
ME4	(8,7,7,7)	(6,4,5,4)	(5,2,4,3)	(10,9,6,7)	(10,9,9,8)	(4,5,4,7)	(2,4,6,4)	(5,6,8,8)	(5,4,3,6)	(2,6,2,2)	(5,3,6,4)	(5,6,6,5)

Highly matured processes are the strength and least mature process can be regarded as the weakness of this scenario when practically implemented. Hence, the strengths and weaknesses of each scenario differ according to the experts' opinions.

We applied the proposed p-robust stochastic DEA model for the efficiency analysis of EA scenarios. First, we used the model

Error! Reference source not found. to obtain the ideal efficiency score of each DMU according to each experts' opinion. The related results are reported in Fig. 1. For example, the second column of this figure reports the ideal efficiency scores according to data gathered from the first expert. According to the results, DMU1, 4, 5, 6 and 8 attained the efficiency score of one.
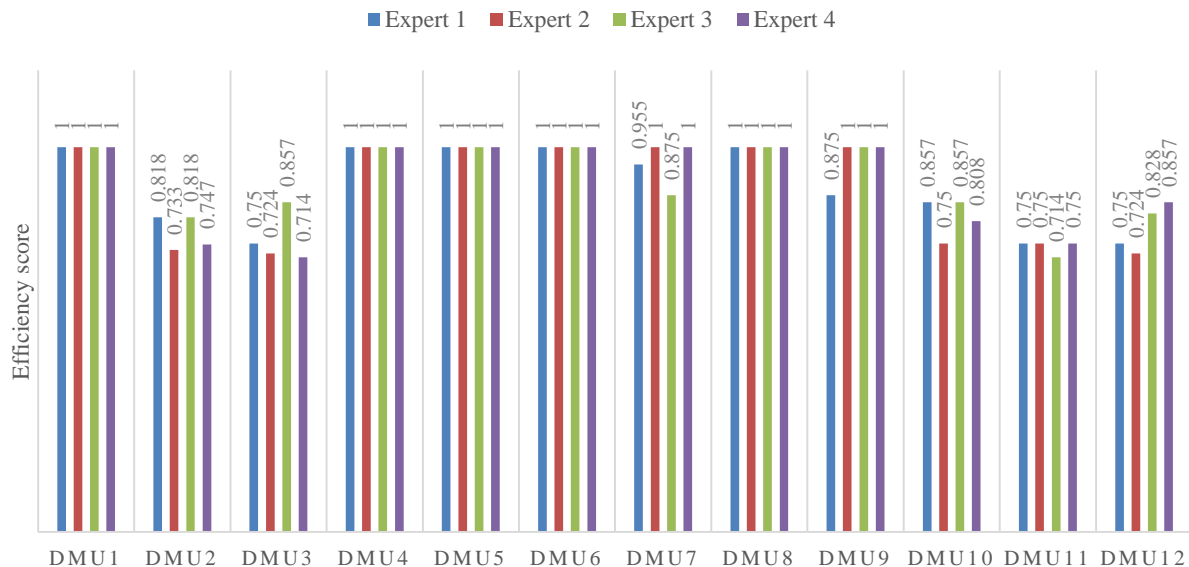

Fig. 1. Ideal efficiency scores according to the experts' opinion

Then, with the use of the ideal score results, we solved model (4). The results of solving this model with different p values and equal weights of 0.25 for each expert are shown in

Table 4. According to these results, model (4) gives infeasible results for some EA scenarios when small values are determined for p such as $p = 0.30, 0.31, 0.32, 0.33$. As we increase the p values, we observe feasible results. For example, by increasing

the p value from 0.34 to 0.41, the efficiency score of DMU3 improves. This improvement can be seen in other DMUs such as 7, 10, and 12. Model (4) maximizes the weighted efficiency score of a given EA scenario according to all experts' opinions whereas p-robust constraints control the relative difference between its efficiency score generated by the model and ideal efficiency from each expert' view. Accordingly, we can obtain the EA scenario ranking based on the p-values on mind.

TABLE 4. THE RESULTS OF SOLVING THE PROPOSED MODEL FOR DIFFERENT P VALUES

p value	0.3	0.31	0.32	0.33	0.34	0.35	0.36	0.37	0.38	0.39	0.4	0.41	0.42	0.43	0.44	0.45
DMU1	0.908	0.908	0.908	0.908	0.908	0.908	0.908	0.908	0.908	0.908	0.908	0.908	0.908	0.908	0.908	0.908
DMU2	0.615	0.615	0.615	0.615	0.615	0.615	0.615	0.615	0.615	0.615	0.615	0.615	0.615	0.615	0.615	0.615
DMU3	Inf^a	0.533	0.536	0.538	0.5401	0.5414	0.5423	0.5431	0.5439	0.5447	0.5455	0.5463	0.546	0.546	0.546	0.546
DMU4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
DMU5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
DMU6	0.833	0.833	0.833	0.833	0.833	0.833	0.833	0.833	0.833	0.833	0.833	0.833	0.833	0.833	0.833	0.833
DMU7	Inf	Inf	0.691	0.692	0.6933	0.6943	0.6944	0.694	0.694	0.694	0.694	0.694	0.694	0.694	0.694	0.694
DMU8	0.859	0.859	0.859	0.859	0.859	0.859	0.859	0.859	0.859	0.859	0.859	0.859	0.859	0.859	0.859	0.859
DMU9	0.735	0.735	0.735	0.735	0.735	0.735	0.735	0.735	0.735	0.735	0.735	0.735	0.735	0.735	0.735
DMU10	Inf	Inf	Inf	Inf	0.5497	0.5514	0.5526	0.5530	0.553	0.553	0.553	0.553	0.553	0.553	0.553	0.553
DMU11	0.611	0.611	0.611	0.611	0.611	0.611	0.611	0.611	0.611	0.611	0.611	0.611	0.611	0.611	0.611	0.611
DMU12	0.599	0.599	0.600	0.600	0.6009	0.6014	0.6014	0.601	0.601	0.601	0.601	0.601	0.601	0.601	0.601	0.601

^a **Infeasible**

B. *Comparison to other methods*

There are two most studied robustness measures, i.e., the minimax cost and the minimax regret, that protect a model against the worst-case scenarios. The former, minimize the maximum scenario cost, and the latter minimize the maximum regret scenario. Since the minimax cost (i.e., here maximin efficiency) and minimax regret methods protect against the worst-case scenarios, they are known to be too conservative from managerial point of view. In contrast, our model maximizes the weighted efficiency of each DMU while taking into accounts all the scenarios and controls the relative regret of scenarios using *p*-robust constraints. Owing to the obtained results, the proposed method is less conservative than the other worst-case models.

The maximin efficiency and minimax regret models are formulated in model (4) and model (5) respectively.

$$\text{maximize } \min_{s \in S} E_s(u,v)$$

subject to:

$$\sum_{r=1}^{k} u_r y_{rj}^s - \sum_{i=1}^{m} v_i x_{ij}^s \leq 0, \quad j=1,...,n, \; s=1,...,S,$$

$$\sum_{i=1}^{m} v_i x_{ij}^s = 1, \quad j=1,...,n, \; s=1,...,S. \quad (4)$$

$$u_r, v_i \geq 0.$$

$$\text{minimize } \max_{s \in S} \frac{E_s^* - E_s(u,v)}{E_s^*} \leq p$$

subject to:

$$\sum_{r=1}^{k} u_r y_{rj}^s - \sum_{i=1}^{m} v_i x_{ij}^s \leq 0, \quad j=1,...,n, \; s=1,...,S, \quad (5)$$

$$\sum_{i=1}^{m} v_i x_{ij}^s = 1, \quad j=1,...,n, \; s=1,...,S.$$

$$u_r, v_i \geq 0.$$

Next, models (2), model (5) and model (6) are applied, and the results were compared. For comparison of these three models, two measures were considered. The first measure was the average weighted efficiency (AWE) of each DMU and the second measure was the average relative regret (ARR) of each DMU. After solving each model and obtaining $E_s(u,v)$, these measures were calculated using the following equations:

$$\text{AWE} = \sum_{s=1}^{S} w_s E_s(u,v) \quad (6)$$

$$ARR = \sum_{s=1}^{S} w_s \frac{E_s^* - E_s(u,v)}{E_s^*} \quad (7)$$

The results are reported in

Table 5 and illustrated in Figure 2 and

Figure 3. In this experiment, $p = 0.34$ and $w_1 = w_2 = w_3 = w_4 = 0.25$.

TABLE 5. AVERAGE WEIGHTED EFFICIENCY (AWE) AND AVERAGE REGRET (ARR) CRITERIA

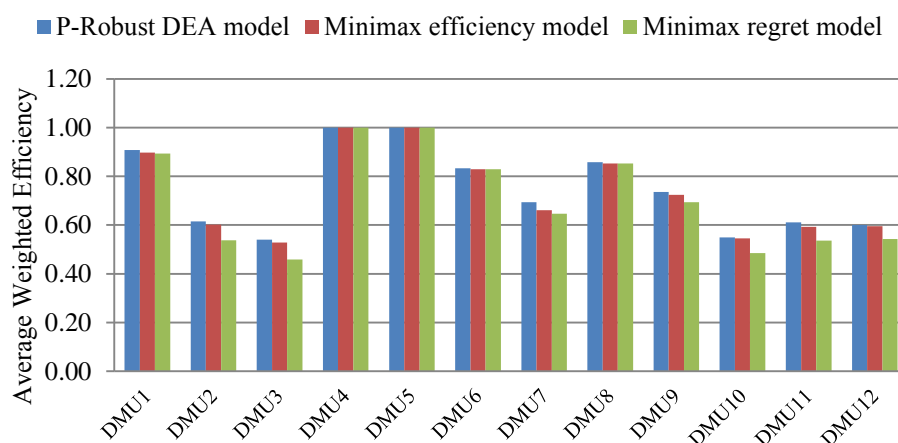| DMU No.	The proposed p-robust stochastic DEA model		Maximin efficiency model		Minimax regret model	
	AWE	ARR	AWE	ARR	AWE	ARR
DMU1	0.9079	0.0921	0.8973	0.1027	0.8929	0.1145
DMU2	0.6146	0.2078	0.6020	0.2254	0.5376	0.3186
DMU3	0.5401	0.2896	0.5280	0.3029	0.4591	0.4332
DMU4	1	0	1	0	1	0
DMU5	1	0	1	0	1	0
DMU6	0.8327	0.1673	0.8291	0.1709	0.8291	0.2061
DMU7	0.6933	0.2765	0.6612	0.3073	0.6466	0.3964
DMU8	0.8586	0.1414	0.8531	0.1469	0.8531	0.1721
DMU9	0.7353	0.2395	0.7246	0.25	0.6939	0.3684
DMU10	0.5497	0.3279	0.5452	0.3320	0.4853	0.4985
DMU11	0.6111	0.1741	0.5931	0.1993	0.5362	0.2569
DMU12	0.6009	0.2374	0.5947	0.2433	0.5427	0.3280

Figure 2. Comparison of the proposed p-robust stochastic DEA, maximin efficiency and minimax regret models in terms of average weighted efficiency criterion
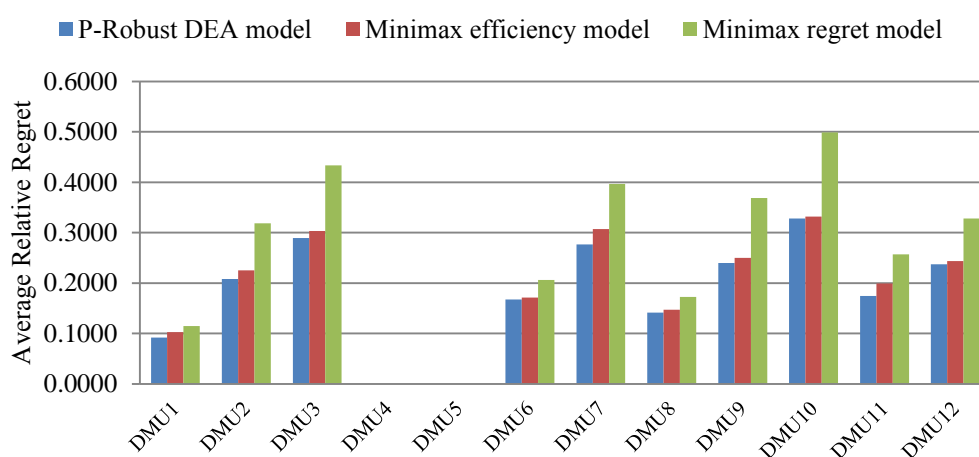

Figure 3. Comparison of the proposed p-robust stochastic DEA, maximin efficiency and minimax regret models in term of average regret criterion

The results of Table 5 and Figure 2 confirms that average weighted efficiency of each DMU obtained by our proposed method is higher than that of provided by the maximin efficiency and minimax regret models. Moreover, average regret values of our model are lower than those of provided by model (5) and model (6). This matter is also reflected in

C. Sensitivity analysis of the experts' weight

In this Section, we run some experiments for understanding the sensitivity of our model to the experts' weights and contrast the results to the sensitivity of model (4) and model (5). The first row of Table 6 presents the of weight vector of $W = (w_1, w_2, w_3, w_4)$. In fact, the w_s indicates the important of the sth experts' opinion in our group decision-making process. Then, each model was solved using these weights and the difference between expected efficiency of each DMU with the average ideal efficiency was obtained. The difference was obtained using following equation:

$$Gap = \sum_{s=1}^{S} w_s E_s^* - \sum_{s=1}^{S} w_s E_s(u,v) \qquad (8)$$

Figure 3. The average relative regret value indicates the relative difference between efficiency of each model and the ideal efficiency from each expert's viewpoint. Hence, the small value of this measure indicates that the model generates close results to the ideal efficiencies.

The smaller value of the gap for a model approves that the model generates more accurate results, since the average weighted efficiency of that model is closer to the ideal weighted efficiency. Model (3), model (4), and model (5) were solved considering different weight values presented in the first four rows of Table 6, and the gap values were calculated for each model. The gap results are reported in Table 6. Comparison of different models with varying weights, confirms that the proposed p-robust stochastic DEA model generates better results as the differences obtained by our model are smaller than those of obtained by other models. This affirms the superiority of our proposed model in comparisons to other competing worst case models.

TABLE 6. DIFFERENCE BETWEEN THE AVERAGES OF THE WEIGHTED EFFICIENCY SCORE AND THE WEIGHTED IDEAL EFFICIENCY SCORE PROVIDED BY DIFFERENT MODELS

W	(0.7,0.1,0.1,0.1)	(0.1,0.7,0.1,0.1)	(0.1,0.1,0.7,0.1)	(0.1,0.1,0.1,0.7)	(0.4,0.2,0.2,0.2)	(0.2,0.4,0.2,0.2)	(0.2,0.2,0.4,0.2)	(0.2,0.2,0.2,0.4)	(0.3,0.3,0.2,0.2)	(0.3,0.2,0.3,0.2)	(0.3,0.2,0.2,0.3)	(0.2,0.3,0.3,0.2)	(0.2,0.3,0.2,0.3)	(0.2,0.2,0.3,0.3)
The proposed p-robust stochastic DEA model														
DMU1	0.049	0.050	0.050	0.095	0.079	0.086	0.093	0.098	0.086	0.089	0.089	0.092	0.093	0.098
DMU2	0.152	0.100	0.175	0.097	0.164	0.144	0.180	0.146	0.156	0.174	0.162	0.166	0.152	0.164
DMU3	0.110	0.191	0.215	0.165	0.186	0.214	0.232	0.214	0.201	0.214	0.204	0.228	0.217	0.227
DMU4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU6	0.136	0.086	0.089	0.091	0.166	0.147	0.154	0.154	0.163	0.168	0.165	0.154	0.162	0.159
DMU7	0.173	0.214	0.239	0.242	0.233	0.269	0.263	0.256	0.256	0.254	0.245	0.266	0.269	0.267
DMU8	0.057	0.057	0.073	0.081	0.115	0.114	0.128	0.133	0.114	0.140	0.130	0.143	0.130	0.143
DMU9	0.173	0.197	0.258	0.197	0.217	0.229	0.246	0.223	0.226	0.233	0.220	0.238	0.230	0.240
DMU10	0.240	0.216	0.228	0.221	0.266	0.258	0.264	0.252	0.264	0.271	0.259	0.269	0.257	0.263
DMU11	0.100	0.090	0.081	0.100	0.137	0.121	0.113	0.143	0.132	0.128	0.143	0.117	0.132	0.128
DMU12	0.130	0.130	0.161	0.180	0.174	0.180	0.191	0.186	0.179	0.187	0.182	0.189	0.183	0.193
Maximin Efficiency model														
DMU1	0.095	0.105	0.105	0.105	0.100	0.104	0.104	0.104	0.102	0.102	0.102	0.104	0.104	0.104
DMU2	0.201	0.150	0.201	0.158	0.185	0.168	0.185	0.171	0.176	0.185	0.178	0.176	0.169	0.178
DMU3	0.227	0.211	0.291	0.205	0.231	0.226	0.253	0.224	0.229	0.242	0.228	0.239	0.225	0.238
DMU4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU6	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171
DMU7	0.276	0.328	0.253	0.328	0.289	0.307	0.282	0.307	0.298	0.286	0.298	0.294	0.307	0.294
DMU8	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147
DMU9	0.196	0.240	0.271	0.271	0.228	0.243	0.253	0.253	0.235	0.240	0.240	0.248	0.248	0.253
DMU10	0.278	0.238	0.302	0.273	0.274	0.261	0.283	0.273	0.268	0.279	0.274	0.272	0.267	0.278
DMU11	0.156	0.144	0.135	0.156	0.151	0.147	0.144	0.151	0.149	0.147	0.151	0.145	0.149	0.147
DMU12	0.171	0.156	0.218	0.235	0.187	0.182	0.203	0.208	0.184	0.195	0.198	0.192	0.195	0.206
Minimax Regret model														
DMU1	0.095	0.105	0.105	0.105	0.100	0.104	0.104	0.104	0.102	0.102	0.102	0.104	0.104	0.104
DMU2	0.194	0.182	0.194	0.184	0.190	0.186	0.190	0.187	0.188	0.190	0.188	0.188	0.186	0.188
DMU3	0.228	0.223	0.248	0.222	0.229	0.228	0.236	0.227	0.229	0.233	0.228	0.232	0.228	0.232
DMU4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DMU6	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171
DMU7	0.215	0.294	0.271	0.294	0.251	0.277	0.269	0.277	0.264	0.260	0.264	0.273	0.277	0.273
DMU8	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147
DMU9	0.248	0.255	0.269	0.269	0.256	0.259	0.263	0.263	0.258	0.260	0.260	0.261	0.261	0.263
DMU10	0.280	0.259	0.280	0.270	0.275	0.268	0.275	0.271	0.271	0.275	0.273	0.271	0.270	0.273
DMU11	0.153	0.152	0.148	0.153	0.152	0.152	0.150	0.152	0.152	0.151	0.152	0.151	0.152	0.151
DMU12	0.189	0.185	0.201	0.205	0.193	0.192	0.197	0.198	0.192	0.195	0.196	0.194	0.195	0.198

V. CONCLUSION

This paper describes an ongoing research project for EA scenario analysis considering the business and IT alignment, as a key step for enhancing the performance of an organization through evaluating the IT processes of organizations.

For taking critical strategic decisions in large organizations, the consistency and reliability of the final solution when using automated tools exploiting multiple experts' opinion is a challenging task. In this paper, we introduced a novel group-based DEA model, which is one of the most efficient tools for efficiency estimations. The proposed technique has the unique feature of controlling the difference in opinions of experts with the incorporation of p-robustness measure. This technique was applied for selecting the best EA scenario as the most suitable candidate for implementation. Furthermore, the COBIT processes were used as the output data for assessing the performance of EA scenarios to achieve business and IT alignment. Several numerical experiments were conducted, and the performance of the proposed model was compared with two mostly studied techniques: maximin efficiency and the minimax regret. As well, the experiments indicate the closeness of our technique to the ideal solution in regard the other two compared techniques.

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