Journal of Universal Computer Science, vol. 17, no. 10 (2011), 1390-1411
submitted: 30/10/10, accepted: 15/4/11, appeared: 1/6/11 © J.UCS

Representing a Composing Fuzzy-DEA Model to Measure Knowledge Workers Productivity based upon their Efficiency and Cost Effectiveness

Ali Abdoli
(Amirkabir University of Technology, Tehran, Iran
ali.abdoli@aut.ac.ir)

Jamal Shahrabi
(Amirkabir University of Technology, Tehran, Iran
jamalshahrabi@aut.ac.ir)

Jalil Heidary
(Amirkabir University of Technology, Tehran, Iran
heidaryd@aut.ac.ir)

Abstract: By entering the knowledge age and the appearance of knowledge economy, organizations are more dependent on knowledge workers productivity. Productivity means doing the right things right. It shows how a knowledge worker makes use of resources to fulfill the goals of the organization. This definition makes productivity be the result of simultaneous existence of efficiency "doing the things right" and effectiveness "doing the right things". Since factors influencing knowledge workers productivity cannot be definitely measured, uncertainty theory plays an important role in this area. So in this paper, first, dimensions of productivity will be introduced and then, by the use of linguistic fuzzy approach and DEA, efficiency and effectiveness of knowledge workers will be measured. Next, a model for measuring knowledge workers productivity will be presented on the basis of efficiency and effectiveness. Finally, values of knowledge workers productivities will be ranked. In the last section, the result of this five-step method is examined through a case study.

Keywords: Knowledge worker, Productivity, Efficiency, Effectiveness, Fuzzy DEA
Categories: M.9

1 Introduction

Productivity is a determinant factor for the success of any organization. This holds true also in the case of knowledge-intensive organizations, which can be defined as any organization in which "Knowledge has more importance than other inputs" [Antikainen and Lonnqvist 05]. During recent decades, the core of organizations has moved from being capital or labor intensive to being technology intensive, and the current direction of evolution is towards becoming knowledge intensive [Chang 09]. With the advent of knowledge economy, knowledge is known as the strategic priority and the main source of competitive advantage of the organization [Choi et al. 08]. As a result, knowledge workers (KW) as people with a high degree of education or expertise whose work primarily involves the creation, distribution, or application of knowledge play a major role [Davenport02]. Peter Drucker (1999) states the challenge today is to measure and increase KW's productivity and declare making knowledge workers productive will be the great management task of this century. Measuring knowledge workers productivity is the first step in this important management task.

Why did Drucker – and why should we - believe that knowledge workers and their productivity would be so important? There are three key reasons [Davenport (08)]:

- First, knowledge workers are a large and growing category of workers. If we can't figure out how to make a quarter to a third of the labor force more productive, we are going to have problems with our economy overall.
- Second, knowledge workers are the most expensive type of worker that companies employ, so it's doubly shameful if they're not as productive as they could be.
- Third, knowledge workers are essential to the growth of many economies. Agricultural and manufacturing work is moving to countries with low labor costs, such as China, which means that the jobs that remain in knowledge-based economies are particularly critical to these countries' survival.

Potential advantages of measuring knowledge worker productivity include: Improved personal selection, job assignment, identification of redundant skills within an organization, rewards and bonuses, performance forecasts, identification of KW capacity based on 100 percent productivity, strategic planning, address specific needs, work balancing, reduce subjectivity from evaluation, and establish benchmarks [Ramirez and Nembhard 04]. Meanwhile, it is difficult to measure the productivity of workers whose tasks are not fixed, have no standard production times, and whose task can be performed differently by various workers and not be easily observable [Davenport and Prusak 00].

Today, between one-fourth and one-third of all workers in advanced economies are knowledge workers. Knowledge workers create the innovation and devise the strategies that keep their competitive. They are key to organizational growth, yet few companies have explicitly addressed the productivity and performance of their knowledge workers, and most continue to manage this new breed of employee with techniques designed for the Industrial Age. As this critical sector of the workforce continues to grow in size and importance, failing to address knowledge worker performance is a mistake that could cost companies their future[Davenport (08)].

There are numerous methodologies suggested in the literature to measure the productivity for specific types of knowledge workers (quality, outcome, cost, etc.). These are structured methods to measure productivity in one or more dimensions. Some have seen applications across a range of industries, while other methods have been proposed in theory but have seen little application[Ramirez and Nembhard 04]. These Traditional productivity measures, total or partial, have certain requirements: The outputs compared have to be similar and comparable both in characteristics and in quality and the data used in measurement has to be quantitative [Kemppila and Lonnqvist 03]. Furthermore, crisp DEA methods have been employed in cases in which the decision making units were homogeneous; therefore, they are not applicable for workers with contrasting and intangible characteristics.

Currently, there is no universally accepted method that could be used in measuring knowledge worker productivity and much of the literature focuses on differences between knowledge workers and manual workers, and does not identify specific methods for measuring KW productivity [Ramirez and Nembhard 04]. Consequently, a new technique is asked for through which the knowledge-intensive organizations can measure, compare and manage the knowledge worker productivity, in different levels of any organization and even in various industries.

Though the terms like productivity, efficiency and effectiveness have been used together, and practitioners sometimes alternate their meanings, however we must not identify productivity with efficiency and/or effectiveness [Rutkauskas and Paulavičienė 05]. Indeed, productivity is the outcome of simultaneous presence of effectiveness "doing the right things" and efficiency "doing things right". Thus, regarding this general definition of productivity and using fuzzy linguistic approach and fuzzy DEA, a five-step model for measuring knowledge workers productivity in an individual/group level based upon their efficiency and effectiveness is introduced in this paper. Applying this model will make it possible to compare knowledge workers of different sections and even industries having heterogeneous inputs and outputs and dissimilar characteristics.

2 The Approach to Measure Knowledge Worker Productivity

In the section a five-step model for measuring knowledge workers productivity based upon their efficiency and effectiveness is presented in order to capture all three elements of efficiency, effectiveness and productivity of knowledge workers.

First step in measuring knowledge workers productivity is to determine the dimensions of their productivity according to measured society.

During recent decades, researchers have introduced various dimensions of productivity as measures of Knowledge workers productivity. The following dimensions being summarized generally are taken from the results of these studies:

- Quantity [Ramirez and Nembhard 04]: The number of tangible outputs of knowledge workers which are expressed quantitatively.
- Cost / Revenue [Ramirez and Nembhard 04]: Cost/revenue that enter into the system via knowledge workers directly or indirectly.
- Timeliness [Ramirez and Nembhard 04]: is associated with completion of predefined times, spent overtime for performing the task and other time-related issues.
- Authority [Ramirez and Nembhard 04]: The independence and power given to knowledge workers for doing a certain task and successfully employing these utilities in production.
- Quality [Ramirez and Nembhard 04]: Things that are done right, and can fulfill qualitative goals.
- Creativity/innovation[Ramirez and Nembhard 04]: The ability of knowledge worker in creating effective ideas to increase productivity.
- Experience [Nickolas00; Steward97]: Work experience in a certain place and familiarity with its science that affect the knowledge work.

- Education [Drucker94; Liebowitz and Wright 99]: Official, analytical and theoretical knowledge which is essential for developing the products and new services.

According to the presented approach in this paper, the above-mentioned dimensions will be categorized into two groups (figure 1):

- Dimensions influencing knowledge workers efficiency: education, experience, Creativity/innovation, quality, authority, timeliness, quantity.
- Dimension influencing knowledge workers effectiveness: cost

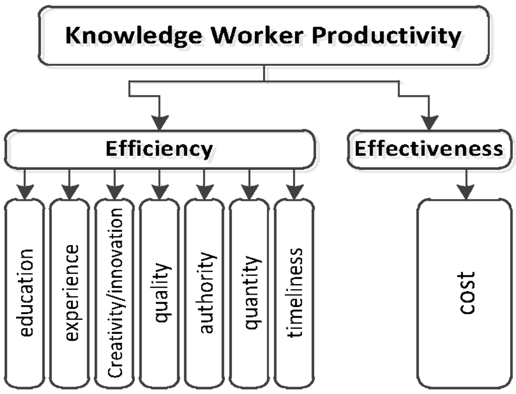

Figure 1: Hierarchical diagram for classifying dimensions of KW productivity

The above approach is a general approach. According to various factors such as the company's goals, analyzer's goals, knowledge worker'stasks, etc, it is possible to make use of all dimensions or to consider and classify some of them.

<u>Second step</u>: measuring knowledge workers efficiency.

To do this, we should separate the inputs and outputs of dimensions on knowledge workers efficiency according to figure (2).

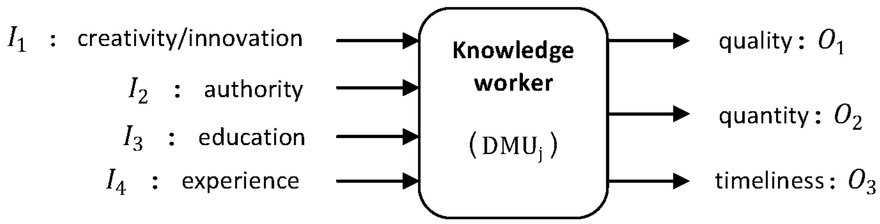

Figure 2: Inputs and outputs on knowledge workers efficiency

Finally, accessing corresponding amounts of inputs and outputs in figure (2) for each knowledge worker in form of linguistic variables (table 1) and applying fuzzy

DEA model introduced in section 3, the efficiency of knowledge workers will be calculated.

Linguistic Variables	Corresponding TFNs
Extremely high (EH)	(0.9 , 1.0 , 1.0)
Very high (VH)	(0.7 , 0.9 , 1.0)
High (H)	(0.5 , 0.7 , 0.9)
Fair (F)	(0.3 , 0.5 , 0.7)
Low (L)	(0.1 , 0.3 , 0.5)
Very low (VL)	(0.0 , 0.1 , 0.3)
Extremely low (EL)	(0.0 , 0.0 , 0.1)

Table 1: linguistic variables and their corresponding triangular fuzzy numbers

Third step: measuring knowledge workers effectiveness.

In this step, based on determined goal (minimizing cost), the analyzer assess the individual relative effectiveness of knowledge worker by the use of illustrated equation in section 4.

Fourth step: measuring knowledge workers productivity on the basis of measured efficiency and effectiveness in the second and third steps.

In this state by the use of efficiency and effectiveness taken from steps three and four, fuzzy productivity of knowledge workers, according to introduced model in section 5, can be measured.

Fifth step: ranking knowledge workers productivity values.

In final step, maintained fuzzy numbers for each knowledge workers productivity using introduced method in section four will be ranked.

The overall view of this model demonstrated in figure (3).

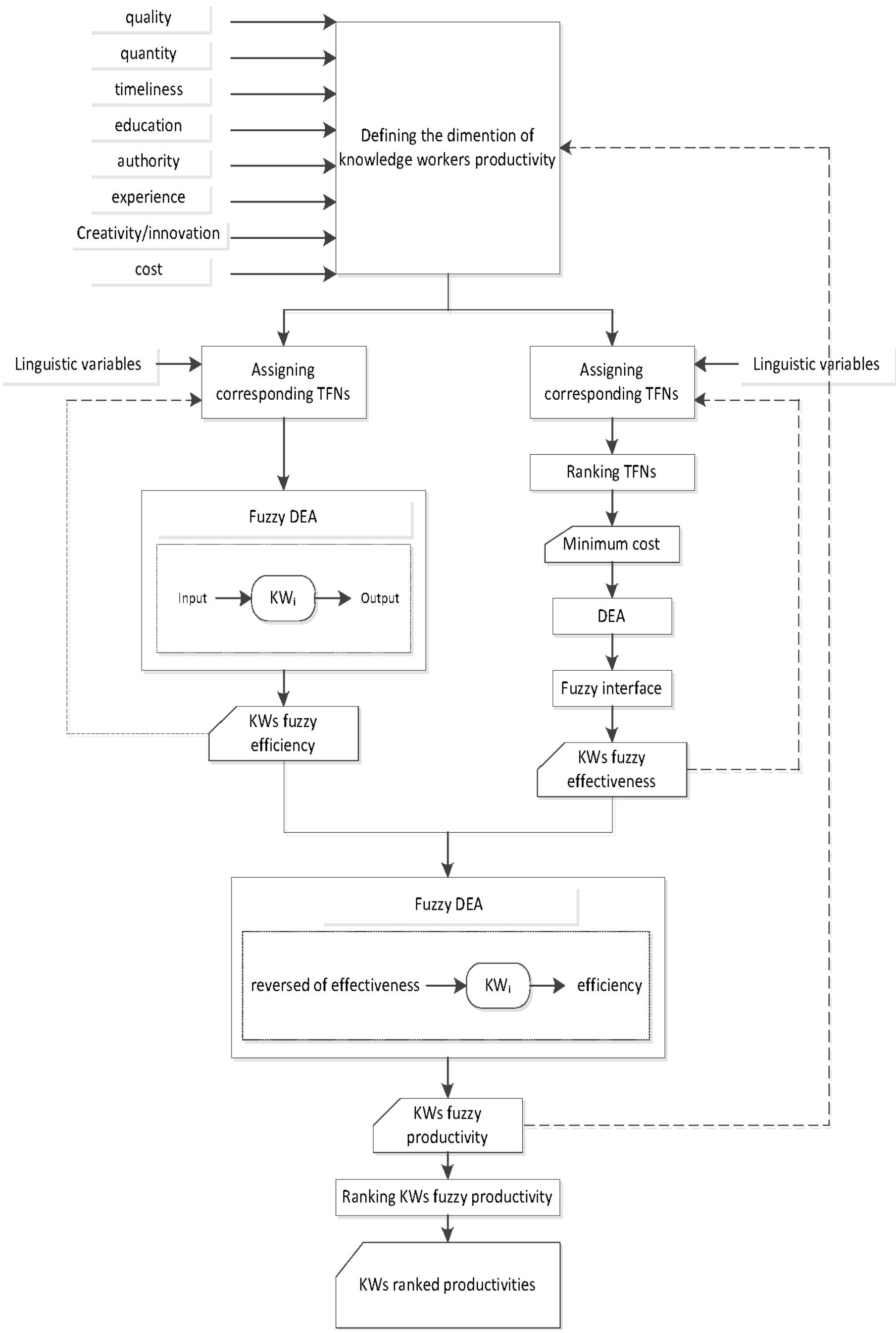

Figure 3: Hierarchal model of measuring knowledge workers' productivity

3 Measuring Knowledge Workers Efficiency

Measuring the efficiency of a decision making unit (DMU) has long been considered as a difficult task because one is dealing with complex economic and behavioral entities. This task becomes more difficult when it involves multiple inputs and multiple outputs, in that a set of weights has to be determined to aggregate the outputs separately to form a ratio as the efficiency [Kau and Liu 00].To solve this problem Data Envelopment Analysis (DEA) method was proposed by charneset al.(1978)for assessing relative efficiency of decision making units with several inputs and outputs. Today DEA is an important tool for analysis and research in managing research in performance, system engineering, decision analysis and etc. [Wen and Li 09].

Since the pioneering work of Charnes et al. (1978), a great variety of models and application have been reported [Seiford96]. This approach has one characteristic; that is, the efficiency measures are very sensitive to data. If there is an outlier, than the efficiency measures of most DMUs will change drastically. Therefore, a key to the success of the DEA approach is the accurate measure of all factors, including inputs and outputs [Kau and Liu 00]. However, we are faced with many problems when all or some inputs and outputs are ambiguous and indefinite. To deal quantitatively with imprecision in decision process, in this paper we apply a method which is able to provide fuzzy efficiency for DMUs with fuzzy observation. For instance we are forced to use some linguistic variants such as good, bad, average, etc., when assessing the performance of knowledge workers.

Doing calculations through fuzzy numbers has countless complexities. In order to eliminate this problem, Dubois and Prade proposed a certain type of fuzzy numbers, called LR fuzzy numbers. The most predominant fuzzy numbers in this category are triangular fuzzy numbers whose characteristics and membership function are depicted in equation (1) and figure (4).

$$\mu_{\tilde{A}(x)} = \begin{cases} (x-L)/(M-L) & L \leq x \leq M \\ (U-x)/(U-M) & M \leq x \leq U \\ 0 & otherwise \end{cases} \tag{1}$$

Triangular fuzzy numbers are contacted as $\tilde{A} = (\mathrm{L}, \mathrm{M}, \mathrm{U})$ in this representation.

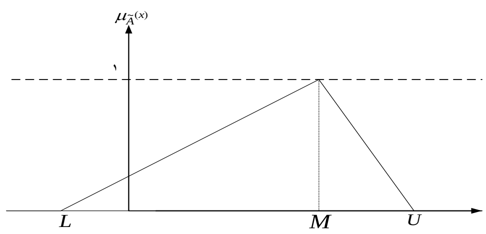

Figure 4: Triangular Fuzzy Number $\widetilde{\mathrm{A}}$

Suppose two positive triangular fuzzy numbers

$\tilde{A} = (L_1, M_1, U_1)$ *and* $\tilde{B} = (L_2, M_2, U_2)$. According to expanded basics and specifications by Lotfizadeh [Zadeh65], [Zadeh99], the algebraic operations for these numbers are as follows:

$$add = \tilde{A} + \tilde{B} = (L_1 + L_2, M_1 + M_2, U_1 + U_2) \tag{2}$$

$$subtraction = \tilde{A} - \tilde{B} = (L_1 - U_2, M_1 - M_2, U_1 - L_2) \tag{3}$$

$$miltiple = \tilde{A} \times \tilde{B} \cong (L_1 L_2, M_1 M_2, U_1 U_2) \tag{4}$$

$$\text{divisions} = \tilde{A} \div \tilde{B} \cong (\frac{L_1}{U_2}, \frac{M_1}{M_2}, \frac{U_1}{L_2}) \tag{5}$$

$$reverse = \frac{1}{\tilde{A}} \cong \left(\frac{1}{U_1}, \frac{1}{M_1}, \frac{1}{L_1}\right) \tag{6}$$

$$\alpha . \tilde{A} = (\alpha L_1, \alpha M_1, \alpha U_1) \tag{7}$$

The result of equations (4-6) is not a triangular fuzzy number, yet it can be estimated by a triangular fuzzy number.

In continuation to compute efficiency of knowledge workers, we suppose n knowledge workers (DMU) each with m inputs and s outputs. $x_{ij}\,(i = 1,2,\dots,m)$ and $y_{rj}\ (r = 1,2,\dots,s)$ knowledge worker respectively.

All inputs and outputs are thought to be unknown, and they are assumed as triangular fuzzy numbers. $\tilde{x}_{ij} = (x_{ij}^L, x_{ij}^M, x_{ij}^U)$, $\tilde{y}_{rj} = (y_{rj}^L, y_{rj}^M, y_{rj}^U)$ in which $x_{ij}^L > 0$ and $y_{rj}^L > 0$ for $i = 1,2,\dots,m$ and $r = 1,2,\dots,s$ and $j = 1,2,\dots,n$.

Crisp inputs and outputs are shown as a special kind of triangular fuzzy numbers in which $\mathrm{x}_{\mathrm{ij}}^{\mathrm{L}} = \mathrm{x}_{\mathrm{ij}}^{\mathrm{M}} = \mathrm{x}_{\mathrm{ij}}^{\mathrm{U}}$ and $\mathrm{y}_{\mathrm{rj}}^{\mathrm{L}} = \mathrm{y}_{\mathrm{rj}}^{\mathrm{M}} = \mathrm{y}_{\mathrm{rj}}^{\mathrm{U}}$ .For measuring the fuzzy efficiency of the j decision making unit, the following DEA model is presupposed [Wang09]:

$$Maximize \quad \tilde{\theta}_0 \approx [\theta_0^L, \theta_0^M, \theta_0^U] \tag{8}$$

$$Subject\ to \quad \tilde{\theta}_j \approx \left[\theta_j^L, \theta_j^M, \theta_j^U\right]$$

$$j = 1, \dots, n$$

0 indicates the observed decision making unit (there KW) and θ_0^{L} , θ_0^{M} , θ_0^{U} are gained from solving the following three liner planning (LP):

$$Maximize \quad \theta_0^L = \sum_{r=1}^{s} u_r y_{r0}^L \tag{9}$$

$$Subject\ to \quad \sum_{i=1}^{m} v_i\, x_{i0}^U = 1$$

$$\sum_{r=1}^{s} u_r y_{rj}^U - \sum_{i=1}^{m} v_i x_{ij}^L \leq 0\,, \quad j = 1, \ldots, n$$

$$u_r\,, v_i \geq 0\,, \quad i = 1, \ldots, m; r = 1, \ldots, s$$

$$Maximize \quad \theta_0^M = \sum_{r=1}^{s} u_r y_{r0}^M \tag{10}$$

$$Subject\ to \quad \sum_{i=1}^{m} v_i\, x_{i0}^M = 1$$

$$\sum_{r=1}^{s} u_r y_{rj}^U - \sum_{i=1}^{m} v_i x_{ij}^L \leq 0\,, \quad j = 1, \ldots, n$$

$$u_r\,, v_i \geq 0\,, \quad i = 1, \ldots, m; r = 1, \ldots, s$$

$$Maximize \quad \theta_0^U = \sum_{r=1}^{s} u_r y_{r0}^U \tag{11}$$

$$Subject\ to \quad \sum_{i=1}^{m} v_i\, x_{i0}^L = 1$$

$$\sum_{r=1}^{s} u_r y_{rj}^U - \sum_{i=1}^{m} v_i x_{ij}^L \leq 0\,, \quad j = 1, \ldots, n$$

$$u_r\,, v_i \geq 0\,, \quad i = 1, \ldots, m; r = 1, \ldots, s$$

By solving LP models (9-11) for each knowledge worker, the best relative fuzzy efficiencies of n knowledge workers can be obtained. Many experts have confined their assessments of decision-making units just to efficiency measurements, and have occasionally regarded it as productivity. However, in this paper, after introducing models of measuring effectiveness, how effectiveness as well as efficiency has impact on productivity will be illustrated.

4 Measuring Knowledge Workers Effectiveness

In the management literature, efficiency is often associated with performing activities as well as possible or ‘‘doing things right’’, whereas effectiveness is often equated with the proper selection of the activities or ‘‘doing the right things’’. Thus, an organization or decision making unit (DMU) is effective to the degree to which it achieves its goals. Measures of effectiveness evaluate the performance of business units’ efforts with respect to strategic goals, and serve as a critical component in the management planning and control processes [Asmid et al. 07].
Effectiveness is the degree and amount of achieved predetermined objectives. That is to say, effectiveness depicts the amount of presupposed objectives’ fulfilment succeeded by accomplished endeavour. In this part, first, minimum cost will be defined using ranking fuzzy method and then, by putting DEA and algebraic fuzzy numbers’ operators, a method to measure effectiveness will be presented.

Using DEA, Asmild and others [Asmid et al. 07] introduced method for measuring crisp data effectiveness which are going to be stated; furthermore, applying fuzzy numbers algebraic operators equation for measuring the effectiveness of the knowledge workers will be presented in proceeding parts.

A set of decision making units (knowledge workers) with m inputs and s outputs are assumed, $x_j = (x_{1j}, \dots, x_{mj})$ and $y_j = (y_{1j}, \dots, y_{sj})$ show the input and output vectors for the j unit, $j = 1, \dots, n$. X indicates the matrix $m \times n$ for inputs and Y indicates the matrix $s \times n$ for outputs.

If the objective of the production units, or the objective assigned by the analyst, is cost minimization, then the input prices $c \geq 0$ must be known. The overall minimum cost of producing output vector y_0 is obtained by solving the following:

$$\begin{aligned} &Minimize \quad c^T x \qquad (12)\\ &Subject\ to \quad x \geq X\lambda \\ &y_0 \leq Y\lambda \\ &1^T\lambda = 1 \\ &\lambda \geq 0 \end{aligned}$$

Cost effectiveness (OE_i) is determined by dividing overall minimum cost $c^T x^*$ by observed cost:

$$OE_i = \frac{c^T x^*}{c^T x_0} \tag{13}$$

Generally, it is not possible to determine the precise values of knowledge workers' cost, so by assuming the approximate values in triangular fuzzy numbers' form, we can estimate knowledge workers' cost-effectiveness through the equations (5,13).

$$\widetilde{OE}_i = \left(OE_{\mathrm{i}}^{\mathrm{L}}, OE_i^M, OE_i^U\right) \approx \left(\frac{[\mathrm{c^T}]^{\mathrm{L}}\,\mathrm{x}^*}{[\mathrm{c^T}]^{\mathrm{U}}\,\mathrm{x_0}}, \frac{[\mathrm{c^T}]^{\mathrm{M}}\,\mathrm{x}^*}{[\mathrm{c^T}]^{\mathrm{M}}\,\mathrm{x_0}}, \frac{[\mathrm{c^T}]^{\mathrm{U}}\,\mathrm{x}^*}{[\mathrm{c^T}]^{\mathrm{L}}\,\mathrm{x_0}}\right) \tag{14}$$

5 Measuring Productivity Based Upon Efficiency and Effectiveness

Productivity showed how an organization makes use of its resources to achieve its goals. This definition depicts that productivity is the result of simultaneous existence of efficiency "doing things right" and effectiveness "doing right things". Productivity determines whether the activity of an organization is efficient and effective. Though the terms like productivity, efficiency and effectiveness have been used together and practitioners sometimes alternate their meanings, however, we must not identify productivity with efficiency and/or effectiveness. Productivity requires both efficiency and effectiveness, because a certain activity will not be productive if it is only efficient, but not effective, or effective, but not efficient [Rutkauskas and Paulavičienė 05]. Thus, productivity can be defined as doing right thing right; and any knowledge worker, which is doing its best to accomplish the established objectives, is identified as productive. In a word, productivity is first to find the proper issues and then, to do them properly [Malbotra97]. Based upon this explanation and the total goal of DEA "maximum output with minimum input", following model is introduced for productivity of any knowledge worker (DMU).

$$I\ \text{(reversed of cost effectiveness)} \longrightarrow \boxed{DMU_j} \longrightarrow \text{(Efficiency)}\ O$$

Figure 5: Productivity model (Goal: cost minimization)

Since production of the maximum output with the minimum input is aimed in DEA models, so in this represented model the reversed effectiveness is assumed as the input. Based upon illustrated model in figure (5), productivity can be measured by applying effectiveness and efficiency respectively as input and output of the knowledge worker, and utilizing DEA fuzzy model.

6 Case Study

Pooyeshpajooh consulting Engineers Company is one of the well-known companies in the northwestern part of Iran .This organization is highly ranked and serves in refinery and petrochemical fields, oil and gas transition pipes. Scientific products and service of this company show that all the workers are knowledge workers, and the company is knowledge intensive this establishment consists of seven work groups. They include the following groups: process, mechanics, safety, civil, electrical and planning. One knowledge worker has been selected from each group (table 2), and their performance are monitored for three months.

KW_1	process team head	KW_9	mechanic expert
KW_2	safety team head	KW_{10}	architecture expert
KW_3	mechanic team head	KW_{11}	civil expert
KW_4	civil team head	KW_{12}	electrical expert
KW_5	electrical team head	KW_{13}	precision instrument expert
KW_6	planning team head	KW_{14}	civil planner
KW_7	process expert	KW_{15}	electrical planner
KW_8	safety expert	KW_{16}	mechanical planner

Table 2: the considered statistical society

We follow the stated five steps to assess their productivity.

First step: determine the dimensions of KWs productivity according to measured society.

Quality (O_1):

The outputs of designing projects and explanatory designs are in form of plans, documents, records and CDs which are revised by the project manager; and in case of any erroneous point, it will be modified by cooperative activities and transferring it to the supposed person. After the documents are sent, the employer checks all documents and in case of any probable mistakes, the noted modifications are rectified and sent back to the company. This procedure is carried on until the employer's demand is fulfilled. Thus, in this example quality means doing things right with the fewest errors and the best approval of the costumer. Estimation of this variable is presented in appendix 1 (table-app1).

Quantity (O_2):

The aforesaid knowledge workers were working on designing projects of oil terminals and were preparing justifying plans in this field during the period of performing measurements. Occasionally, cooperation of entire working groups is necessitated in executing some projects; while some other projects such as preparing explanatory designs and etc. require cooperation of certain work groups or even particular experts which were directly chosen by the senior management of the organization. Therefore, Quantity here means the number of projects that the knowledge worker i (i=1,2,…,14) was involved in team (table-app2).

Timeliness (O_3):

After defining any project via the senior management of the organization and determining the members of the project team, the planning and project control coordinator prepares the estimated time-plan and provides it for all team-members. The project is controlled daily by means of specific forms, and comparative performance of work groups and team members are shared. At the end of the project, the probable delay and mean digression of members from the original schedule are accessible. Therefore,Timeliness in this example means the amount of on time completed projects and the absence of delay (table-app3).

Creativity/Innovation (I_1):

The significance of this dimension varies for different jobs of the statistical society, and has been estimated as described in appendix 1 (table-app4).

Authority (I_2):

The upper we move in the structure of the company, the more authority is allocated to supposed members. Regarding the nature of any team work, making decisions on assigning tasks, choosing methods and etc. is held to be a responsibility for these work-groups. Moreover, within the work-groups, the team head according to past project experiences and the qualities of experts determines the areas in which employees are allowed to perform. Consequently, Authority of the experts in different work groups might be disparate as described in appendix 1 (table-app5).

Experience (I_3):

In this example experience is supposed to be the years of knowledge worker's cooperation with pooyeshpajooh company. As it has been a little more than ten years since the foundation of the company, experience is measured as follow. The maximum experience is assumed 10 years (Details are presented in table-app6).

Education (I_4):

The basis for the education of knowledge workers in this example is valid educational/academic degree. This factor doesn't have the same significance for knowledge workers of statistical society and needs to be ranked as described in appendix 1 (table-app7).

Cost:

The major source for cost in this firm is its workers, yet beside knowledge workers output, the company has other source of revenue whose profit and revenue functions are not available. Therefore, minimizing the cost of knowledge workers has been selected as the strategy for their management. In this part, cost for salary, transportation, insurance, productivity reward, food and etc, are taken into account(Costs are presented in table-app6).

Second step: Measuring knowledge workers efficiency

In this phase the experts 'comments about the inputs and outputs of each knowledge worker have been collected, and the results are presented in table (3).

The values for each knowledge worker's efficiency are calculated by solving the linear planning models (8-10).

Outputs			Inputs				KW
O_3	O_2	O_1	I_4	I_3	I_2	I_1	
VH	H	H	H	F	EH	H	1
VH	VH	VH	H	H	EH	EH	2
H	F	F	F	F	VH	H	3
F	H	F	F	H	VH	L	4
H	H	H	F	H	EH	H	5
VH	VH	VH	L	F	VH	L	6
H	H	VH	H	F	H	VH	7
H	F	VH	H	L	H	VH	8
F	F	H	F	VL	H	VH	9
L	F	H	F	EL	F	F	10
F	F	F	F	L	F	F	11
F	H	H	F	H	H	F	12
H	F	H	H	H	H	VH	13
L	H	F	H	H	VL	VH	14
F	H	H	F	VH	VL	F	15
H	F	EH	F	L	VL	VH	16

Table 3: inputs and outputs of statistical society's knowledge workers

Third step: Measuring knowledge workers effectiveness

The cost for each knowledge worker in the measuring period is as shown in table app8. The minimum cost is for the 8th knowledge worker, the values of cost effectiveness for each knowledge worker have been assessed. The results are shown in table (4).

Fourth step: measuring knowledge workers productivity on the basis of measured efficiency and effectiveness in the second and third steps.

By having values of efficiency and effectiveness for every equation (8-10) for efficiency as output and reversed effectiveness as input from equation (6), the values for knowledge workers productivity are measured (table 4).

productivity	**effectiveness($\widetilde{OE}_i$)**	**efficiency($\widetilde{\theta_0}$)**	KW
(0.0641,0.1243,0.1812)	(0.2564,0.3333,0.4375)	(0.2822,0.4211,0.4678)	1
(0.0580,0.0999,0.1447)	(0.25,0.3158,0.4118)	(0.262,0.3571,0.3968)	2
(0.0595,0.1405,0.2283)	(0.333,0.4615,0.5833)	(0.2016,0.3438,0.442)	3
(0.0578,0.1424,0.2465)	(0.2941,0.4,0.5385)	(0.2221,0.402,0.5169)	4
(0.0524,0.1125,0.1948)	(0.3030,0.4,0.5385)	(0.1953,0.3177,0.4085)	5
(0.1112,0.2474,0.3341)	(0.3571,0.48,0.5833)	(0.3515,0.582,0.6467)	6
(0.0845,0.1791,0.2798)	(0.4167,0.5456,0.7)	(0.2291,0.3707,04513)	7
(0.0966,0.2084,0.3286)	(0.4545,0.6,0.7778)	(0.24,0.3922,0.477)	8
(0.0934,0.3673,1.000)	(0.625,0.8571,0.667)	(0.1687,0.4839,0.6774)	9
(0.1102,0.3815,0.6763)	(0.625,0.9231,1.2727)	(0.1991,0.4667,0.6)	10
(0.0741,0.2369,0.4642)	(0.5,0.6667,0.9333)	(0.1673,0.4012,0.5616)	11
(0.0757,0.1931,0.3380)	(0.4167,0.5714,0.7778)	(0.2051,0.3817,0.4907)	12
(0.0514,0.1321,0.2147)	(0.3571,0.4615,0.5833)	(0.1929,0.3233,0.4157)	13
(0.0595,0.2378,0.3924)	(0.3846,0.5454,0.7)	(0.1746,0.4924,0.633)	14
(0.0896,0.3483,0.5551)	(0.5263,0.7059,0.875)	(0.1923,0.5571,0.7163)	15
(0.1995,0.4491,0.9005)	(0.7143,1,1.4)	(0.3153,0.7099,0.7263)	16

Table 4: Efficiency, effectiveness and productivity values for knowledge workers

Fifth step: ranking knowledge workers productivity values

In this step the fuzzy productivity values are ranked. The ultimate results are as follows:

$$KW_{16} > KW_9 > KW_{10} > KW_{15} > KW_{11} > KW_6 > KW_{14} > KW_8 > KW_{12} > KW_7 > KW_4 > KW_3 > KW_{13} > KW_1 > KW_5 > KW_2$$

As observed, the 16th knowledge worker (mechanical planner*)* has been the most productive and the second knowledge worker (safety team head) has had the least productivity.

7 Conclusions

So far, a method for measuring knowledge worker productivity on the basis of its general definition (i.e. doing effective things, efficient) has not been presented.

Moreover, measuring the productivity of the knowledge workers was mostly considered as traditional measurement of efficiency i.e. measuring output in relation to the input. It means that a knowledge worker might be efficient and doing the tasks properly, but he might not be able to help the company in achieving its goals. In the cited example also, we saw that the ranking of knowledge workers productivity has been altered after application of effectiveness. Furthermore, in most of the represented methodologies, homogeneous and similar groups of knowledge workers have been considered in doing the assessments, and there was no general way for measuring knowledge workers productivity individually. Nevertheless, in this paper, while regarding the productive knowledge workers as personnel who first recognize the proper ways to achieve pre-arranged objectives of the organization and then perform these tasks with best quality on the scheduled time, we make the possibility of measuring productivity of different knowledge workers with different job descriptions, different working characteristics and conditions both in the level of individuals/groups and industries. For instance we compared two knowledge works of different educational and innovation parameters like a drafter and electrical team head, an experience never conducted by past usual methods.

In this article we suppose that knowledge workers can identify goal system themselves and they able to assess whether their activities are oriented towards this goal, while, managers can improve this goal system and a goal programming approach can be extend our method.

Furthermore, this general presented approach has the capacity to be generalized in other areas which deal with uncertainty. It is recommended that this approach be examined in other business fields. Moreover, the organizational objective considered for measuring the effectiveness of knowledge workers (minimizing cost) in this paper can be developed in future studies.

References

[Antikainen and Lonnqvist05]Antikainen, R., Lonnqvist, A.: "Knowledge Work Productivity Assessment", Institute of Industrial Management, Tampere University of Technology (2005).

[Asmidet al.07] Asmild, M.,Paradi,J. C.,Reese,D. N., Tam, F.: "Measuring overall efficiency and effectiveness using DEA", European Journal of Operational Research 178 (2007) 305–321.

[Chang09]Chang,T.H.,Wang,T.C.: "Using the fuzzy multi-criteria decision making approach for measuring the possibility of successful knowledge management",Information Science, 197 (2009) , 355-370.

[Charneset al.78] Charnes, A.,Cooper,W.W., Rhodes, E.: "Measuring the efficiency of decision making units", European Journal of Operational Research, (1978), Vol. 2 No. 6, pp. 429-444.

[Choiet al.08]Choi, B.,Poon,S.K., Davis,J.G.: "Effects of knowledge management strategy on organizational performance: a complementarity theory-based approach", Omega 36 (2008)235–251.

[Davenport08]Davenport, T.: "Improving Knowledge Worker Performance", Springer,2008, Section 3, 215-235.

[Davenport02]Davenport, T.: "Can you boost knowledge work's impact on the bottom line?", Management Update, (2002), Vol. 7 No. 11, pp. 3-5.

[Davenport and Prusak00]Davenport, T., Prusak, L.: "Working Knowledge: How Organizations Manage What They Know", Harvard Business School Press, (2000), Boston, MA.

[Drucker94]Drucker, P.: "Adventures of a Bystander", Transaction Publishers, New Brunswick, NJ. (1994).

[Drucher99]Drucker, P.: "Knowledge-worker productivity: the biggest challenge", California Management Review (1999) Vol. 41 No. 2, pp. 79-85.

[Kau and Liu00]Kau,C.,Liu,S.T.: "Fuzzy efficiency measures in data envelopment analysis", Fuzzy Sets and Systems, (2000), Vol. 113, pp.427-437.

[Kemppila and Lonnqvist03]Kemppila,S., Lonnqvist,A.: "Subjective Productivity Measurement", The Journal of American Academy of Business, Cambridge, (2003), Vol. 2 No. 2 pp. 531-537.

[Liebowitz and Wright 99]Liebowitz, J., Wright, K.:"A look toward valuating human capital", in J. Liebowitz (Ed) Knowledge Management handbook, CRC press. (1999).

[Malbotra97]Malbotra, Y.: "Knowledge management, Knowledge Organization & Knowledge Workers",: http: www.Brint.com/interview/maeil.htm(1997).

[Nickolas00]Nickolas, F.: "What is in the world of work and working: some implications of the shift to knowledge work", Butterworth-Heinemann Yearbook of Knowledge Management, (2000) pp. 1-7.

[RamirezandNembhard04]Ramirez,Y.W., Nembhard, D.A.: "Measuring knowledge worker productivity: a taxonomy", Journal of Industrial Capital, (2004) Vol. 5 No. 4 pp. 602-628.

[Rutkauskas and Paulavičienė05]Rutkauskas, J., Paulavičienė, E.: "Concept of Productivity in Service Sector", Engineering Economics (2005) No. 3 (43).

[Steward97]Steward, T.A.: "Intellectual Capital:The new wealth of organization". New York: Currency Doubleday. (1997).

[Wang09]Wang,Y.M., Luo,Y., Liang,L.: "Fuzzy data envelopment analysis based upon fuzzy arithmetic with an application to performance assessment of manufacturing enterprises", Expert Systems with Applications 36 (2009) 5205–5211

[Wen and Li 09]Wen, M., Li, H.: "Fuzzy data envelopment analysis (DEA): Model and ranking method", Journal of Computational and Applied Mathematics, 223 (2009) 872-878.

[Zadeh65]Zadeh,L.A.: "Fuzzy Sets", Information and Control 8 (3) (1965) 338-353.

[Zadeh99]Zadeh, L.A.: "Some reflection on the anniversary of Fuzzy Sets and Systems", Fuzzy Sets and Systems 100 (1999) 1-3.

Appendix

position	***quality***	**Triangular fuzzy number**
(Approved without project head) and (employer's correction)	(EH)	(0.9 , 1.0 , 1.0)
(Approved after project head' correction) and (without employer's correction)	(VH)	(0.7 , 0.9 , 1.0)
(Approved without project head's correction) and (After employer's first correction)	(H)	(0.5 , 0.7 , 0.9)
(Approved after project head's correction) and (After employer's last correction)	(F)	(0.3 , 0.5 , 0.7)
(Approved without project head's correction) and (After employer's 2nd correction)	(VL)	(0.1 , 0.3 , 0.5)
(Approved without project head's correction) and (After employer's 2nd correction)	(VL)	(0.0 , 0.1 , 0.3)
(more than twice correction by employer)	(EL)	(0.0 , 0.0 , 0.1)

Table App-1: Definition of variable quality *(O_1)*

position	***quantity***	**Triangular fuzzy number**
12 and more	Extremely high (EH)	(0.9 , 1.0 , 1.0)
10-11	Very high (VH)	(0.7 , 0.9 , 1.0)
8-9	High (H)	(0.5 , 0.7 , 0.9)
5-7	Fair (F)	(0.3 , 0.5 , 0.7)
3-4	Low (VL)	(0.1 , 0.3 , 0.5)
1-2	Very low (VL)	(0.0 , 0.1 , 0.3)
None	Extremely low (EL)	(0.0 , 0.0 , 0.1)

Table App-2: Definition of variable quantity *(O_2)*

Position	***timeliness***	**Triangular fuzzy number**
No negative digression and no delay	(EH)	(0.9 , 1.0 , 1.0)
(*average digression percentage* ≤ *%5*)*And no delay*	(VH)	(0.7 , 0.9 , 1.0)
average digression ≤ *%10*)*And no delay* (*percentage*	(H)	(0.5 , 0.7 , 0.9)
(*average digression percentage* ≤ *%15*)*and* (*delay* ≤ $\frac{1}{10}$ *predicted time*)	(F)	(0.3 , 0.5 , 0.7)
(*average digression percentage* ≤ *%20*)*and* (*delay* ≤ $\frac{1}{10}$ *predicted time*)	(L)	(0.1 , 0.3 , 0.5)
(*average digression percentage* ≤ *%30*)*and* (*delay* ≤ $\frac{1}{10}$ *predicted time*)	(VL)	(0.0 , 0.1 , 0.3)
(*average digression percentage* > *%30*)*and* (*delay* > $\frac{1}{4}$ *predicted time*)	(EL)	(0.0 , 0.0 , 0.1)

Table App-3: Definition of variable timeliness *(O_3)*

New ideas improving outputs	***career***	***Creativity/innovation***	**Triangular fuzzy number**
daily	Team head	Extremely high (EH)	(0.9 , 1.0 , 1.0)
	expert	Extremely high (EH)	(0.9 , 1.0 , 1.0)
	planner	Extremely high (EH)	(0.9 , 1.0 , 1.0)
Periodic in projects	Team head	High (H)	(0.5 , 0.7 , 0.9)
	expert	Very high (VH)	(0.7 , 0.9 , 1.0)
	planner	Extremely high (EH)	(0.0 , 0.0 , 0.1)
In case	Team head	Low (L)	(0.1 , 0.3 , 0.5)
	expert	Fair (F)	(0.3 , 0.5 , 0.7)
	planner	Very high (VH)	(0.7 , 0.9 , 1.0)
Fixed output with no change	Team head	Extremely low (EL)	(0.0 , 0.0 , 0.1)
	expert	Very low (VL)	(0.0 , 0.1 , 0.3)
	planner	Fair (F)	(0.3 , 0.5 , 0.7)

Table App-4: Definition of variable Creativity/innovation (I_1)

position	***authority***	**Triangular fuzzy number**
Team head- independent in decision making	(EH)	(0.9 , 1.0 , 1.0)
Team head- decision making by project head's approval	(VH)	(0.7 , 0.9 , 1.0)
Expert- independent in selection of methods	(H)	(0.5 , 0.7 , 0.9)
Expert-selection of methods by group's approval	(F)	(0.3 , 0.5 , 0.7)
Planner-independent in selection of methods	(L)	(0.1 , 0.3 , 0.5)
Planner-selection of methods by group's approval	(VL)	(0.0 , 0.1 , 0.3)
Planner- no authority ,fixed duties	(EL)	(0.0 , 0.0 , 0.1)

Table App-5: Definition of variable Authority (I_2)

Experience in Organization	**Experience**	**Triangular fuzzy number**
10 years and more	Extremely high (EH)	(0.9 , 1.0 , 1.0)
10 < Experience ≤ 8	Very high (VH)	(0.7 , 0.9 , 1.0)
8 < Experience≤ 5	High (H)	(0.5 , 0.7 , 0.9)
5 < Experience ≤ 3	Fair (F)	(0.3 , 0.5 , 0.7)
3 < Experience ≤ 2	Low (L)	(0.1 , 0.3 , 0.5)
year 2< Experience ≤ 6 months	Very low (VL)	(0.0 , 0.1 , 0.3)
Less than 6 moths	Extremely low (EL)	(0.0 , 0.0 , 0.1)

Table App-6: Definition of variable Experience (I_3)

Educational/academic document	*career*	*Education*	**Triangular fuzzy number**
Post PhD	Team head	Extremely	(0.9 , 1.0 , 1.0)
	expert	Extremely	(0.9 , 1.0 , 1.0)
	drafter	Extremely	(0.9 , 1.0 , 1.0)
PhD	Team head	Very high (VH)	(0.7 , 0.9 , 1.0)
	expert	Extremely	(0.9 , 1.0 , 1.0)
	drafter	Extremely	(0.9 , 1.0 , 1.0)
PhD student	Team head	High (H)	(0.5 , 0.7 , 0.9)
	expert	Very high (VH)	(0.7 , 0.9 , 1.0)
	drafter	Extremely	(0.9 , 1.0 , 1.0)
Masters degree	Team head	Fair (F)	(0.3 , 0.5 , 0.7)
	expert	High (H)	(0.5 , 0.7 , 0.9)
	drafter	Very high (VH)	(0.7 , 0.9 , 1.0)
Bachelor's degree	Team head	Low (L)	(0.1 , 0.3 , 0.5)
	expert	Fair (F)	(0.3 , 0.5 , 0.7)
	drafter	High (H)	(0.5 , 0.7 , 0.9)
Associate degree	Team head	Very low (VL)	(0.0 , 0.1 , 0.3)
	expert	Low (L)	(0.1 , 0.3 , 0.5)
	drafter	Fair (F)	(0.3 , 0.5 , 0.7)
diploma	Team head	Extremely low	(0.0 , 0.0 , 0.1)
	expert	Very low (VL)	(0.0 , 0.1 , 0.3)
	planner	Low (L)	(0.1 , 0.3 , 0.5)
Guidance school	Group	Extremely low	(0.0 , 0.0 , 0.1)
	employee	Extremely low	(0.0 , 0.0 , 0.1)
	planner	Very low (VL)	(0.0 , 0.1 , 0.3)

Educational/academic document	***career***	***Education***	**Triangular fuzzy number**
Elementary school	Group	Extremely low	(0.0 , 0.0 , 0.1)
	expert	Extremely low	(0.0 , 0.0 , 0.1)
	planner	Extremely low	(0.0 , 0.0 , 0.1)

Table App-7: Definition of variable Education (I_4)

KW	**Cost**	**KW**	**Cost**
1	(1600,1800,1950)	9	(600,700,800)
2	(1700,1900,2000)	10	(550,650,800)
3	(1200,1300,1500)	11	(750,900,1000)
4	(1300,1500,1700)	12	(900,1050,1200)
5	(1300,1500,1650)	13	(1200,1300,1400)
6	(1200,1250,1400)	14	(1000,1100,1300)
7	(1000,1100,1200)	15	(800,850,950)
8	(900,1000,1100)	16	(500,600,700)

Table App-8: The cost of each DMU (Knowledge worker)