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An integrated experiment for identification of best decision styles and teamworks with respect to HSE and ergonomics program: The case of a large oil refinery

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ABSTRACT

Decision making failure is a predominant human error in emergency situations. To demonstrate the subject model, operators of an oil refinery were asked to answer a health, safety and environment HSE-decision styles (DS) questionnaire. In order to achieve this purpose, qualitative indicators in HSE and ergonomics domain have been collected. Decision styles, related to the questions, have been selected based on Driver taxonomy of human decision making approach. Teamwork efficiency has been assessed based on different decision style combinations. The efficiency has been ranked based on HSE performance. Results revealed that efficient decision styles resulted from data envelopment analysis (DEA) optimization model is consistent with the plant's dominant styles. Therefore, improvement in system performance could be achieved using the best operator for critical posts or in team arrangements. This is the first study that identifies the best decision styles with respect to HSE and ergonomics factors.

1. Motivation and significance

The importance of failures in complex systems such as petrochemical units and oil/gas refineries has well been recognized in recent years. In this perspective a major part of system failure has been recognized as a result of human errors. The employees are known as the most important asset of any organization. Health, safety and environment management system are a rating point for an organization, beforehand. It is an essential requirement of competitiveness in assigning ideal personnel to crucial tasks. Previous studies have shown that decision styles modeling is one of the most efficient tools for assigning personnel with suitable characteristics to jobs and tasks. In this study, HSE and ergonomics scores are assumed as performance measurement indicators. Moreover, best decision making styles and teamwork of operators are identified for optimum performance with respect to HSE and ergonomics factors. Comprehensive research in this area shows that this study is the first in identifying the best decision styles with respect to HSE and ergonomics factors.

2. Introduction

The purpose of this study is to identify the best decision making approach and team combination considering HSE management system and ergonomic programs, which could result in improving total efficiency. We can define main objective and sub-objectives of this study as follows.The main objectives:

- Determining the efficient operators, considering HSE management system and ergonomic programs.
- Determining the efficient decision styles, based on HSE management system and ergonomic programs.
- Evaluating the efficiency of simulated teamworks.

The sub-objectives:

- Analysis of demographic variables' effects on HSE factors.
- Correlation analysis between decision styles.

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Table 1
The most well-known causes of failures.

No.	Cause of failure	% of total
1	Insufficient knowledge	36
2	Underestimation of influence	16
3	Ignorance, carelessness and negligence	14
4	Forgetfulness	13
5	Relying upon other without sufficient control	9
6	Objectively unknown situation	7
7	Imprecise definition of responsibilities	1
8	Choice of bad quality	1
9	Others	3

In the following, the HSE and decision styles as key areas in achieving the objectives of this study were examined.

2.1. Health, safety and environment

Hazards almost exist everywhere along with technological systems like refineries and petrochemical units. Unfortunately, most of the times they are not identified until an accident occur. Therefore, identification of hazards and risk reduction as preventive measures are important preliminary effort (Lee and Park, 1997; McCoy et al., 2006).

While a safety culture has no well-established scientific support, an integrated concept of health, working environment, environment and safety aspects need to show the company's holistic attitude into "people", "plant" and the "environment" and "social responsibility". The impact of culture differences on safety management is studied in cross-cultural studies (Hsu et al., 2008). The role of nationality on safety performance is also discussed by Mearns and Yule in multi-national company. The management commitments to safety and the efficacy of safety measures are introduced as the most important impacting indicators on human behavior and related hazards (Mearns and Yule, 2009).

Human health in both physical and psychological aspects should be one the first priority for managers (Azadeh et al., 2011). The environmental effects of industries in local and global scales were recognized (has had a great important) in 1960s and 1970s (Crawley and Ashton, 2002). Safety management approach handled by a number of guidelines to implementation and operation of a management system on health and safety (HSE 1991, 1992) consistent with previous standards on quality management (ISO 9001, BS 5750) (Kennedy and Kirwan, 1998). Hoviki et al. (2009) addresses how different workers conceptualize HSE culture, informant differences and HSE aspect varieties.

Five classifications for major causes of engineering disasters presented as: human factors, design flaws, materials failures, extreme conditions and environment and combination of them. The most important causes of failure addressed by May and Deckker are shown in Table 1 (May and Deckker, 2009).

In spite of the fact that one of the major focuses of hazardous industries is safety issue, accident rate with catastrophic outcomes is nearly high. This unacceptable rate of safety system failures guides our research toward the most important known reason of disasters, named "human error" (Kariuki and Lowe, 2006; AICE, 1994). Barraso et al. (2000) have defined human error as "Any human action (or failure to act) which results in an inappropriate or undesirable state of affairs, generally an outcome which detracts from achieving company goals and targets". Inappropriate design of standard operation procedure (SOP) or standard assembly procedure (SAP) is also introduced as important influencing factor and latent reason for unexpected results found during human operation (Yu et al., 1999).

Attention to human as ending point in a process plant and the importance of focus on design of workplace to allow workers to act in an optimal way that reduces human error and disturbances is emphasized by Kjellen (2007). Management deficiencies and design/operator mismatch are introduced as the major cause of human error (AICE, 1994). Operators must be aware about erroneous conditions, possible failures and consequences of each activity. Learning from error could be a feedback, useful or stressful, for responding in emergency situations (Homsma et al., 2008).

Despite this researches and findings in human error analysis, and while human error rate is decreasing gradually, the ratio of human error cases to the total incidents is reported around 20% (Michlitz, 2000). To further reduction in this ratio and increasing system reliability, it is necessary to try to identify and correct hazardous conditions caused by human interaction. Over the years, management systems have had a major role in presented methods to deal with the unexpected events or emergency situations.

Table 2
Five decision making styles.

	Low information use	High information use	
Uni-focus	Decisive	Hierarchical	Systemic
Multi-focus	Flexible	Integrative	

2.2. Decision styles

Decision making to choose corrective procedure in unexpected situations in complex systems like process plants is a crucial task. Decision making is a permanent action in real life but it does not have same form evermore. Park and Jung (2004) have suggested a systematic framework guide to construct a diagnosis procedure based on decision making strategies and the test sequencing technique.

A holistic definition of decision making style stated as: "The learned habitual response pattern exhibited by an individual when confronted with a decision situation". It is not a personality trait, but a habit-based propensity to react in a certain way in a specific decision context (Thonholm, 2004).

Why decision making is important? Decisions are important outcomes for individuals, industries and societies. Decision making under time bounded and uncertainty is one of the crucial and significant roles of workers in process plants, especially in highly risk occasions. The know how to improve these outcomes would benefit all these parts. Furthermore, errors resulted from bias in judgment lead decision maker to make some non-compensable actions. As the tasks become more complex, each biased decision is likely to have implications for a broader level of society. Milkman et al. (2009) studied decision making biases taking into account the cost of decision making errors.

The foundation of this study is based on Driver et al. (1993) definition of decision making style. The amount of information and the number of alternatives considered when making decision are identified as the basic effective factors on differences between decision styles. It is assumed that people have two decision-making styles, the primary decision style named as practical style and the second style presented by role based (Driver et al., 1993). Five decision making styles represented by Driver et al. are shown in Table 2:

- Decisive decision style: characterized by unique focus and using needed amount of data.
- Flexible decision style: characterized by multiple focus and using needed amount of data.
- Hierarchical decision style: characterized by unique focus and using broad amount of data.
- Integrative decision style: characterized by multiple focus and using broad amount of data.

- Systemic decision style: characterized by both unique and multiple focus and using broad amount of data.

Each of these decision making approaches has some positive and negative aspects. Having an efficient and integrated team requires everyone recognize herself and also his colleagues' style. Knowing your style guides you to be flexible in related situations and being aware of your colleagues' style guides you to predict their action and come to less conflict with them. Promptly taken actions, reliability, stability, loyalty and obedience are positive characteristics of Personnel with decisive decision making style while they are inflexible, regulatory, avoiding from changes and avoiding from complexity. Personnel with flexible decision making style have great intuition, entrepreneur, communicative, opportunistic and like rapid actions. Whereas, they do not like planning, have short term vision, oppose to structuring, have a minor focus and they are not reliable people. Personnel with hierarchical decision making style pay more attention to quality. They are logical, exhaustive and are good following. Tendency to debate, inflexibility against events and caring about details are negative characteristics of flexible style. Personnel with integrated decision making style are good auditors. They are creative, aware, charity people that have long term vision more ever. However, they are not decisive, fast and punctual and they also own uncertain personalities. Integrative style resembles both hierarchical and integrated styles in general characteristics and it can also possess combination of their traits.

According to the mentioned studies, the importance of influencing factors contribute in human errors have been recognized during recent years. Improving strategies has been proposed to compensate the failures or mitigate their catastrophic results. In this respect, the role of decision making approach in risk taking systems has not been discussed very much. The main focus of this study is on decision style as a humanity influencer. Some demographic factors like age, gender, weight, height, marital status and so on have also been assessed. HSE indicators are assumed as performance measurement indices. Oil and gas industry encounters hazardous situations, in nature. Oil refining is a capital-intensive, high risk and large scale system. This is the first study that considers decision styles of operators with respect to HSE issues. A DEA approach has been used in ranking and assessing the operators' performance. The effect of different decision approaches in a team working environment has also been examined through simulating various teams including operators of similar and dissimilar decision styles. This method could be an effective approach in recruiting more efficient teams.

3. Methodology, theory and experiment

An integrated qualitative–quantitative approach has been introduced to find the best combination of personnel based on individual decision style to reach the maximum efficiency for HSE and ergonomics factors. More specifically, in this study, a questionnaire with two parts has been distributed. One part has been employed to demonstrate decision style of each operator. However, another part, the most effective operators were specified based on HSE and Ergonomic factors. Finally, combining results of these questionnaires, the most effective decision styles have been revealed.

All we done, was measuring the workers or teamwork efficiency from the point of view of HSE and ergonomics performance. Moreover, the most effective decision styles have been determined based on efficient operators' decision styles. Fig. 1 depicts steps of the proposed algorithm.

Process industries or process manufacturing units are building blocks for many products. Most of the human fundamental needs like food, shelter and health are met by process industries by using a large amount of energy. These industries are faced with major challenges to meet the present generation's needs with respect to the future demands. This matter challenges companies to more safer, economical and flexible processes to face with increasing industrial competitiveness. To be pioneer in such competitive market, being able to skip from restrictions and have some excellence points are inevitable. Market handling and business process engineering are common management strategies. Nevertheless, these are not the only strategic points for managers. HSE consideration is introduced as one of the major challenges in oil industry (http://www.naftnews.net/view-7573.html). A talented, trained and efficient operator is always one of the most basic issues in oil companies. Deficit of capable human resources are more important challenges than developing and updating the technology. Integration of teamwork and the variety of expertise are basic concepts in this perspective. Integration management, optimization of production and on time decision making are basic concepts for management in every domain.

In order to evaluation of the HSEE and decision style evaluation in the related plant, the personnel evaluation indicators have been divided into main categories, each of which has its own sub-indicators as follows:

- Physical conditions of working place: Quality of light, Possibility of light adjustment, Quality of noise, Noise detraction actions, Quality of temperature, Quality of ventilations.
- Chemical conditions of working place: Awareness about hazardous materials in plant, Notice about pollutants existence and their hazards, Using protective equipment, Garbage collection and detachment, Pureness of working place.
- Organizational factors: Availability and updating the procedures, Training, Probability of occurrence of unforeseen events.
- Design of equipment: Proper locating of machines and equipments, Proper locating of warning equipments, Quality of labels readability, Reasonable space for moving, Availability of levers, Designing an backrest for workers, Equipment audit.
- Safety equipments: Regular replacement of safety equipments, Proper appliance of safety equipments, Good training for safety equipment usage, The management priority for safety concept.
- Performance of certifications: Efficiency of ISO 9001, Efficiency of HSEMS, Effects of OHSAS, Effects of ISO 14000.
- Individual characteristics: Job satisfaction, Ability of decision making in failure modes, Pleasure to talking about job, Consent to co-workers, Receiving help and support from partners, Familiarity with responsibilities, Feeling job security, Ability of finding irregular conditions, Personnel emphasis on speed.

3.1. Reliability and validity

Statistical analysis methods are used to validate and verify the questionnaires. Reliability analysis is performed to confirm that it yields the same results on different occasions. Cronbach's alpha was used to examine the reliability of selected factors to assess HSE performance and decision making approach. The reliability coefficient (Cronbach's α) for majority of variables was above the acceptable margin 0.6. Validity analysis describes what questionnaire is supposed to measure. The content validity of the questionnaire is ensured by reuse of instrument from previous studies. Questions were programmed based on authors' researches and experiences, and standard published questionnaires like The Copenhagen Psychosocial Questionnaires (Charnes et al., 1978). Construct validity is analyzed through Factor Analysis. It shows that measures that are selected to a criterion represent the size and direction of it and measures are not interface to each other. The most common technique used in factor analysis is to select factors with Eigenvalues

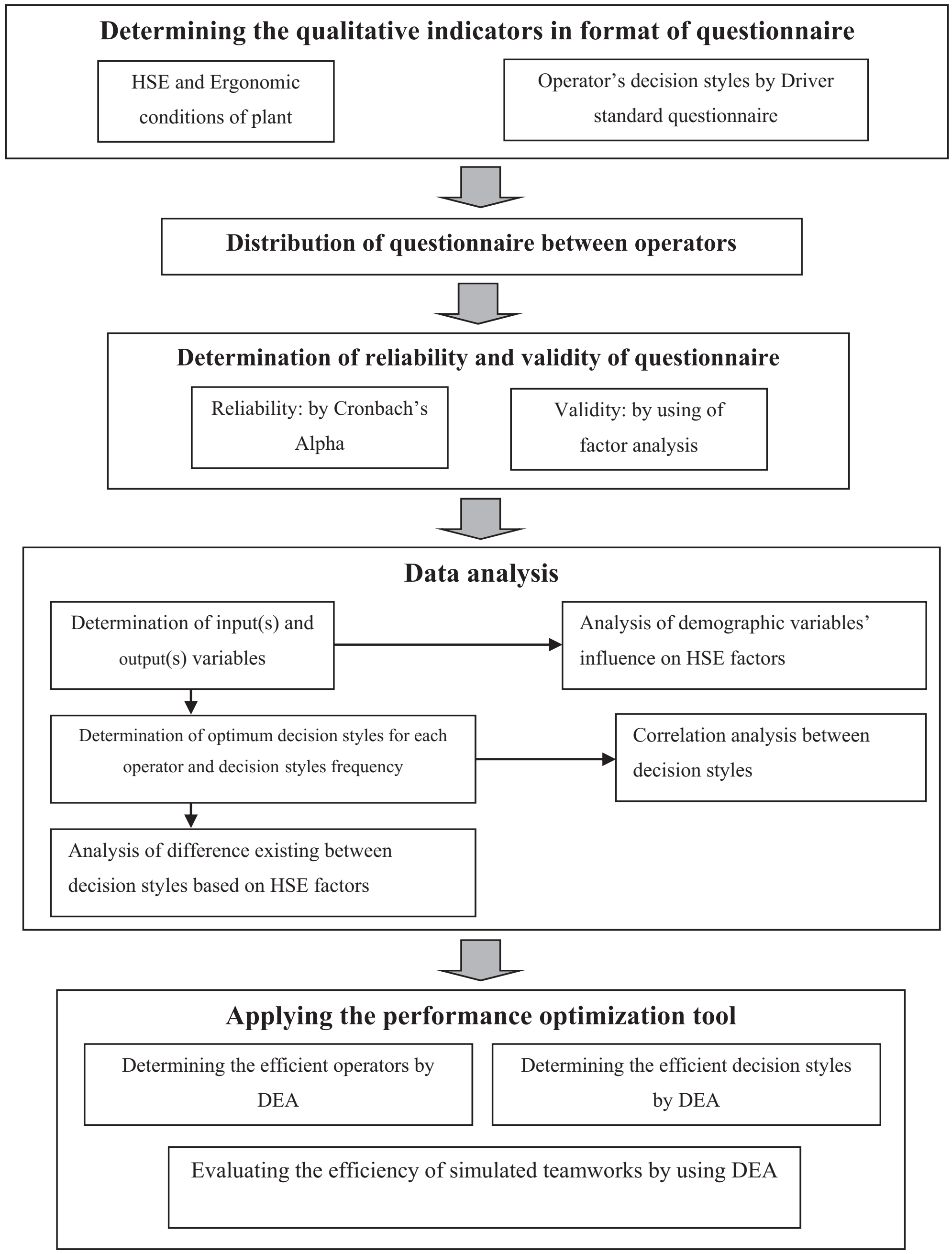


Fig. 1. Structure of the proposed algorithm.

more than one as significant factors. This method is also used in this study.

In order to do Factor Analysis and Cronbach's alpha techniques, questions have been categorized into 13 groups so that within each group, questions have the most conceptual approximation and are valid statistically. For keeping coherency and consistency of mentioned groups, we had to omit some of our questions. However, we did our best to cover all materials and to not deviate from our examining principals. Table 3 represents the reliability and constructs validity analysis.

3.2. Inputs and outputs

This study considers HSE influencing factors with respect to human's decision making approach as a performance influencing factor. Achieving this purpose, a structured questionnaire designed and distributed among an oil refinery personnel. HSE department is now an active office in this plant aiming at integrating the health, safety and environmental programs to confirm that potential hazards related to HSE issues are removing or under control. The major focus of this department is health, safety and firefighting, environment, personnel, projects and training. No one wants to harm to people, plant or the environment. But human error is inevitable inherently. Selected personnel were expert engineers that nominated to have more experience and also free time to answer the questions. The respond number was 77 questionnaire applied to analysis tasks. The first part of the questionnaire was concentrated on HSE factors in related site. The second part of the questionnaire was concentrated on human's decision making approach based on driver's theory. The human influencing factor is the major focus of this study as an important agent in process safety. To this respect, demographic characteristics like age, gender, education, marital

Table 3
Reliability and validity analysis results.

Group type	Reliability	Factor analysis		
	Cronbach's alpha	Number of question	Component 1	
1	Hazardous materials	0.67	1	0.83
			2	0.83
			3	0.53
			4	0.55
2	Noise	0.62	1	0.85
			2	0.85
3	Temperature of environment	0.62	1	0.85
			2	0.85
4	Relation with co-workers	0.60	1	0.68
			2	0.66
			3	0.78
			4	0.56
5	Organizational factors	0.70	1	0.80
			2	0.82
			3	0.79
			4	0.50
6	Individual characteristics	0.54	1	0.76
			2	0.73
			3	0.68
7	Accidence audit	0.90	1	0.96
			2	0.96
8	Job factors	0.62	1	0.83
			2	0.72
			3	0.72
			4	0.27
9	Ergonomics	0.64	1	0.35
			2	0.41
			3	0.69
			4	0.29
10	Design of equipment	0.64	1	0.72
			2	0.75
			3	0.56
			4	0.61
			5	0.52
11	Labels characteristics	0.72	1	0.78
			2	0.58
			3	0.71
12	Inspection of equipment	0.57	1	0.35
			2	0.90
			3	0.89
13	Quality of light	0.76	1	0.82
			2	0.91
			3	0.75
			4	0.58

Table 4
Input and output variables.

			Associated group	DMUs (operators)				
				1	2	3	4	5
Inputs	1	Quality of light	No. 13: Quality of light	3	3	3	3	3
	2	Quality of temperature	No. 3: Temperature of environment	1	3	4	1	2
	3	Quality of noise	No. 2: Noise	2	3	2	3	3
	4	Readability of labels	No. 11: Labels characteristics	3	1	4	4	2
	5	Access to equipment	No. 12: Inspection of equipment	3	3	3	2	3
	6	Training program arrangement	No. 5: Organizational factors	2	3	4	4	3
	7	Position of equipment	No. 10: Design of equipment	3	4	3	3	3
	8	Quality of ventilation tools	No. 3: Temperature of environment	4	3	3	4	3
	9	Acquisition with hazardous materials	No. 1: Hazardous materials	2	1	1	3	3
	10	Acquisition with the danger of hazardous materials	No. 1: Hazardous materials	3	1	3	5	2
	11	Existence of auxiliary equipment	No. 9: Ergonomics	1	3	3	3	2
	12	Existence of backrest	No. 9: Ergonomics	3	3	2	2	4
	13	Existence of additional movement area	No. 9: Ergonomics	3	2	1	3	3
Outputs	1	Job satisfaction	No. 8: Job factors	3	3	3	1	3
	2	Decision making ability in emergency situation	No. 6: Individual characteristics	1	1	1	1	1
	3	Reduction in happening accidents	No. 7: Accidence audit	1	4	2	1	3
	4	Work speed	No. 4: Relation with co-workers	4	4	4	5	2

Table 5
Dependency of age on HSE factors.

Demographic variable	HSE indicator				
	Emphasis on speed	Ability to know irregular conditions	Decision making ability in emergency situations	Job satisfaction	Necessity of using procedures in emergency situations
Age	0.005	0.012	0.34	0.62	0.81

Table 6
Dependency of height, weight and marital status on HSE factors.

Demographic variable	HSE indicator	
	Job satisfaction	Performance dependency on shift
Marital status	–	0.97
Height	0.99	–
Weight	0.61	0.35

status, height, weight and the society size is asked to answer. Effect of these factors on HSE indicators is assessed if it is possible. In this study, in order to evaluate the plant efficiency, 77 DMUs (operators) have been taken into consideration. Output, input variables and associated groups for each one with their values for first 5 operators among 77 of them have been presented in Table 4. Output and input values for all operators are shown in Appendix 1.

4. Computational results and discussion

4.1. Analysis of demographic variables on HSE

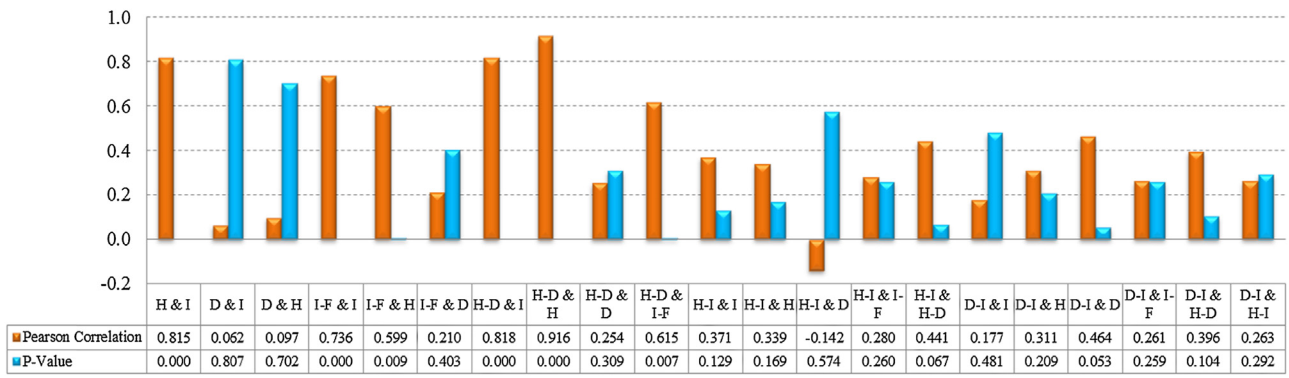
Demographic characteristics introduced as performance influencing factors. Next part of this study considers the relation of operator's demographic features with some of the HSE factors. Demographic factors are defined as "statistical socio economical characteristic or variables of population such as age, sex, education level, income level marital status, occupation, religion, birth rate, death rate, average size of a family, average age of marriage" (BusinessDictionary.com). The result of dependency relation between age (age groups_year: 25–35, 35–45, 45–55 and up to 55), height (height groups_cm: 160–170, 170–180, 180–190 and up to 190), weight (weight groups_kg: 60–70, 70–80, 80–90, 90–100 and up to 100) and marital status (married or single) with affected HSE factors are shown in Tables 5 and 6. These tables show that a significant relationship exists between age's groups with "Ability to know irregular conditions" and "Emphasis on speed" (in 95% confidence level ($P < 0.05$)).

Table 7
Decision style for each operator.

Operator Code	Decision Style	Operator Code	Decision Style	Operator Code	Decision Style	Operator Code	Decision Style
1	I	21	I	41	H	61	H-D
2	H	22	H	42	H-D	62	H
3	I-F	23	I	43	I-F	63	-
4	I-F	24	I	44	H-D	64	H
5	H	25	I	45	I-F	65	I
6	I	26	H	46	H	66	-
7	H	27	H-D	47	D-I	67	D
8	I	28	H-D	48	I	68	D
9	H	29	I	49	H	69	H
10	H	30	I	50	D	70	H
11	I	31	I	51	H-I	71	H
12	I	32	I	52	I	72	I-F
13	I	33	I-F	53	H	73	-
14	H	34	H	54	H	74	H-D
15	H	35	I-F	55	H	75	H-I
16	H	36	I	56	H	76	H
17	H	37	H	57	H-I	77	H
18	I	38	H	58	H		
19	I	39	H	59	H		
20	H	40	I-F	60	H-I		

Table 8
The frequency of decision styles in related population.

Decision Style	H	I	I-F	H-D	H-I	D	D-I
Frequency	32	20	8	6	4	3	1



	H & I	D & I	D & H	I-F & I	I-F & H	I-F & D	H-D & I	H-D & H	H-D & D	H-D & I-F	H-I & I	H-I & H	H-I & D	H-I & I-F	H-I & H-D	D-I & I	D-I & H	D-I & D	D-I & I-F	D-I & H-D	D-I & H-I
Pearson Correlation	0.815	0.062	0.097	0.736	0.599	0.210	0.818	0.916	0.254	0.615	0.371	0.339	-0.142	0.280	0.441	0.177	0.311	0.464	0.261	0.396	0.263
P-Value	0.000	0.807	0.702	0.000	0.009	0.403	0.000	0.000	0.309	0.007	0.129	0.169	0.574	0.260	0.067	0.481	0.209	0.053	0.259	0.104	0.292

Fig. 2. The correlation analysis between decision styles.

4.2. Determination of decision styles

Decision making styles, as a subset of human factors, are set to assume being one of the main reasons of accidents. Therefore, examining different decision making styles may have a vital role in preventing accidents. Appendix 2 presents the criteria for selecting decision styles that considered by Driver et al. The attributes shown in Appendix 2 as criteria used in selecting decision styles confirm this issue.

As stated in previous sections, operator's decision style is the major focus of this study. It is determined by a standard questionnaire recommended by Driver et al. We grouped the personnel to 4 categories as Decisive, Hierarchical, Flexible and integrated decision styles with D, H, F and I abbreviations, respectively. Decision styles for each operator are shown in Table 7. The frequency of estimated decision styles are shown in Table 8. It is necessary to mention that 3 workers are deleted from this table because they have similar frequency for all styles.

4.3. Correlation between decision styles

Correlation analysis between different styles reveals that there is a positive correlation between H and I, I-F with I and H, H-D with I, H and I-F. These results are not surprising because each style correlates with at least 2 styles that have common modes in information processing and alternative handling. Fig. 2 represents the correlation analysis results.

It was important to see whether operator's decision style have significant influence on their views and consequently on research's findings. Thus, we used Kruskal Wallis experiment and analyzed differences in answers according to each worker. Fig. 3 shows that a significance difference exists between decision style's groups in 95% confidence level ($P < 0.05$). This emphasized the importance of this study.

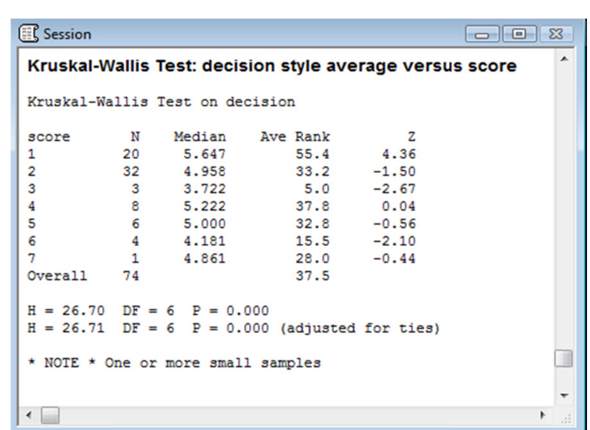
4.4. Decision styles versus HSE factors

A correlation analysis between hierarchical and integrated styles for some selected HSE factors revealed that there is a considerable difference between them when they decide to choose a procedure. For the other HSE factors, namely, the need to procedures, speed, complexity and innovation, there is no difference between the selected styles. The results are shown in Table 9. The integrated and hierarchical styles are selected arbitrary because they have the most frequencies in related population. The frequency of the other styles is relatively low.

4.5. Identification of efficient operators by DEA

BCC output oriented model are used for calculation of technical efficiency and operator's ranking that are presented in Table 10. Efficiency values and ranking for first 5 operators among 77 of them have been presented in Table 4. Efficiency values and ranking for all operators are shown in Appendix 3. Examining Appendix 3, 44 operators have technical efficiency equal to 1.

Technical efficiency refers to the ability of a DMU to minimize input use in the production of a given output vector, or the ability to obtain maximum output from a given input vector. The measure of technical efficiency is very important, because it indicates the ability of a DMU to survive in a competitive environment. It should be noted that in determining the technical efficiency and ranking of each unit, the model type (i.e. input-oriented or output-oriented) makes no difference in the results. Moreover, since the technical efficiency of the operators lies between zero and one,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Session
Kruskal-Wallis Test: decision style average versus score

Kruskal-Wallis Test on decision

score       N   Median   Ave Rank      Z
1          20    5.647       55.4   4.36
2          32    4.958       33.2  -1.50
3           3    3.722        5.0  -2.67
4           8    5.222       37.8   0.04
5           6    5.000       32.8  -0.56
6           4    4.181       15.5  -2.10
7           1    4.861       28.0  -0.44
Overall    74                37.5

H = 26.70  DF = 6  P = 0.000
H = 26.71  DF = 6  P = 0.000  (adjusted for ties)

* NOTE * One or more small samples
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Fig. 3. Hypothesis analysis for decision styles.

Table 9
Statistical difference between hierarchical and integrated styles based on HSE factors.

HSE indicator	The need for procedures	Count of procedures preference	Innovation	Complexity	Speed
P-value	0.1	0.047	0.089	0.116	0.323

Table 10
Efficiency and operators ranks resulted from DEA (BCC output oriented).

Operator Code	TechnicalEfficiency	Efficiency for Ranking	Ranking
1	1.00	1.02	35
2	1.00	1.14	4
3	0.95	0.99	48
4	1.00	1.07	23
5	0.87	0.96	57

Table 11
The frequency of efficient styles.

Style	H	I	D	F
	H, H-D, H-I	D-I, H-I, I, I-F	D, D-I, H-D	I-F
Frequency	22	20	4	4

hence operators with efficiency of one are efficient. In other words, these branches are located exactly at efficiency frontier. Appendix 4 presents the explanation of DEA.

Considering the set of $n = 77$ observations on the DMUs (operators), each observation for DMU$_j$ ($j = 1, \ldots, 35$), uses $m = 13$ inputs x_{ij} ($i = 1, 2, \ldots, 13$) to produce $s = 4$ outputs y_{rj} ($r = 1, 2, 3$ and 4). The selected DEA model for this case has been applied as follows:

$$\max \varphi + \varepsilon \left(\sum_{i=1}^{13} s_i^- + \sum_{r=1}^{4} s_r^+ \right)$$

$$\text{s.t.} \quad \begin{aligned} &\sum_{j=1}^{77} \lambda_j x_{ij} + s_i^- = x_{io} && i = 1, 2, \ldots, 13; \\ &\sum_{j=1}^{77} \lambda_j y_{ij} - s_r^+ = \varphi y_{ro} && r = 1, 2, \ldots, 4; \\ &\sum_{j=1}^{77} \lambda_j = 1 \end{aligned} \tag{1}$$

4.6. *Efficient decision styles by DEA*

Table 11 summarizes the frequency of efficient styles (Technical Efficiency = 1). As it is evident from Table 11, the single hierarchical decision style or combination of hierarchical decision style (H-D, H-I) among is more frequent than others. It is similar to (agree with) the dominant style nominated (specified) in last stage. Therefore, it is an efficient style where operators work individually. If this is not the case, the grouping efficiency of different styles should be considered.

4.7. *Efficiency of teamwork by DEA*

Groups' efficiency has been examined from two different perspectives. Moreover, experts in the field identified the importance of the stated two groups due to nature and importance of decision styles and work domain. More explanations are as follows:

4.7.1. *Grouping based on working domain*

People whose working domains are similar to each other have been classified as one cluster, so that there might be personnel with different decision making styles within a group. In this stage, the efficiency values for different groups were computed. The working groups were middle managers of Tehran oil refinery in refining engineering, general engineering, inspection, repairs, renovations and ... groups that are selected at random. The efficiency scores for each group were calculated as the average of individual efficiencies. Table 12 represents the efficiency scores for each group. Examining Table 12, group 6 has the highest efficiency.

4.7.2. *Grouping based on decision making style*

People with similar decision making styles have been grouped as one cluster, so that a group might contain personnel of different working domains. The operators were grouped based on styles and the efficiency values and efficient operators were determined. Similar decision making styles have been categorized in same classes. Then average efficiency of operators in each class has been considered as efficiency index of its related style. The simulation results are shown in Table 13.

The other categories suggested for simulation process were a unified combination of styles applied to consider the interaction of different styles. For this purpose, a compression is made between efficiency scores resulted from different hypothetical groups consisting of 2, 3 or 4 different styles. We supposed that the efficiency scores could be as a weight for DEA model. It expected that introducing weights into model would improve the efficiency. Moreover, we run the model twice, first without weight and the other time with weights. The second model resulted from dividing the outputs into efficiency values. Tables 14 and 15 represent the efficiency scores based on different style combinations without and with weight, respectively. These results are confirmed by Driver et al. statements. They declare that the most efficient groups

Table 12
The efficiency scores for different groups.

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10
Technical Efficiency	1.00	0.98	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.98
Efficiency for Ranking	1.09	1.10	1.20	1.27	1.29	1.42	1.11	1.34	1.15	1.10
Ranking	10	9	5	4	3	1	7	2	6	8

Table 13
The efficiency scores for different styles.

	I-F	I	H -I	H-D	H	D
Technical Efficiency	1.00	0.97	1.00	1.00	0.96	0.97
Efficiency for Ranking	1.17	1.08	1.31	1.20	1.06	1.18
Ranking	4	5	1	2	6	3

Table 14
The efficiency of teamwork based on styles without weight.

Style combinations	H-D, I	H, D, I	I-F, D-H, H-I	I-F, D, H	D, H-D	H, D	H, H-D	H, H-I	I, D	I, I-H	I, I-F
Technical efficiency	0.97	0.97	0.99	0.98	1.00	0.99	0.99	0.97	0.97	0.97	0.98
Efficiency for ranking	1.09	1.06	1.12	1.08	1.15	1.09	1.08	1.09	1.09	1.10	1.09
Ranking	4	11	2	10	1	7	9	7	4	3	6

Table 15
The efficiency of teamwork based on styles with weight.

Style combinations	H-D, I	H, D, I	I-F, D-H, H-I	I-F, D, H	D, H-D	H, D	H, H-D	H, H-I	I, D	I, I-H	I, I-F
Technical efficiency	1.00	0.99	1.00	0.99	1.00	1.00	1.00	1.00	0.99	1.00	1.00
Efficiency for ranking	1.11	1.07	1.13	1.09	1.16	1.10	1.09	1.10	1.11	1.12	1.11
Ranking	5	11	2	10	1	7	9	8	4	3	6

consist of same decision styles. Each person tends to have more conformances with more common points. It means that, in decision style content, a person likes to work with someone with same information processing capability. For example a hierarchical decision style likes to work with an integrated style with respect to information processing (high) or decisive style with regard to focus (uni-focus).

As it is obvious from Tables 14 and 15, the technical efficiency is getting better when the weights are added into the model. The fuzzy DEA model is run based on weighted model. According to the nature of problem, we are faced with human detraction. Thus, using fuzzy concept is worthy.

5. Limitations

This section addresses aspects of this specific study that limit the validity of the inferences/conclusions made in the discussion. These aspects include threats to construct, internal, external and conclusion validity as four types of validity. In the following, the basic threats of each one are shown (http://www.socialresearchmethods.net/kb/index.php):

- External validity: This type of validity refers to the approximate truth of conclusions the involve generalizations. External validity is the degree to which the conclusions made in the study would

Table 16
The features of proposed methodology versus other studies.

Study or method	Feature					
	HSE and ergonomics modeling and assessment	Optimization by DEA methodology	Optimum decision styles	Determining the best combination for efficient teamwork	Determining the efficient or productive operators	Evaluating the efficiency of simulated teamworks
Azadeh et al. (2008)	√				√	√
Standard Driver's Questionnaires (1993)			√			√
Yu et al. (1999)	√					
Kennedy and Kirwan (1998)	√					
Ersdal and Aven (2008)	√		√			
Kariuki and Lowe (2006)	√					
Thonholm (2004)			√		√	
Milkman et al. (2009)			√			
The integrated algorithm of this study	√	√	√	√	√	√

hold for *other persons* in *other places* and at *other times*. Hence, there are three major threats to external validity (people, places and times). The results of this study are due to the particular type of people who were in the study (expert engineers that nominated to have more experience and also free time). Also, this study has been done on oil refinery; therefore, results might only work in this specific area. Besides, we did our study in a particular time which may have effect on final results.
- Construct validity: Like external validity, construct validity is related to generalizing. But, construct validity involves generalizing from my program or measures to the concept of my program or measures. This study does not have construct validity.
- Internal validity: Internal validity is approximate truth about inferences regarding cause-effect or causal relationships. For example, in this study, we have only considered the impact of HSEE factors on efficiency of operators, teamworks and effectiveness of decision styles. But there may be lots of reasons, other than HSEE factors, that can have an effect on mentioned items.
- Conclusion validity: this type of validity is the degree to which conclusions we reach about relationships in our study are reasonable. For example, are efficient selected persons or decision style highly effective?

In next section we discuss on how these limitations can be overcome in future works.

6. Conclusion and future work

Human factors have contributed to the causes of several recent incidents, in a variety of safety critical industries. The impact of failing to address the management of human factor issues in engineering is discussed in several studies. Skill, experience, education, speed, demographic indicators like age, height, weight and are individual performance influencing factors recognized by several studies. Some organizational factors such as management commitment to HSE factors, training courses programs, design and implementation of business process factors affect the human performance as environmental factors. Performance influencing factors are divided into four basic categories including operating environment, task characteristics, operator characteristics and organization and social factors. In this study, human decision making approach is viewed as a performance influencing factor. HSE and ergonomics factors are considered as performance measurement indictors.

Decision style includes extracting required information, applying them in related settings and integrating them with a coherent decision rule. Driver et al. subscribes the amount of information and the number of alternatives used in decision making process as the predominant factor in decision style categorization. According to their classification of decision style, the operator's decision making approaches were divided into 4 categories, decisive, flexible, hierarchical and integrated decision style. A hypothesis analysis reveals that there are no difference between hierarchical and integrated decision styles based on speed, innovation, complexity and dependence to procedures in this situation. But the results show that the operators preference in using one or more procedures have considerable differences for these styles.

The dominant and efficient decision style in the stated plant was hierarchical decision style. Personnel with this style evaluate the quality of results with optimum quality. The best approach in their logic is to reviewing more information and selecting the choice with focusing on the quality rather than cost, efficiency and short time results. They concentrate on analysis until they could select a decisive method to act. They want to clearly know when, how and what they should do. They accept new ideas and usually do not dispute. Managing a group with hierarchical dominant style requires showing that they are expert and influential persons. They can make great problems if they are managed inappropriately. They dictate operational solution with their logical hypothesis. An effective relationship with hierarchical person demands more thinking and completely envelopment of issues. They are logical and might be good planners.

Grouping the operators based on styles reveals that the integrated and decisive styles will be non-efficient and risky combinations. This matter happened because there is no common point between them. Each of the stated styles has different information processing focus and alternative selection preference in their decision making patterns. Thus, it is good for managers to be cautious about this group of operators before their contradictions result dangerous behaviors. Same conditions are feasible for integratives and flexibles, and decisives and hierarchics.

Table 16 presents the features of the proposed methodology. It is capable of determine the best decision style with respect to HSE program through DEA. It is also capable of handling the possible human error and data vagueness by means of fuzzy logic.

6.1. Future works

Future research should concentrate on extension and application of decision making styles in other complex systems such gas refineries and petrochemical plants (External validity-place). Moreover, future research can be done in several intervals of time and then comparing the results (External validity-time). Identification of optimum work groups with respect to decision making styles of control room and maintenance operators would considerably reduce the rates of injuries, deaths, accidents and incidents in such complex systems (External validity-people). Also, mathematical models could be developed to tackle small to medium sized decision making styles problems by considering several objectives and constraints. In addition, meta-heuristics such as particle swarm optimization (PSO) and multi objective genetic algorithm may be used to solve large decision styles problems. Optimum decision styles in work teams will ultimately reduce the rates of incidents and accidents (Conclusion validity). In future studies, not only HSEE factors, but also other factors can be considered to be effective in operators, groups and decision styles performance (Internal validity).

Furthermore, the future work can employ Kirkpatrick's Four-Level Training Evaluation Model. This model can help managers and objectively analyze the effectiveness and impact of training for future use (Kirkpatrick, 1959, 1976, 1996). The four levels of evaluation in Kirkpatrick's model are reaction, learning, behavior, and results criteria. Reaction and learning focus on what occurs within the training program and therefore, they are considered as internal criteria. Behavioral and results criteria are seen as external criteria because they focus on changes that occur outside (and typically after) the program. It is also useful to keep in mind that external criteria are likely to be influenced by factors other than learning, such as larger organizational or economic contexts (Kirkpatrick, 1959, 1976, 1996; Alliger et al., 1997).

Reaction criteria: they are trainees' perceptions of training (Kirkpatrick, 1959, 1976, 1996). This level measures how your trainees (the people being trained), reacted to the training. It is important to measure reaction, because it helps us understand how well the training was received by the audience (Alliger et al., 1997).

Learning criteria: At this level, we measure what your trainees have learned. How much has their knowledge increased as a result of the training? It is important to measure this, because knowing what the trainees are learning and what they are not will help us improve future training (Alliger et al., 1997).

Behavioral criteria: At this level, we evaluate how far the trainees have changed their behavior, based on the training they received. Specifically, this looks at how trainees apply the information. In organizations, behavioral criteria are typically operationalized as supervisor ratings or objective indicators of performance such as job outputs (Alliger et al., 1997).

Results criteria: At this level, we analyze the final results of the training. Results criteria are both highly desirable and most difficult to evaluate. This includes outcomes that we or our organization have determined to be good for business, good for the employees, or good for the bottom line (Alliger et al., 1997).

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Appendix 1. Input and output values.

Operators	Inputs													Outputs			
	1	2	3	4	5	6	7	8	9	10	11	12	13	1	2	3	4
1	3	1	2	3	3	2	3	4	2	3	1	3	3	3	1	1	4
2	3	3	3	1	3	3	4	3	1	1	3	3	2	3	1	4	4
3	3	4	2	4	3	4	3	3	1	3	3	2	1	3	1	2	4
4	3	1	3	4	2	4	3	4	3	5	3	2	3	1	1	1	5
5	3	2	3	2	3	3	3	3	3	2	2	4	3	3	1	3	2
6	3	1	2	1	3	3	3	3	1	3	3	2	1	3	5	1	4
7	4	2	1	1	4	4	4	4	4	4	3	4	3	2	3	3	4
8	4	2	2	3	3	3	3	3	2	2	2	1	1	1	1	1	3
9	5	1	3	4	3	4	4	4	1	1	3	4	1	4	1	4	5
10	3	1	2	3	2	3	4	4	2	2	1	2	1	4	1	3	3
11	3	2	3	1	2	3	2	3	1	3	1	2	2	2	2	1	4
12	4	4	3	4	3	4	4	4	2	4	3	3	3	3	2	2	4
13	4	1	2	3	4	2	2	4	1	3	2	3	3	2	4	3	3
14	4	3	3	4	3	4	4	4	3	2	3	3	1	3	1	1	5
15	3	2	3	4	3	2	4	3	2	2	3	3	3	4	3	3	3
16	3	2	3	2	4	3	3	4	3	3	3	2	2	2	1	2	4
17	4	3	4	4	2	5	4	2	2	3	3	3	1	2	3	3	3
18	4	4	2	4	2	5	4	5	1	3	4	3	1	4	1	1	5
19	3	3	2	3	3	4	3	3	3	3	3	4	4	3	1	3	4
20	3	3	2	3	3	3	3	2	3	3	4	4	2	4	1	4	4
21	2	3	2	3	1	2	2	3	1	2	1	2	3	3	3	4	3
22	3	2	2	2	4	3	3	3	2	3	3	3	2	2	1	1	4
23	3	2	2	2	2	3	3	3	1	2	3	2	3	2	1	2	4
24	4	3	3	2	3	3	4	3	2	4	3	2	2	3	1	4	3
25	4	2	1	2	3	4	3	3	3	4	3	4	2	2	1	3	5
26	4	3	4	4	2	4	3	4	1	4	3	2	3	3	1	2	3
27	4	4	3	3	2	4	3	3	2	2	3	3	2	3	1	3	4
28	4	4	3	4	2	5	4	4	2	2	3	4	4	4	1	5	3
29	4	2	3	4	3	3	3	4	2	4	3	3	3	3	2	3	4
30	4	2	1	5	5	1	3	5	4	5	3	2	3	4	1	5	5
31	4	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3	4
32	3	2	3	2	3	2	3	3	3	2	3	3	2	3	1	3	4
33	3	3	3	3	1	2	2	2	3	2	2	4	3	3	3	2	3
34	4	4	3	3	3	4	4	3	3	3	2	2	1	4	1	4	4
35	3	4	3	3	3	5	3	3	3	3	3	3	2	4	1	3	4
36	4	2	3	2	3	3	2	2	1	2	2	1	2	3	1	3	5
37	3	3	3	3	1	4	2	3	3	3	2	2	2	3	1	4	5
38	4	2	2	3	4	3	3	4	1	3	3	4	3	4	1	2	5
39	3	3	3	3	3	2	3	4	2	3	2	3	3	3	1	3	4
40	3	5	2	4	3	3	3	4	1	2	4	1	1	2	1	1	4
41	3	2	2	2	3	4	3	4	3	3	3	2	2	3	1	3	5
42	4	4	3	4	3	4	4	4	2	2	2	1	2	4	1	2	3
43	4	4	3	3	3	3	3	3	3	3	3	1	1	3	1	2	2
44	3	4	3	3	2	2	3	4	2	3	2	3	1	3	1	3	4
45	3	3	4	3	2	2	4	2	2	3	2	2	2	4	5	3	3
46	3	5	3	3	4	2	4	3	1	3	3	4	1	3	5	3	4
47	4	2	3	2	4	3	4	4	3	3	3	4	2	4	5	3	4
48	4	2	3	3	4	2	3	2	3	3	2	1	4	4	2	5	3
49	4	4	3	4	3	2	4	3	3	3	3	3	3	4	2	5	4
50	4	3	3	3	3	3	3	2	2	3	1	4	3	5	3	3	5
51	1	4	3	4	4	1	4	4	1	2	1	3	1	3	3	3	5
52	4	3	4	4	3	2	4	3	2	2	3	3	3	3	5	3	3
53	4	3	4	4	3	2	4	3	2	2	3	3	3	3	5	3	3
54	4	2	3	4	3	1	3	4	3	3	3	4	2	4	4	4	5
55	4	2	3	4	3	1	2	4	1	2	3	5	4	4	4	4	4
56	3	2	2	3	3	2	3	3	3	3	3	4	3	4	5	4	4
57	4	3	4	4	2	3	3	4	3	3	3	4	3	3	5	3	4
58	3	3	4	2	1	3	2	4	2	3	2	4	2	3	4	3	4
59	4	2	3	4	3	4	4	3	3	4	3	4	4	4	5	3	3
60	4	3	3	4	4	3	3	4	4	4	2	4	3	3	3	4	4

Operators	Inputs													Outputs			
	1	2	3	4	5	6	7	8	9	10	11	12	13	1	2	3	4
61	4	5	4	2	2	4	2	2	2	2	1	1	1	4	4	3	4
62	4	3	3	3	2	3	3	4	3	3	3	3	3	3	3	2	3
63	4	2	2	3	2	2	4	4	2	3	2	4	3	3	2	3	4
64	4	1	3	2	2	3	4	3	2	3	3	4	1	3	5	3	5
65	3	2	4	3	3	1	3	3	4	3	2	4	3	3	4	3	3
66	3	2	3	3	4	3	4	4	2	3	3	3	3	4	4	3	4
67	4	2	4	4	3	2	4	4	3	4	3	3	4	4	5	4	4
68	4	2	4	3	3	2	4	4	3	3	2	4	3	3	4	3	2
69	4	2	3	3	3	3	3	4	2	3	4	4	3	3	4	4	3
70	3	3	3	2	3	4	3	3	3	2	3	2	3	4	4	4	3
71	4	3	4	4	3	2	4	4	2	3	3	4	3	4	4	4	4
72	4	4	3	3	4	3	4	4	3	4	3	2	3	4	5	5	4
73	4	1	3	3	3	3	3	3	3	3	3	4	3	3	3	3	3
74	4	1	3	3	3	3	4	2	3	3	3	1	1	4	2	3	4
75	4	2	3	1	2	4	3	2	1	2	3	1	2	4	4	2	4
76	3	2	3	3	1	4	4	3	2	3	3	2	3	3	3	3	4
77	3	2	4	2	3	3	3	3	2	2	3	3	2	2	4	2	4

Appendix 2. The criteria for selecting decision styles.

Attribute	Favorable styles for 1–4 scores in attribute ratting survey	Favorable styles for 4–7 scores in attribute ratting survey
Time pressure	H or I	D or F
Task overload	H or I	D or F
Complexity of input	D or F	H or I
Task uncertainty	D or H	I or F
Speed in task	H or I	D or F
Involvement of others	D or H	I
Amount of interaction	D or H	I or f
Utilizing logical reasoning	F	H
Ability to have an impact on system	None	H or I
Preference for analytical reasoning	F	H or I
Preference for several methods	D or H	I or F
Utilizing creativity & intuition	D or H	I or F
Using rules & scripts	I or F	D or H
Unfamiliarity	D or H	I or F
Span of control	None	H
Amount of power	I or F	H or D
Planning demand	D or F	H or I
Dealing with confusion	D or H	I or F

Appendix 3. Efficiency and operators ranks resulted from DEA (BCC output oriented).

Operator Code	Technical Efficiency	Efficiency for Ranking	Ranking	Operator Code	Technical Efficiency	Efficiency for Ranking	Ranking	Operator Code	Technical Efficiency	Efficiency for Ranking	Ranking
1	1.00	1.02	35	27	0.80	0.93	69	53	0.93	0.97	54
2	1.00	1.14	4	28	0.90	0.96	62	54	1.00	1.07	24
3	0.95	0.99	48	29	0.80	0.93	70	55	1.00	1.14	7
4	1.00	1.07	23	30	1.00	1.23	2	56	1.00	1.11	13
5	0.87	0.96	57	31	0.87	0.96	60	57	0.98	0.99	47
6	1.00	1.15	3	32	1.00	1.00	44	58	1.00	1.09	22
7	1.00	1.11	12	33	1.00	1.03	34	59	0.94	0.98	51
8	0.62	0.87	75	34	0.86	0.95	66	60	0.79	0.91	72
9	1.00	1.10	16	35	0.96	0.99	49	61	1.00	1.09	20
10	1.00	1.09	19	36	1.00	1.12	10	62	0.71	0.91	73
11	1.00	1.05	29	37	1.00	1.12	9	63	1.00	1.01	40
12	0.69	0.87	76	38	1.00	1.07	1.12 25	64	1.00	1.11	11
13	1.00	1.06	26	39	0.86	0.95	64	65	1.00	1.04	32
14	0.81	0.92	71	40	0.90	0.97	56	66	1.00	1.00	43
15	1.00	1.01	37	41	1.00	1.04	31	67	0.99	1.00	45
16	0.84	0.95	67	42	0.78	0.91	74	68	0.80	0.94	68
17	0.93	0.98	50	43	0.61	0.86	77	69	0.98	0.99	46
18	1.00	1.09	21	44	0.93	0.98	52	70	1.00	1.05	30
19	0.88	0.96	58	45	1.00	1.11	14	71	0.87	0.95	65
20	1.00	1.06	27	46	1.00	1.06	28	72	1.00	1.01	39
21	1.00	1.14	5	47	1.00	1.01	41	73	1.00	1.00	42
22	0.88	0.96	61	48	1.00	1.14	6	74	1.00	1.09	18
23	1.00	1.01	38	49	1.00	1.02	36	75	1.00	1.11	15
24	0.88	0.96	59	50	1.00	1.09	17	76	1.00	1.03	33
25	1.00	1.12	8	51	1.00	1.27	1	77	0.92	0.97	55
26	0.78	0.96	63	52	0.93	0.97	53				

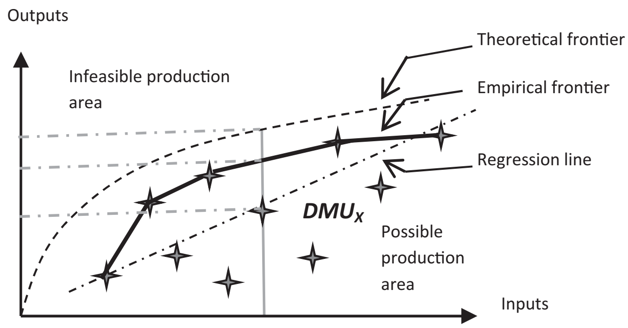

Fig. 4. Empirical and theoretical frontier.

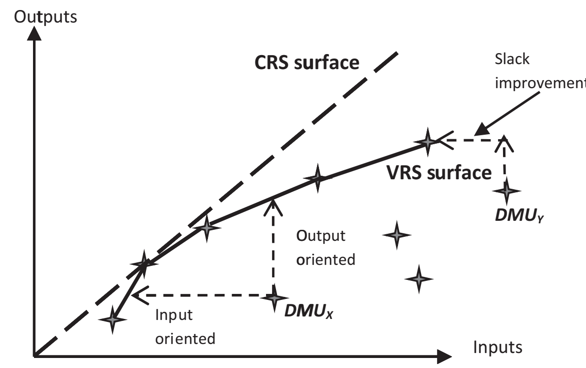

Fig. 5. Envelopment surface and orientation.

Appendix 4. Data envelopment analysis

Consistent with DEA terminology, the term 'DMU' refers to the individuals in the evaluation group. DEA generates a surface called the frontier that follows the peak performers and envelops the remainder (Charnes et al., 1978). Fig. 4 illustrates the concepts of the empirical and theoretical production frontiers in a two dimensional surface to generalize the case of a multi-dimensional surface. The theoretical frontier represents the absolute maximum possible production that a DMU can achieve in any level of inputs. However, the theoretical relationships between input and output parameters of a system are generally difficult to identify and to express mathematically. For this reason, the theoretical frontier is usually unknown. Therefore, the relative or empirical frontier based upon real DMU is used. The empirical frontier connects all the 'relatively best' DMUs in the observed population. Note that if the performance of all observed DMUs is generally poor, then your empirical frontier gives you only the best of a bad lot. The theoretical frontier would clearly indicate that the poor DMUs were indeed poor.

By providing the observed efficiencies of individual DMUs, DEA may help to identify possible benchmarks toward which performance can be targeted. The weighted combinations of peers and the peers themselves may provide benchmarks for relatively less efficient organizations. The actual levels of input use or output production of efficient organizations (or a combination of efficient organizations) can serve as specific targets for less efficient organizations, while the processes of benchmark organizations can be promulgated for the information of managers of organizations aiming to improve performance. The ability of DEA to identify possible peers or role models as well as simple efficiency scores gives it an edge over the other measures.

The four basic DEA models are the Charnes, Cooper and Rhodes (CCR) model, the Banker, Charnes and Cooper (BCC) model, the multiplicative model, and the additive model. Only the CCR and BCC will be discussed here. These models can be distinguished by the envelopment surface and the orientation (Banker et al., 1984). As shown in Fig. 5, the envelopment surface can take the form of constant-return-to-scale (CRS) or variable-return-to-scale (VRS) as evaluated in the CCR model and the BCC model, respectively.

Given the assumption of CRS, the size of the DMU is not considered to be relevant in assessing its relative efficiency. The CRS surface is represented by a straight line that starts at the origin and passes through the first DMU that it meets as it approaches the observed population. It seems that in the models with CRS envelopment surface, an increase in inputs will result a proportional increase in outputs. Small DMUs can produce outputs with the same ratios of input to output, as larger DMUs can do this. This is because there are no economies (or diseconomies) of scale present, so doubling all inputs will generally lead to a doubling in all outputs. However, this assumption is inappropriate for services which have economies of scale (or increasing returns to scale). In these services, doubling all inputs should lead to more than a doubling of output because providers are able to spread their overheads more effectively or take advantage of procuring supplies and other items in bulk. For other services, DMUs might become too large and diseconomies of scale (or decreasing returns to scale) could set in. In this case, a doubling of all inputs will lead to less than a doubling of outputs. It would be an advantage of DMU to ensure that its operations are in the optimal size – neither too small if there is an increasing returns to scale (IRS) nor too large if there is decreasing returns to scale (DRS). If it is likely that the size of service providers will influence their ability to produce services efficiently, the assumption of constant returns to scale is inappropriate. The less restrictive variable returns to scale frontier allows the best practice level of outputs to inputs to vary with the size of the DMUs in the sample.

The VRS surface envelops the population by connecting the outermost DMUs, including the one approached by the CRS surface. The VRS model allows an increase in input values to result in a non-proportional increase of output levels – IRS occur below the point where CRS and VRS meet, and DRS above. The CRS surface passes through the points where the DMUs have the highest output to input ratios, given their relative size, and then runs parallel to the respective axes beyond the extreme points. The scale efficiency of an organization can be determined by comparing the technical efficiency scores of each service producer under constant returns to scale and variable returns to scale.

The distance from the respective frontier determines the technical efficiency under each assumption. The distance between the constant returns and the variable returns frontiers determines the scale efficiency component. The distance from the variable returns frontier determines the technical efficiency resulting from factors other than scale. Thus, when efficiency is assessed under the assumption of variable returns, the efficiency scores for each organization indicate only the technical inefficiency resulting from non-scale factors. The technical efficiency scores calculated under variable returns, therefore, will be higher than or equal to those obtained under constant returns.

The other essential characteristic of DEA models is orientation, which indicates the direction that an inefficient DMU approaches to the efficient frontier: either an increase in its output levels while maintaining the same input level (output-oriented) or a decrease in its input levels while maintaining the same output level (input-oriented). The output-oriented approach may be more relevant for many government service providers, particularly those supplying human services, as the community often wants more of these services while budgetary pressures make it difficult to increase inputs. The input-oriented efficiency scores range between 0 and 1.0, whereas the output-oriented efficiency scores range between 1.0 and infinity and in both cases 1.0 is efficient. If a DMU is technically inefficient from an input-oriented perspective, then it will also be technically inefficient from an output-oriented perspective.

However, the values of the two technical efficiency scores typically will differ, as will the presence and extent of slacks. Depending on whether an input-saving or output-expanding orientation is utilized, the peers for DMU_X will also differ. The output-oriented optimization of DMU_Y in Fig. 5 is slightly different in that the DMU is not fully enveloped by the surface. In this case, DMU_Y first approaches the frontier by increasing its output and then by using the 'slack' variables to reach the efficient frontier. The VRS surface is used in this research; therefore, only the BCC model will be discussed in detail.

The objective of DEA is to obtain the weights that maximize the efficiency of the DMU under evaluation, while limiting the efficiency of all DMUs to less than or equal to 1.0 (for input-oriented models). Variables of this model are the efficiency score and the input–output weights, and the inputs and outputs of the DMUs are known.

Charnes et al. (1978) recognized the difficulty in seeking a standard set of weights to calculate the relative efficiency, which might cause DMUs to value inputs and outputs differently and thus adopt different weights. Therefore, they proposed that each DMU should adopt weights which show it in the most favorable light relative to the other DMUs. This flexibility in the weights is both a weakness and strength of this approach. It is a weakness because the judicious choice of weights by a DMU possibly unrelated to the value of any input or output may allow a DMU to appear efficient, but it may have more to do with the choice of weights than operational efficiency. This flexibility may also be considered strength because a DMU which is inefficient with even the most favorable weights cannot argue that the weights are unfair. As that might be, relationships can be incorporated into the model to constrain the weights as deemed appropriate.

It is very important to know that the efficiency values produced by DEA are only valid within that particular group of peers. A DMU that is efficient in one group may be quite inefficient when compared with another group. In other words, if a group of very poor DMUs were evaluated using DEA, you would still have efficient DMUs. As discussed later, developing a practical frontier is one way of addressing this shortcoming. Also, if the set of DMUs is small, then there is little discrimination between them. Consider Fig. 5, where five of the nine DMUs are on the efficient frontier. A general rule is that the DMUs should be there at least for three times, as there are variables (inputs + outputs) in the model. In the case of DMU prequalification, often there are 10 or fewer DMUs to evaluate per contract. This would restrict the number of evaluation variables to three, which is simply too few for a thorough and reliable prequalification. Therefore, it is desirable to identify a standard set of best performers in construction prequalification, i.e. to identify the practical frontier that would act as a fixed framework in which all DMUs could be compared (Azadeh et al., 2015).

The adopted VRS output-oriented DEA model can be expressed as follows:

$$\begin{aligned}
&\max \varphi + \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+\right)\\
&\text{s.t.}\\
&\sum_{j=1}^{n}\lambda_j x_{ij} + s_i^- = x_{io} \qquad i = 1, 2, \ldots, m;\\
&\sum_{j=1}^{n}\lambda_j y_{ij} - s_r^+ = \varphi y_{ro} \qquad r = 1, 2, \ldots, s;\\
&\sum_{j=1}^{n}\lambda_j = 1
\end{aligned} \tag{2}$$

Considering the set of n observations on the DMUs, each observation for DMU_j ($j = 1, \ldots, n$), uses m *inputs* x_{ij} ($i = 1, 2, \ldots, m$) to produce s outputs y_{rj} ($r = 1, 2, \ldots, s$). After solving this model, if then the current output levels cannot be increased (proportionally) and indicates that DMU_j is on the frontier. However, if then DMU_j is dominated by the frontier. represents the (output-oriented) technical efficiencies (TE) of DMU_j which is deemed efficient if and only if $\varphi^* = 1$ and $s_i^{-*} = s_r^{+*} = 0$.

In cases with multiple efficient DMUs with $\varphi^* = 1$ development of methods for complete ranking becomes necessary. For this purpose, this study subscribes to the suggested model by Jahanshahloo et al. (2004), which uses common set of weights. Following this way, in addition to determining the efficiency and ranking of DMUs, the lack of output indicators can be identified and efficient targets ($\hat{y}_{ro}$) of each DMU can be calculated through the following equation:

$$\hat{y}_{ro} = \varphi^* y_{ro} + s_r^{+*} \quad r = 1, 2, \ldots, s; \tag{3}$$

It is important to note that the competency of the above model can be limited in conditions of uncertainty. A method therefore is needed to add to the potency of this model at this particular situation. Fuzzy DEA is a tool for evaluation of performance under uncertain conditions, which uses the theory of fuzzy sets to demonstrate uncertain data and analyze them more accurately. Saati et al. (2002) proposed a fuzzy version of DEA using triangular fuzzy numbers substituting $\tilde{x}_{ij} = (x_{ij}^m, x_{ij}^l, x_{ij}^u)$ and $\tilde{y}_{ij} = (y_{ij}^m, y_{ij}^l, y_{ij}^u)$ into the model. They offered a new idea by α-cut in fuzzy DEA version converted into certain intervals and choose a point in intervals variables to satisfy the limitations and at the same time optimize the objective function. This fuzzy DEA model can be expressed as follow (Saati et al., 2002):

$$\begin{aligned}
&\max \varphi + \varepsilon\left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+\right)\\
&\text{s.t.}\\
&\sum_{j=1}^{n}\lambda_j (x_{ij}^m, x_{ij}^l, x_{ij}^u) + s_i^- = x_{io} \qquad i = 1, 2, \ldots, m;\\
&\sum_{j=1}^{n}\lambda_j (y_{ij}^m, y_{ij}^l, y_{ij}^u) - s_r^+ = \varphi \tilde{y}_{ro} \quad r = 1, 2, \ldots, s;\\
&\sum_{j=1}^{n}\lambda_j = 1
\end{aligned} \tag{4}$$

Efficiency of a DMU in Fuzzy DEA is not a crisp number rather it is a fuzzy number. Using α-cuts, also called α-level sets, the inputs and outputs can be represented by different level of confidence intervals. The fuzzy DEA model is, therefore, transformed to a family of crisp DEA models with different α-level sets.

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