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Data Envelopment Analysis Model for the Appraisal and Relative Performance Evaluation of Nurses at an Intensive Care Unit

Ibrahim H. Osman · Lynn N. Berbary · Yusuf Sidani · Baydaa Al-Ayoubi · Ali Emrouznejad

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Abstract The appraisal and relative performance evaluation of nurses are very important and beneficial for both nurses and employers in an era of clinical governance, increased accountability and high standards of health care services. They enhance and consolidate the knowledge and practical skills of nurses by identification of training and career development plans as well as improvement in health care quality services, increase in job satisfaction and use of cost-effective resources. In this paper, a data envelopment analysis (DEA) model is proposed for the appraisal and relative performance evaluation of nurses. The model is validated on thirty-two nurses working at an Intensive Care Unit (ICU) at one of the most recognized hospitals in Lebanon. The DEA was able to classify nurses into efficient and inefficient ones. The set of efficient nurses was used to establish an internal best practice benchmark to project career development plans for improving the performance of other inefficient nurses. The DEA result confirmed the ranking of some nurses and highlighted injustice in other cases that were produced by the currently practiced appraisal system. Further, the DEA model is shown to be an effective talent management and motivational tool as it can provide clear managerial plans related to promoting, training and development activities from the perspective of nurses, hence increasing their satisfaction, motivation and acceptance of appraisal results. Due to such features, the model is currently being considered for implementation at ICU. Finally, the ratio of the number DEA units to the number of input/output measures is revisited with new suggested values on its upper and lower limits depending on the type of DEA models and the desired number of efficient units from a managerial perspective.

Keywords Data envelopment analysis · Health care services · Nursing appraisal · Performance evaluation · Ratio pitfalls of units to measures · Talent management

I. H. Osman (✉) · L. N. Berbary · Y. Sidani
Olayan School of Business, American University of Beirut, Beirut, Lebanon
e-mail: ibrahim.osman@aub.edu.lb

L. N. Berbary
e-mail: lb07@aub.edu.lb

Y. Sidani
e-mail: ys01@aub.edu.lb

B. Al-Ayoubi
Faculty of Science I, Lebanese University, Beirut, Lebanon
e-mail: ayoubib@ul.edu.lb

A. Emrouznejad
Aston Business School, Aston University, Birmingham, UK
e-mail: a.emrouznejad@aston.ac.uk

Introduction

The healthcare sector has been focusing lately on developing quality standards, assessment and evaluation methods in order to improve the provision of health care services and to evaluate the performance of health care professionals. It is of a great challenge to develop a relevant appraisal and evaluation method that is highly linked to the delivery of optimal health care services, [12]. More specifically, the nurses at hospitals have a major role in the provision of high-quality health-care services at cost-effective usage of resources. [26] reported that many attempts and initiatives were developed to better assess the performance of nurses; however, several problems were encountered in developing in "the best" way an "equitable measurement" system capable of addressing problems of subjectivity, fairness, accuracy in rating, adequacy in selecting performance indicators, ability to provide motivation in nursing practices and ability to identify appropriate career development plans to improve performance of nursing services. Moreover, [26]

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in their exploration of the utility of exiting performance assessment methods reported that that no single method is appropriate for assessing clinical performance. Every approach has its advantages and disadvantages and recommended the use of a multi-method strategy for clinical performance assessment in nursing in order to enable the knowledge, skills and attitudes of nurses to be evaluated. Moreover, [8] reported that most of the employees' performance evaluation approaches focus on performance effectiveness rather than efficiency.

Nevertheless, [62] found the performance appraisal tool help registered nurses focus on their development. [43] also reported that development and career issues are among the main drivers of commitment amongst nursing staff. [42] also reported that evaluation of nursing is already proving an indispensable practical tool for raising the quality of health care, and for advancing professional nursing standards. However, conceptual and methodological rigor should be strengthened, and training in research skills should be extended. Therefore, the appraisal and performance evaluation process will remain and continue to grow as a controlling tool linking quality of performance to reward compensation /promotional decisions; and to career development plans. In our view, the shortcoming of existing appraisal and evaluation methods is coming from that fact each performance criterion is evaluated alone. Further, the various evaluations are then put together into some kind of combined functions with a pre-defined fixed weight for each criterion. Hence, the evaluation process generates deviations of individuals from a central tendency of performance rather the best practice performance. They do not allow for "trade-offs" among measured criteria or comparison to the best practice internal benchmark of performers for developing career improvement plans.

In this paper, a Data Envelopment Analysis (DEA) model is proposed to measure the relative performance of nurses and to address the previously mentioned shortcomings. DEA uses measured criteria both on multi-input of resources and multi-output of nurse' services to derive a relative efficiency score for each nurse. The relative efficiency score is computed optimally and it represents a capability index for each nurse in transforming its multiple-input of resources into producing its multiple-output of produced of health care services. The relativity concept comes from the fact all nurses would be evaluated using the same inputs and outputs criteria. The weights of such criteria are re-optimized in the best interest of each nurse rather than using a single set of fixed weights as in traditional approaches. The optimal weights of criteria for each nurse are optimized in the best interest of the individual nurse subject to a restriction that the same weights are used by other peers.

The DEA would produce a classification of nurses into efficient nurses with scores of 1 and inefficient ones with scores less than 1. The set of efficient nurses would form the set of "best practice" efficient benchmark to project career development plans for inefficient nurses. Hence our DEA approach can be seen as an effective talent management and motivational tool to provide clear managerial plans related to training and career development activities from the perspective of nurses, hence increasing their satisfaction, motivation and acceptance of appraisal result. The managerial plans for inefficient nurses are developed with reference to peers i.e. perceived achievements rather than ideal expectations that may not exist. Moreover, our DEA development would overcome human recourse (HR) problems of existing approaches and demonstrate its effectiveness as a good HR strategic decision making tool for measuring impacts of strategic managerial decisions on performance. Moreover, our DEA application is different from the two other DEA applications in the literature on evaluating the performance of administrators of a chain of nursing homes by [36] where the objectives were to improve the operating efficiency of nursing homes using financial, economic and operating measures. Whereas recently [64] included measures on the quality of care to improve the evaluation of performance of administrators in the chain of nursing homes. Finally, nursing managers are realizing that the nursing units are the focus of resource consumption in health care delivery, for which information systems that can capture, analyze, and report on both nursing tasks and decisions are increasingly essential, [18]. Hence, the paper makes a modest contribution along this direction.

The remaining part of the paper is organized as follow. A review of the various appraisal and relative performance evaluation approaches in the nursing sector are discussed in "Review of appraisal and performance evaluation approaches". The most commonly used measurable evaluation criteria in nursing are presented in "Classification of performance criteria into inputs and outputs" in order to select the most relevant criteria for inputs and outputs to use in our performance evaluation DEA model. A brief introduction to DEA and its implementation to the nursing sector are explained in "Data envelopment analysis in nursing care". Our computational experience with the DEA approach for evaluating nursing staff working in an Intensive Care Unit at one of the most important hospitals in Beirut, Lebanon are presented in "Discussion of the performance evaluation experience" in which a comparison with the current appraisal approach is provided, managerial implications are discussed, and the relationship between number of nurses and the number of DEA input and output variables is investigated. Finally, we conclude with further research and suggestions in "Conclusion".

Review of appraisal and performance evaluation approaches

According to [55], the origin of performance appraisals goes back to the third century in China when Philosopher Sin Yu criticized a rater employed by the Wei Dynasty for rating employees on the basis of his own personal likes and dislikes rather than on the basis of individual merit. Appraisal comprises an objective evaluation of an employee's performance combined with an outline of measures to be taken for improvement and counter-signed by both employee and manager, [26]. Appraisal evaluation review has been recognized as an essential step for an organization to move forward and was the most frequently reported and widely used assessment approach at numerous organizations, [14]. Moreover, [39] reported on several reasons for formal performance appraisals to continue in organizations to justify a wide range of human resource decision making activities including pay raise, promotion, demotion, termination and training of employees. Further, the authors reported that the practice of performance appraisal is one of the top 10 drivers for creating a company's competitive advantage. Although the assessment process is an annual cycle, the time requirements to complete, and subsequent additional staff costs are considerable, [70]. Moreover, ineffective appraisal practices can lead to many undesirable problems including low morale, decreased employee productivity, and low enthusiasm to support organizations, [65].

In the literature of nursing health care sector, a variety of methods have been reported in the performance appraisal of nurses. As they are based on widely accepted educational and quality principles, these methods have much in common. However, their implementation is influenced by historical, political, financial, philosophical and sociological forces, [22]. Some of the evaluation methods are formal while others are informal. Informal appraisals involve the assessment of an individual's performance outside any formal structure. Employees are subject to both conscious and unwitting assessments by their supervisors on a daily basis. Much of this assessment is subjective and depends on the ability of a nurse to get on well with the supervisor, nurse's reactions to work under pressure, appearance, degree of organization, levels of attentiveness and interest. While these sorts of informal assessments are difficult to avoid, contemporary wisdom suggests that formal appraisals should be directly related to the specific tasks and duties to be performed, [32]. Formal appraisal system evaluates performance of employee based upon explicit criteria—qualitative as well as quantitative. In this section, we review the most commonly appraisal evaluation and ranking methods. They can be classified as either supervisor, team, self, peer or subordinate based on qualitative features, quantitative dimensions. They are briefly summarized below for more details, we refer to the comprehensive excellent review in [26] and the book by Henderson (1980).

1) ***Self-appraisal method*** gives a nurse an opportunity to voice opinions about the work, thus promoting employee involvement, [14]. [59] recommended that nurses should be able to monitor and assess their own needs for continuing professional development. However, they also pointed out that self-appraisal is a skill which must be learned with subsequent cost-implications for staff training.
2) ***Reflection method*** comprises a battery of approaches including elements of performance review, clinical supervision and professional development opportunities, [7]. It has been reported as a valid tool in the clinical assessment of quality of care in teams of practitioners to develop relevant practice in problem-solving ability and to test professional interests and specialties, [59].
3) ***Portfolio method*** keeps a current record of achievements, professional education and practice, [9]. It may contain self-reflection, learning contracts, evaluations and ratings and provide evidence of professional and academic credibility skills. [20] highlighted several positive aspects such as provision of useful means for nurses to demonstrate their competence in accordance with contemporary professional standards, thus facilitating advancing professional nursing practice. However, they are time-consuming to construct and maintain, careful consideration should be given to content, legal aspect to disclosure of sensitive information and dependency on writing skills and honest reporting.
4) ***Process review*** identifies quality indicators through patient experiences in health care and explores nurse–patient interactions, [34].
5) ***Multisource feedback*** (or 360 degree appraisal approach) requires information from all internal and external sources, [45]. It is defined as a questionnaire based assessment method in which nurses are evaluated by peers, patients and co-workers on key performance behaviors, [38]. [49] described the significance of 360-degree evaluation of residents by the nursing staff on the competencies of interpersonal and communication skills with patients, interactions with peers and professionalism. Collected data are analyzed using statistical tools such the Chi-square test, the *t* test, analyses of Variance and Spearman's Correlation.
6) ***Observation method*** assesses the performance of nurses while performing duties and observation of a broad range of nurse behaviors can be evaluated, [34].

However, it is a time consuming process, and validity and reliability are common concerns, [11].

7) **Supervision method** is widely adopted approach to performance assessment. It may provide more accurate information than interviews or questionnaires. Its drawbacks are its limited focus on observed activities, time-consuming nature and the need for a defined role and function of both supervisors and supervisees, [59].
8) ***Standards method*** compares the extent of clinical competence against predetermined standards of practice. [5] proposes performance management as a primary effective mechanism for an early identification and remedy of poor performance, with an early recognition and feedback on performance, decisive intervention and effective self-regulation.
9) **Management by objectives** method, where the organization goals are divided into objectives and the appraisal method measures the employee performance by examining the extent to which each objective has been met.
10) ***Narrative review methods*** include according to Henderson (1980): i) *Essays Appraisal* where the appraiser provides an overall narrative assessment on the employee's strengths, weaknesses, needed training and developmental plan, and recommendations to improve future performance, ; ii) *Critical Incidents* where managers keep an accurate log sheet of every successful or unsuccessful incident or critical behaviors occurring with each employee; iii) *Field Review* where a Human Resources representative interviews managers and supervisors and ask them about the performance of their immediate employees with reporting like "satisfactory", "unsatisfactory", and "outstanding", iv) *Check list* where the evaluator goes down a list with yes or no answers on some pre-defined behavioral characteristics that apply to the employee.
11) ***Ranking methods*** include i) *Straight Ranking* where a manager classifies employees into 5 ordered groups and each employee in each group is ranked from 1 to 5; ii) *Forced Distribution* where a manager classifies employees according to a normal distribution in which 5% of employees have an *unacceptable* performance; 15% *below average*; 60% *average*; 15% *above average* and 5% have a *superior performance*, [6].
12) **Other formal and popular evaluation methods** include i) the *Rating Scales* (RS) and ii) the *Behaviorally Anchored Rating Scales* (BARS) and their variants. The RS method offers a high degree of structure for appraisals. Each employee trait (or characteristic) is rated on a bipolar scale that usually has several points ranging from "poor" to "excellent". The traits assessed on these scales include nurse attributes such as cooperation, communications ability, initiative, punctuality and technical competence in work skills. [52] reported that the traits selected by some organizations have been unwise and have resulted in legal actions on the grounds of discrimination. [47] described an employee evaluation procedure adopted by a nursing home. The criteria considered were: employee's job attitude, communication skills, and clinical skills. The evaluators used the scoring key for each criterion: Excellent=4, Good=3, Fair=2 and Poor=1. However, the author did not elaborate on how the ratings on various criteria were synthesized and converted into a percentage score. BARS method has unique measurement properties. It relies on a classification of independent dimensions of behavior. A dimension is an axis along which an array of behavioral performance statements (descriptors) varying in quality or intensity (ranging from the most effective to the least effective) are ordered. Evaluators are instructed to read the entire continuum of behaviors and then select the one which most closely describes the actual, or expected, behavior of the evaluated nurse. Each statement is accompanied by a number on the scale (a 5-point or 10-point scale), one of which is recorded to indicate the nurse's performance on that particular dimension. BARS has been used for evaluation of performance in a wide variety of health care sector, we refer readers to [13,25,63] for more details. [69] reported that health care managers should wisely select appropriate words to describe work in performance appraisals when developing appraisal methods such as a RS and BARS. The result of [35] indicated that BARS and other formats appear to differ relatively little with regard to psychometric characteristics such as degree of evaluator participation in scale construction and evaluator preferences for different rating scale formats as well as validity and accuracy.

With respect to dissatisfaction with the appraisal and performance evaluation approaches in the nursing sector, [12] reported that nurse managers tend to rate staff nurses based on recent information gathered which may poorly represent the real performance of nurses throughout the year of services. Some nurses think of the evaluation process as a focus only on their weaknesses and failures, and such evaluation may result in a negative feedback and bad compensation from management. Whereas from the managers' perspective, they view the performance evaluation process as a long and difficult task in the presence of many activities and duties; hence some may not give it enough time to conduct a proper evaluation, especially, when there are a large number of employees. For them, this evaluation process is long, boring, waste of time and not

profitable. Further, nurse managers complain that they "fear" the evaluation process and they do not favor performance management due to its various complexities.

Robert [60] highlighted the importance of employee participation in the appraisal process. It was argued that if employees are confident in the fairness of the appraisal process and perceive a fair decision making process, they are more likely to accept performance ratings. However, if perceived as unfair, unsystematic and not thorough, it is unlikely that they will accept the outcome of the appraisal exercise. Mani (2002) reported that employees' perception of fairness of the appraisal systems is related to trust and satisfaction with their supervisors but not with compliance with the evaluation procedures. Gray (2002) wrote that performance appraisals don't produce more competent, loyal workers because the practice is inherently flawed. However, proponents of performance appraisal system argued that the effects of many of the negative factors can be diminished by following certain set of guidelines, [60].

A ten-point guideline based on the recommendations of both [32,60] is summarized as follows:

1) ***Encourage Employee participation*** to assure the acceptance of the appraisal outcomes and to provide an opportunity to the employees to raise their voice into the appraisal process;
2) ***Develop performance standards*** to measure the essentials of job duties and employee' s responsibilities;
3) ***Set goals*** by assigning employees a series of moderately challenging and accepted tasks to be accomplished in the course of a year. When annual reviews are held, rate the employees' progress in achieving these goals;
4) ***Conduct a sound performance appraisal interview*** to provide undivided attention during the interview, with a full awareness of sensitivity to employee needs for privacy and confidentiality, and reserve adequate time for a full discussion of the feedback issues;
5) ***Request Self evaluation*** to provide employees an opportunity to systematically assess their performance. [44] commented that employees who have an opportunity to assess their own performance often come up with creative solutions that would not have surfaced in the one-sided managerial evaluation;
6) ***Provide Management feedback*** to explain the strength of an employee and to correct weaknesses, employees cannot improve their job performance unless they are told where their performance is inadequate;
7) ***Develop user-friendly procedure,*** to be simple enough and well understood by the evaluators and employees;
8) ***Design specific and relevant appraisal system*** to address the requirements and essential functions on the job. The criteria should be specific and directly related to the job to avoid employee complain;
9) ***Train Evaluator*** to avoid employee and supervisor's frustration with the performance appraisal process. Evaluators should receive extensive training in goal setting, setting performance standards, conducting interviews, providing feedback, and avoid rating biases;
10) ***Revise performance appraisal process*** systematically and regularly to make sure that process and practices are being followed and with effective feedbacks from both managers and employees to generate acceptance and trust of the appraisal system and to add new tasks to the job description and remove obsolete ones.

Classification of performance criteria into inputs and outputs

Performance criteria in the literature

Generally, employees are contracted to perform certain duties and tasks according to the job description guided by an organization's goals and mission. The performance of each employee on the job is then assessed according to a selection a set of main criteria and each criterion may have a certain member of sub-criterion. The set of performance criteria includes among others categories such as job related achieved goals and duties; employees' different work skills; capacities and behavior on the job. Each organization uses different set of performance criteria depending on their mission and nature of work. Therefore, there is no standardized set of performance criteria. In this section, we present a short review of the most commonly used performance criteria which will be used for the identification of criteria for evaluating the performance of nurses.

Table 1 provides a list of the main performance criteria highlighted in bold in column one with their associated sub criterion. Columns 2 to 8 indicate the references where the criterion was reported. The last column represents a total count of used references as a measure of importance. We shall denote by A to G the following references, respectively: [2,6,31,37,53,57,66]. It can be seen from the Table that the evaluation form used at ICU of Hospital G covers most of the commonly used performance criteria.

A brief on the evaluation process of the nursing services at hospital G

Hospital G is a University Medical Center hospital located in Beirut Lebanon. For a confidentiality and consent agreement, no names will be disclosed. Hospital G focuses highly on satisfaction of patients. One of its main interests

Table 1 The most common performance criteria identified from various references

Performance criteria and sub-criterion	References							Total
	A	B	C	D	E	F	G	
1. **Quality**								
o Accuracy		X			X	X	X	4
o Neatness		X			X	X	X	4
o Organization	X	X	X		X		X	5
o Applicability		X			X		X	3
o Follow up on previous issues or actions					X	X	X	3
o Punctuality in replying to internal and external requests		X			X	X	X	4
2. **Quantity (depends on the nature of work)**								
o Amount of work produced (compared to expected standards)	X	X	X	X	X	X	X	7
3. **Timeliness**								
o Daily attendance				X		X		2
o Meeting deadlines				X		X	X	3
o Time management abilities				X		X	X	3
3. **Problem Solving and Decision Making**								
o Initiative		X		X	X	X	X	5
o Creative	X	X	X		X	X	X	6
o Error depiction and correction	X	X		X			X	4
o Problem solving skills		X			X	X	X	4
o Risk Taking	X		X			X		3
o Technical Orientation	X					X	X	3
o Information gathering and use						X		1
o Analytical Orientation	X				X	X		3
o Provide suggestions for work improvement				X		X	X	3
o Objectivity—Open Minded	X			X		X		3
o Thoroughness	X				X	X	X	4
o Discernment	X							1
o Effective use of resources	X	X			X	X	X	5
4. **Relationship with people**								
o Cooperation with colleagues	X	X	X	X	X	X	X	7
o Teamwork	X			X		X	X	4
o Responsibility			X				X	2
o Accountability	X				X	X		3
o Down up communication skills	X				X	X	X	4
o Negotiation skills	X			X		X	X	4
o Persuasiveness	X							1
o Customer focus	X						X	2
o Respect and courtesy	X	X	X	X			X	5
o Confidence and trustworthiness	X			X				2
o Extroversion	X		X					2
o Awareness and alertness	X		X				X	3
o Conflict management	X						X	2
o Listening	X	X					X	3
o First impression	X							1
o Formal Presentation	X							1
o Political astuteness	X		X					2

Table 1 (continued)

Performance criteria and sub-criterion	References							Total
	A	B	C	D	E	F	G	
5. **Behavioral Observations**								
o Job Knowledge						X	X	2
o Effectiveness in using work tools and equipment		X			X	X	X	4
o Office tidiness and orderliness	X							1
o Reliability	X	X		X	X	X		5
o Flexibility	X			X	X	X		4
o Boldness	X					X		2
o Pleasant			X	X				2
o Anxiety			X					1
o Conformity			X					1
o Social participation			X					1
o Value Orthodoxy			X				X	2
o Aggression			X					1
o Emotional stability			X					1
o Intellect			X					1
o First impression	X							1
o Focus—attentiveness	X			X				2
o Self esteem	X		X			X		3
o Optimism—faith	X					X		2
o Multi-tasking	X						X	2
o Compliance with policies and procedures		X			X	X	X	4
o Compliance with safety standards		X		X	X	X	X	5
6. **Management skills (if applicable)**								
o Strategic planning	X				X	X	X	4
o Goal setting	X					X	X	3
o Tactical planning	X					X		2
o Hiring high standard people	X	X			X			3
o Direction skills	X	X						2
o Coordination with subordinates	X	X		X			X	4
o Performance assessment to subordinates	X	X				X	X	4
o Follow up on human development and training		X			X	X	X	4
o Fair implementation of personnel policies and procedures		X			X			2
o Support-affection	X		X	X	X	X	X	6
7. **Leadership skills**								
o Strategic vision	X	X						2
o Determination	X	X					X	3
o High standards	X	X						2
o Delegation	X	X						2
o Decisiveness	X	X				X		3
o High standards	X	X					X	3
o Mentoring	X	X		X			X	4
o Passion for Company	X	X		X			X	4
o Inspiring role model-integrity	X	X		X				3
8. **Pertinent performance factors**								
o Attendance of seminars and workshops		X					X	2
o Work on professional development						X	X	2
o Joining Professional or International Association		X						1

is to improve the quality of health care services and to provide high standards of patient care. All staff members at ICU are annually evaluated, and they include doctors, nurses, administrators and parking attendants. The performance evaluation is conducted to measure the achievement of hospital's goals on patient services. The general measures include: adaptability, flexibility, teamwork, exceptional patient relationship and drivers on patient' satisfaction with health care services, excellent appearance, politeness, general knowledge and education. The detailed descriptions of such criteria are listed in Table 2.

The nursing staff performance evaluation at Hospital G is conducted annually, usually at the end of the year. It is an on-going cycle starting with the employee's performance and development advances throughout the year. The evaluation criteria are divided into three sections. "Introduction" describes the instructions for evaluators on how to conduct the performance appraisal. It also defines the two performance evaluation areas with their weights: service excellence standards (25% weight) and job-specific competencies (75% weight). The nurse's total score is then calculated as the total sum of the weighted points earned in each area. The nurses are classified into five performance categories: G1 "rarely meets standards with scores 0–24"; G2 "occasionally meets standards with scores 25–49"; G3 "meets standards with scores 50–75"; G4 "occasionally exceeds standards with score 75–89" and finally G5 "consistently exceeds standards with scores 90–100". The performance measures of Hospital G consist of 45 criteria. They include 36 on qualitative traits with weight of one for each criterion. The other 9 criteria are on competencies, each is given a weight greater than one. The details on such criteria are provided in Table 2. Each criterion is assessed using a 5-point scale starting from 0 to 4. The total sum of scores over all criteria are summed and averaged over the 36 traits to derive an average value, which is then multiplied by the section weight of 25%. The competence duties using the 9 performance criteria are similarly evaluated. The average score is then derived and multiplied by the section weight of 75%. The two individual weighted averages of both sections are added to obtain the percentile score of each nurse.

Table 2 provides a list of 45 criteria with their corresponding managerial weights and descriptions as they are currently used at the ICU of hospital G. However, the 45 criteria are classified into a set of inputs and a set of outputs in order to use them in our proposed DEA performance evaluation model. The input variables are considered as resources or acquired skills that a nurse uses to produce a set of tangible output or intangible outcomes. Throughout the paper, an output is used interchangeably to refer to both an output and an outcome. It can be seen that some of the main criteria have several sub-criterion to measure it. For instance, in Table 2, the job knowledge is measured using sub-criterion C10 to C13. Moreover, since some of the criterion has similar functionality but presented in different way for validation purposes, we have combined them into a single measure, e.g. output 1 is the combination of criteria C1, C19–C22. Similarly output 4 is a combination of criteria C4 and C5.

Data envelopment analysis in nursing

In this section, we present a brief background on data envelopment analysis and its application to the performance evaluation of nurses at the intensive care unit at the hospital.

Data envelopment analysis background

DEA was proposed by [15] as a non-parametric method of efficiency analysis to compare the relative performance of units relative to their best peers (efficient frontier) rather than average performers, and to identify benchmarks for inefficient units. It does not require any assumption on the shape of the DMUs efficient frontier surface and it makes simultaneous use of multiple inputs and multiple outputs. DEA defines the relative efficiency for each decision making unit (DMU) (i.e. nurse, school, bank, any production process) by comparing the DMU's inputs and outputs to other DMUs data in the same "cultural or working" environment. The outcomes of a DEA includes: *i*) A piecewise linear empirical *envelopment frontier surface of the best practice internal benchmark*, consisting of DMUs exhibiting the highest attainable outputs for their given level of inputs; *ii*) An *efficiency metric (score) to represent the maximal performance measure* for each DMU measured by its distance to the efficient frontier surface; iii) *Efficient projections onto the efficient frontier to project improvement with an identification of a reference* set of *efficient* units which consists of the "close" efficient DMUs to suggest internal benchmarks to guide *inefficient* units; iv) a *ranking of units* from best (highest score) to worst (lowest score).

There are mainly two types of DEA models: [15] introduced a constant *returns-to-scale* (CRS, or CCR) model and [3] introduced the *variable returns-to-scale* (VRS or BCC) model. The VRS model is one of the extensions of the CRS model where the efficient frontiers set is represented by a convex curve passing through all efficient DMUs, [17]. Both DEA models can be further classified *as input-oriented, output-oriented or radial-additive* models based on the direction of projection of inefficient units onto the efficient frontier surface. In all models, the weights for both inputs and outputs of an

Table 2 Classification of performance criterion at hospital G into input and output

Criteria number	Managerial weight	Description of criterion
Output (1) Planning/Organization:		
1	3	Performs initial and ongoing assessment of the nursing needs of patients. Includes, preparing, administering and implementing a nursing care plan for each patient in unit. Nursing needs include physical, emotional and psychological needs
19	1	Establishes clear and attainable objectives
20	1	Organizes duties and work
21	1	Identifies resources required to meet objectives
22	1	Meets deadlines
Output (2) General Practice Performance		
2	3	Performs nursing functions for the comfort and well being of patients and in support of medical care according to established standards and practices. Includes receiving and orienting newly admitted patients, completing patients medical history form, maintaining medical record file, performing nursing interventions, ensuring patient safety and observing infection control policies and procedures
6	3	Maintains patients medical record and charts on nursing observations and action taken, such as medications and treatments given, intravenous administration, change of wound dressing, vital signs, physiological, psychological and emotional status, etc...,
Output (3) Nursing Practice Performance		
3	3	Communicates and consults with physicians and other health care professionals when indicated. Transcribes and carries out physicians' orders. Includes requesting prescribed pharmaceutical items and supplies, laboratory and diagnostic tests, electronically etc...Includes checking results of tests and reporting to physician abnormalities.
Output (4) Technical Practice Performance		
4	3	Prepares, administers and documents electronically prescribed medications, intravenous solutions and treatments as orders by physicians as per established procedures. Assesses patients' reaction to medications and treatments, reports side effects, observes progress of intravenous infusion, and checks the patient for presence of phlebitis or infiltration. Observes, records and reports to physician patient's conditions, reactions to drugs, treatments and significant incidence.
5	3	Provides nursing treatments as ordered by physician and according to nursing procedure guidelines. Includes, making rounds with physician to discuss patient's response to treatment and updates patients' plan of care
Output (5) Patient Education Performance		
7	2	Assesses educational needs of patients and/or family. Teaches them as necessary during the hospitalization and in preparation for continuing care after discharge. Includes explaining treatments and procedures requested to gain patient's cooperation and allay apprehension.
Output (6) Emergency Work Follow-up		
8	3	Maintains readiness of emergency cart and equipment in unit. Ensures availability of medications and medical supplies in unit store. Includes reporting malfunction of equipment to supervisor for action
Output (7) Taking Responsibility		
9	2	Performs other related duties, such as rotating on various shifts, responding promptly to unforeseen and emergency situations, informing supervisor of any accident or incident occurring on the unit, participating in the orientation in training of auxiliary,
Input (1) Job Knowledge		
10	1	Demonstrates the knowledge and skills necessary
11	1	Understands the expectations of the job
12	1	Performs responsibilities as per job policies and procedures
13	1	Requires minimal supervision
Output (8) Quality/Quantity of Work		
14	1	Completes assignments accurately, thoroughly, neatly and on time
15	1	Exhibits concern for the goals and expectations of the department customers
16	1	Handles responsibilities in an effective manner
17	1	Completes assignments as per quality standards
18	1	Completes the appropriate amount of work assigned

Table 2 (continued)

Criteria number	Managerial weight	Description of criterion
Input (2) Work Habits		
23	1	Complies with organization rules and regulations such as: dress code, wearing of identification badges, safety regulations...etc
24	1	Uses time effectively
25	1	Takes on additional tasks when job demands it
Output (9) Problem Solving Creativity		
26	1	Identifies and analyzes problems
27	1	Formulates alternative solutions logically
28	1	Takes or recommends appropriate
29	1	Follows up to ensure problems are solved
30	1	Initiates creative ideas and techniques
31	1	Willing to change/try new approaches
32	1	knows when to refer matters to supervisor
Input (3) Teamwork and cooperation		
33	1	Demonstrate harmonious relationship with coworkers
34	1	Resolves conflicts with others directly; constructively
35	1	Accepts constructive criticism and suggestions
36	1	Provides assistance and support to others
37	1	Contributes effectively as a team player
Input (4) Interpersonal skills		
38	1	Is positive and effective with workers
39	1	Demonstrates respect for all individuals
40	1	Shows integrity and ethical behavior
Input (5) Using Equipment Skills		
41	1	Protects resources against waste, loss or misuse
Input (6) Communication		
42	1	Communicates clearly both verbally and in writing to do the job
43	1	Listens carefully and seeks clarifications; responds appropriately
44	1	Provides oral guidance and assistance to customers
45	1	Shares information with others as appropriate

individual DMU are optimized in the best interest of the evaluated DMU unit, relative to its DMU peers. In the present study, both *input-oriented* and *output-oriented* DEA models are used to derive some managerial insights for managing and developing the career of nurses.

Next, a mathematical formulation of the basic CRS model is introduced. Consider a set $N=\{1,2,...,n\}$ of nurses (or DMUs) for evaluations. Let X_j and Y_j be the column-vectors of ***m*** *inputs and* ***s*** *outputs* values for each *j* in N, respectively, let also *u* be the *m*-dimension column-vector of input weights (resource values), and *v* be the ***s***-dimension column-vector of output weights (output values). Given a DMU_0 to be evaluated, the DEA-CRS model of [15] measures the efficiency productivity of DMU_0 as the ratio of its total virtual outputs over its total virtual inputs. The virtual productivity ratio $\Theta^* = \frac{u_r^* Y_0}{v_i^* X_0}$ is maximized subject to the condition that the virtual ratio Θ of any unit j does not exceed 1 and all the weights are strictly positive. This non-linear model can then be re-written more explicitly in a linear format as follows:

$$Minimize\, \Theta_0 = \sum_{i=1}^{m} v_i x_{ij_0} \tag{1}$$

Subject to:

$$\sum_{r=1}^{s} u_r y_{rj_0} = 1 \tag{2}$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0\ ; \qquad j = 1, \ldots, n \tag{3}$$

$$u_r,\ v_i \geq \varepsilon \quad ; \quad i = 1, \ldots m,\ \&\, r = 1, \ldots s \tag{4}$$

Where:

- Θ_0 efficiency score of $j0^{th}$ nurse being assessed in the set of $j=1,...,n$ nurses
- ε a non-Archimedean value to enforce strict positivity of the weights
- y_{rj} observed amount of r^{th} output produced by nurse j
- x_{ij} quantity of i^{th} input used by nurse j
- u_r the weight given to output r as determined by the linear programming
- v_i the weight given to input i as determined by the linear programming

The objective in Eq. 1 minimizes the value of the weighted sum of virtual inputs while keeping the weighted sum of virtual outputs for the j_0^{th} nurse (DMU_0) equals to one (numerator of virtual productivity ratio) as shown in Eq. 2. The productivity ratios in Eq. 3 imply that all the nurses are on or below the frontier, that is, the efficiency of all the nurses has an upper bound of one. The weights u_r and v_i are treated as unknown variables and they are optimized in the linear programming solution in the best interest of the nurse being evaluated and Eq. 4 are the non-negativity constraints.

The above CRS model is only appropriate when all the nurses are working at an optimal level (scale). In reality, some factors, such as work load, stress and pressure may prevent a nurse from operating at an optimal scale. To allow the calculation of technical efficiency that is free from the scale efficiency effects, [3] proposed a variable returns to scale (VRS) model by introducing an *extra free-sign* variable (u_0) to determine the return to scale level in the following VRS model.

$$Minimize\ \Theta_0 = \sum_{i=1}^{m} v_i x_{ij_0} + u_0 \tag{5}$$

Subject to:

$$\sum_{r=1}^{s} u_r y_{rj_0} = 1 \tag{6}$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} + u_0 \le 0\ ; \qquad j = 1, \ldots, n \tag{7}$$

$$u_r,\ v_i \ge \varepsilon \quad ; \quad i = 1, \ldots m,\ \&\ r = 1, \ldots s \tag{8}$$

$$u_0 \text{ is free in sign} \tag{9}$$

Where the interpretations of its solution value are:

- $u_0>0$ indicates that the unit under evaluation is having an increasing return to scale
- $u_0=0$ indicates the unit under evaluation is having a constant return to scale and
- $u_0<0$ indicates that the unit under evaluation is having a decreasing return to scale.

The unit under evaluation, DMU_0, is said to be *efficient if and only* if $\Theta_0^* = 1$; and is said to be weakly efficient if it is efficient and has a reference set of different efficient units. Otherwise, when $\Theta_0^* < 1$, DMU_0 is said to *inefficient* and dominated by at least one of the set efficient units which identify its corresponding benchmarks, i.e., an inefficient unit needs either to increase its output level or decrease its input levels by projection onto this efficient frontier. The above CRS and VRS are said to be *input-oriented efficiency* models as each attempts to decrease the value of the weighted sum of inputs of the assessed unit in (1) while keeping its weighted sum of outputs in (2) constant equal to one. Similarly one can generate the *output-oriented* models where the weighted sum of outputs can be maximized while keeping constant the weighted sum of inputs. More details on DEA models can be found in [17].

DEA applications are numerous in financial services, regulation, police services, health care services, education, manufacturing, telecommunication, and auditing. But in the Human Resource (HR) health care sector they are very limited to [36], Wagner et al. (2003) appraised performance of primary care physicians, and [64] measured performance of administrators in the chain of nursing homes; [1,61] evaluated physician practices and measured routine nursing service efficiency, and [48] studied the cost per patient day. [29] presented a good review on DEA applications to hospitals and to the wider context of general health care. However, in a wider HR context, Thanassoulis (1995) assessed the performance of police forces in England and Wales; Paradi et al. (2002) appraised the performance of engineering design personnel at Bell Canada; [33] identified "best" applicants in recruitment; [40] evaluated performance efficiency of core employees; [10] allocated fairly annual and long-term compensations to both men and women to assure gender equity; [8] evaluated performance of salesperson; [16] measured the efficiency of bank and thrift CEOs; [50] measured performance of Lebanese banks and their mergers; and [51] appraised the performance academic faculty staff at higher education according to organizational objectives and goals. For a recent comprehensive bibliography with over 4000 references on DEA theory and applications, we refer to [21].

DEA Implementation to the performance evaluation of nurses

This section discusses several issues related to our implementation of DEA to the nursing sector following the guideline of [19] on avoiding pitfalls and with

suggested protocols in order to achieve a successful application of DEA methodology. *First,* the homogeneities of units are satisfied as all the nurses are working in the same hospital with similar work environments. *Second*, selected inputs should have direct impact on the outputs, and both inputs and outputs should cover a wide range of performance measures with factors common to all units, [68]. The evaluation form of nursing staff in our application uses the most critical and important performance criteria used in the literature as in Tables 1 and 2. The 45 criteria are further grouped into inputs and outputs in Table 2 to facilitate the DEA application. *Third*, a reasonable level of discrimination among compared units is assured by meeting the relationship among number of DMUs and number of inputs and outputs of [24,30] who suggested as "a rule of thumb" that the number of nurses, n, should be at least twice the total number of (m) input and (s) output variables, i.e. $\{n \geq 2*(m+s)\}$. The total number of evaluated nurses (n=32) with the original performance criteria regrouped into m=6 input variables and s=9 output variables meet the following relationship (32>2(6+9)) with corresponding details presented in Tables 2 and 3. *Fourth,* the input and output variables should have measurable scales with no high values in order to avoid "round-off errors", Meng et al. (2008). Our provided data from Hospital G shows that all inputs and outputs have a scale from 0 to 4, hence avoiding the "round error" pitfall. *Fifth, the* input and output measures should meet the "isotonic data property", i.e., the inputs should have values to decrease whereas outputs should have values to increase in order to maximize the efficiency of a given DMU. However, there are some output (input) criteria which require decreasing (increasing) rather than increasing (decreasing) values to achieve a better efficiency. To meet the "isotonic properties", the inverse of such numbers are used following the guideline in [68].

DEA data preparation

The performance appraisal data used in the year 2008 of the 32 nurses working in at the Critical Care Units (the Intensive Adult Care Unit, the Intensive Pediatric Care Unit, the Cardiac Surgery Unit and the Organ Transplant Unit) at Hospital G are used in our analysis. The original data is provided in Table 3 where the first column of the table represents the 45 performance criteria and the first row represents the indices for the 32 nurses. The entries represent the managerial mark for each nurse on each criterion. The raw data in Table 3 cannot be used directly without transformation. Since, some of the input and output variables are combinations of more than one criteria, therefore, the average scores are taken to represent their final scores (i.e., Input 1 "*Job Knowledge*" is a combination of criteria C10–C13, and the average value of these criteria is computed to derive a final score for each nurse. Moreover, since input 1 is an isotonic variable, it needs to be minimized, the inverse of its score is computed to reflect this definition, (i.e., Nurse 4 score on input 1 is calculated as $\left\{\frac{1}{(4+4+4+3)} = 0.267\right\}$ and rounded up to two decimals as shown in column 2 of Table 4. The same transformation is applied to similar inputs data in Table 3 to derive their corresponding values in Table 4 for another aggregated model with 3 inputs and 5 outputs, namely, Model 8 (or M8) in Table 5.

It should be noted that the combined criteria (say C10 to C13) using the average approach gives equal importance for each criterion. However, other reduction approaches could be used to generate different weights for the original criteria before averaging them. The analytic hierarchy process was used to derive such weights from experts' opinions for reducing the number of criteria in the DEA application of Meng et al. (2008), and Ramanathan (2006). Finally, the results obtained using DEA-Solver software of [17].

Discussion of the performance evaluation experience

This section discusses the performance evaluation results for nurses as well as managerial implications of interests to demonstrate the usefulness of the proposed approach. Furthermore, it investigates the relationship ratio of the number of decision making units to the total number of inputs and input variables. The relationship is one of the most important issues in DEA as it affects directly the number of efficient units and the DEA efficiency analysis.

Analysis of the number of DMUs to the number of input/output variables

In the literature, the analysis of the number of Nurses (DMUs) to the number of input/output variables (N_IO) is expressed in terms of a ratio value (Rv) where, $Rv = \left\{\frac{n}{(m+s)}\right\}$. It is known that if Rv is too small, DEA loses its discrimination power in terms of number of efficient and inefficient units, [56]. Moreover, a number of rules of thumb are suggested in the literature to set an appropriate value for Rv. [24] recommended first rule (R1) in which Rv should be greater than *two*. [4,17] suggested second rule (R2) in which Rv should be greater than *three*. [19] suggested third (R3) in which n should be greater than 2(m×s). However, the mentioned studies report only lower limits on Rv but no discussion on setting any upper limit on Rv. In this study, an attempt is made to investigate the impact of different Rv values on the DEA performance analysis and suggest a guideline for an appropriate ratio range from the perspective of a human resource management. For instance, Hospital G

Table 3 Original data as provided by the hospital

	Index of Nurses																														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
C1	3	3	3	3	3	3	3	4	4	4	3	3	3	3	3	3	2	3	2	3	3	3	2	4	3	2	3	3	3	3	3	3
C2	3	3	3	3	3	3	3	3	4	4	3	3	3	3	3	3	3	3	3	3	4	3	3	4	3	3	2	3	2	3	3	3
C3	3	3	3	4	3	3	3	4	4	4	3	3	3	3	3	2	2	3	3	3	4	3	3	3	3	3	3	2	2	2	3	3
C4	3	3	3	4	3	3	3	4	4	4	3	4	3	3	3	3	3	3	3	3	4	3	3	3	4	3	3	2	3	3	3	4
C5	3	3	3	4	4	3	3	3	4	4	3	3	3	3	3	3	2	3	3	3	4	2	2	4	4	2	3	3	3	3	3	3
C6	4	3	4	4	4	3	4	3	3	4	3	3	3	3	3	3	3	3	3	3	4	3	3	4	3	3	3	3	3	2	2	3
C7	3	3	3	3	3	3	3	2	3	2	2	2	3	2	2	2	2	2	2	2	2	2	2	3	2	2	2	3	2	3	2	3
C8	3	3	3	4	3	3	3	3	3	4	3	3	3	3	3	3	2	2	3	4	4	3	2	4	3	2	3	2	3	3	3	3
C9	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	2	3	3	3	2	3	3	2	3	2	3	3	3	3	3	3
C10	3	3	3	4	4	3	3	3	4	3	3	3	3	2	3	3	2	2	3	3	3	3	2	3	4	2	3	3	3	3	3	3
C11	3	3	3	4	4	3	3	3	3	3	3	3	3	3	3	3	2	3	3	4	3	3	3	3	3	2	3	3	3	2	3	3
C12	3	3	3	4	3	3	3	3	3	4	3	3	3	3	2	2	2	3	3	3	3	2	3	3	3	2	3	2	3	3	2	3
C13	3	3	3	3	3	3	3	3	3	4	3	3	3	3	3	3	2	3	3	4	3	3	2	3	4	2	2	3	3	2	2	3
C14	4	3	4	3	3	3	4	3	3	3	3	2	3	3	3	3	2	3	3	4	4	3	3	3	3	2	3	3	3	3	3	4
C15	3	3	3	4	4	3	3	3	4	3	3	3	3	2	2	3	2	2	2	3	3	2	2	2	4	2	2	3	3	2	2	3
C16	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	2	2	3	3	4	3	3	3	3	4	2	3	3	3	3	3	3
C17	4	3	4	4	3	3	4	3	3	3	3	3	3	2	3	2	2	2	3	3	3	2	2	3	3	2	3	2	3	3	3	4
C18	3	3	4	4	3	3	4	3	3	3	3	3	3	3	3	3	2	3	3	3	4	3	3	3	4	2	3	3	3	3	2	3
C19	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	2	3	3	3	2	3	3	2	3	2	3	2	2	2
C20	3	3	3	3	3	3	3	3	4	3	3	3	3	3	3	3	2	3	3	4	4	3	3	3	4	2	2	3	2	3	3	3
C21	3	3	3	4	3	3	3	3	4	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	2	2	2	3	2	2	2
C22	3	3	3	4	4	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	4	3	2	3	3	2	3	3	3	3	3	3
C23	4	4	4	4	4	4	4	3	4	4	3	3	3	3	3	3	3	3	2	3	3	3	2	3	3	3	3	3	3	2	3	3
C24	4	4	4	4	4	3	4	3	4	4	3	3	3	3	3	3	3	3	3	3	4	3	3	3	3	3	3	2	3	3	3	3
C25	3	3	3	4	4	3	3	3	3	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	3	3	3	3	3	3	3
C26	3	3	3	4	3	3	3	3	4	4	3	3	3	3	3	3	2	3	3	3	3	3	3	3	3	2	3	3	3	3	3	3
C27	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	3	2	3	3	2	3	2	2	2	2	3
C28	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	2	3	3	3	4	2	2	3	3	2	3	3	3	3	2	3
C29	3	3	3	4	3	3	3	4	3	4	3	3	4	3	3	3	2	3	2	4	4	3	2	3	4	2	2	3	3	2	2	3
C30	4	3	4	4	3	3	3	4	4	3	3	3	4	3	3	2	2	3	3	3	3	3	2	3	4	2	2	2	3	2	2	4
C31	4	3	4	3	3	3	4	3	3	4	3	3	4	3	3	3	2	3	2	3	4	3	2	3	3	2	3	2	2	2	2	4
C32	4	3	4	4	3	3	4	4	3	4	3	3	4	3	3	3	2	3	3	4	4	3	3	3	3	2	2	3	3	3	2	1
C33	4	4	4	4	4	4	4	4	3	4	3	4	4	4	4	4	3	4	3	3	4	3	3	3	3	3	3	3	3	3	3	3
C34	3	3	3	4	3	3	3	4	3	4	3	3	3	3	3	3	2	3	3	4	4	2	3	3	3	2	3	3	3	2	2	2

Table 3 (continued)

Index of Nurses	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
C35	3	4	3	4	3	4	3	3	3	4	3	4	4	4	4	2	2	4	3	3	4	3	2	4	3	2	3	3	3	3	3	2
C36	3	3	3	4	3	3	3	4	3	4	4	3	4	4	4	3	2	4	3	4	4	3	3	4	3	2	3	3	3	3	3	2
C37	3	4	3	4	4	3	3	4	3	4	3	3	3	3	3	4	2	3	3	3	4	3	3	3	4	2	3	3	3	3	3	3
C38	3	3	3	4	3	3	3	3	3	4	3	3	4	3	4	3	3	3	3	4	4	3	3	3	3	3	3	3	3	3	3	3
C39	4	4	4	4	4	4	4	4	3	4	4	4	4	4	4	3	3	4	3	4	4	4	3	4	3	3	3	3	3	3	3	2
C40	3	3	3	4	4	3	3	3	3	4	3	4	3	4	3	3	3	4	3	4	3	4	2	3	3	3	3	3	3	2	3	2
C41	3	3	3	4	3	3	3	3	3	4	3	4	3	3	3	3	2	3	3	4	4	3	2	3	3	2	3	3	3	3	3	3
C42	3	3	4	4	4	3	3	3	4	3	3	4	3	3	3	3	3	3	3	3	4	3	3	3	3	3	3	3	3	3	3	4
C43	3	4	4	4	4	3	4	3	4	3	3	4	4	3	3	3	2	3	3	3	3	3	3	3	3	2	3	3	3	2	3	3
C44	3	4	3	4	4	4	4	3	4	3	3	3	3	3	3	3	2	3	3	3	3	2	2	3	3	2	3	3	3	2	3	4
C45	4	3	4	4	4	3	3	3	4	3	3	3	3	3	3	3	2	3	3	3	4	3	2	3	3	2	3	3	3	2	3	3

guideline expects to have one Group, namely G5, consisting of 10% of nurses "to consistently exceed standards" (i.e., DEA efficient). Moreover, the European Credit Transfer System (ECTS) developed by the European Commission in order to provide generally, valid and accepted procedures for the recognition of study qualifications gained by students on courses outside their home country uses a letter grading scale on a student performance relative to peers in the same class. In ECTS, students are divided into five classes as follows: the top 10% of students gets a grade of A "excellent/outstanding performance/efficient"; next 25% gets grade B "very good/ above average/weakly efficient"; next 30% gets grade C "solid overall performance", next 25% gets grade D satisfactory "acceptable performance" and the last 10% of students gets grade E "satisfy minimum performance". Both Hospital G and ECTS performance classification follow a forced grading system based on a normality distribution assumption during which the human performance of group is expected to exhibit a normally-distributed behaviour. In our analysis, we have a total of 32 nurses which is the minimum required sample size to meet the normality assumption of data.

In order to find the best value for *Rv*, an experiment was designed to construct different combinations (models) of input/output variables starting from Model 1 with $(m+s)=15$ and $Rv=2.1$ down to Model 14 with $(m+s)=2$ variables and $Rv=16$. The process of creating combinations of input/output variables is carefully designed. The original managerial 45 criteria are grouped into fifteen constructs/ categories as reported in Table 2. However, such constructs are relabelled into inputs/outputs variables—six inputs (m= 6) and a set of nine output (s=9) for DEA analysis and to meet the suggested R1 rule. This combination is referred to as Model 1 (M1). The fifteen inputs and outputs of Model 1 are further combined using correlation results amongst variables within the same construct. The two variables having the highest correlation value are combined into a new single variable with a corresponding performance value computed as the average performance of its ancestors. Table 5 shows the 14 generated combinations starting from Model 1 (or M1) with 15 variables and ending with Model 14 (or M14) of 2 variables.

The results from running the various DEA models are summarised in Table 6. Its first line shows the DEA models. Each model is executed under two different scenarios: input-oriented CRS and input-oriented VRS. The results of such scenarios are reported in rows of Table 6 in terms of the average efficiency scores (CRS-means, VRS-means), corresponding standard deviations (Std. Dev), and number of efficient units (No_Eff_Units). The best appropriate DEA model can be identified from the degree of meeting the following tow conditions. *First*, the DEA efficiency scores are expected to follow a normal

Table 4 The transformed dataset for Model 8 having 3 inputs (I) and 5 outputs (O) variables derived from the original information available in Tables 2 and 3

Nurse	(I) 1	(I) 3&6	(I) 2, 4 &5	(O) 4&5	(O) 7	(O) 9	(O) 2&8	(O) 1, 3, 6
1	0.33	0.30	0.28	3.3	3.0	3.4	3.2	3.0
2	0.33	0.27	0.30	3.0	3.0	3.0	3.0	3.0
3	0.33	0.26	0.32	3.3	3.0	3.6	3.2	3.0
4	0.27	0.25	0.26	3.3	3.0	3.6	3.8	3.7
5	0.29	0.25	0.29	3.3	3.0	3.2	3.0	3.2
6	0.33	0.30	0.31	3.0	3.0	3.0	3.0	3.0
7	0.33	0.27	0.32	3.3	3.0	3.6	3.1	3.0
8	0.33	0.33	0.30	2.5	3.0	3.0	3.7	3.5
9	0.31	0.25	0.32	3.3	3.0	3.2	3.6	3.7
10	0.29	0.29	0.27	3.0	3.0	3.0	3.8	4.0
11	0.33	0.33	0.32	2.5	3.0	2.8	3.0	3.0
12	0.33	0.31	0.29	2.5	3.0	2.8	3.0	3.2
13	0.33	0.32	0.29	3.0	3.0	3.0	3.3	3.0
14	0.36	0.33	0.29	2.5	2.0	2.6	2.9	3.0
15	0.36	0.33	0.29	2.5	3.0	2.8	3.0	3.0
16	0.36	0.33	0.33	2.5	3.0	2.6	2.4	3.0
17	0.50	0.39	0.41	2.5	2.0	2.0	2.0	2.2
18	0.36	0.33	0.29	2.5	3.0	2.6	3.0	2.7
19	0.33	0.37	0.34	2.5	3.0	2.8	2.9	2.7
20	0.29	0.33	0.29	2.5	3.0	3.4	3.1	3.3
21	0.33	0.29	0.27	3.0	2.0	3.4	3.8	3.7
22	0.36	0.35	0.32	2.5	3.0	2.6	2.9	2.8
23	0.40	0.40	0.40	2.5	3.0	2.6	2.6	2.2
24	0.33	0.33	0.31	3.5	2.0	2.8	3.0	3.8
25	0.29	0.33	0.32	2.5	3.0	3.6	3.1	3.3
26	0.50	0.39	0.43	2.5	2.0	2.0	2.5	2.2
27	0.36	0.33	0.35	2.3	3.0	2.8	2.8	3.0
28	0.36	0.37	0.35	3.0	3.0	2.8	2.3	2.5
29	0.33	0.33	0.34	2.3	3.0	3.0	2.4	3.0
30	0.40	0.42	0.37	2.8	3.0	2.8	2.2	3.0
31	0.40	0.33	0.36	2.3	3.0	2.6	2.6	3.0
32	0.33	0.31	0.41	3.0	3.0	3.4	3.0	3.2

distribution from the managerial perspective assumption. The generated efficiency scores of each DEA model are then tested against the normal distribution fitness, and the fitness of each model is measured using Chi-square χ^2 statistic value. The model having the smallest χ^2 value is the best normal distribution fit. @RISK software is applied to the efficiency scores of each model to estimate the normal distribution parameters including χ^2 values. *Second,* the managerial expectation (Hospital G and ECTS) that state 10% of units must be fully efficient is checked from the No_Eff_Units obtained by each model.

From Table 6, it can be seen that the best CRS model occurs when the number of input and output variables (No_IO) has a value of 8 in M8 with a smallest χ^2 value of 1.4 and a No_Eff_Units of 2, which is 6% less than the expected managerial value of 10%. In order to satisfy the efficiency threshold of 10%, the No_IO of variables in CRS model has to increase from 8 to either 9 variables in M7 which has No_Eff_Units of 3 (9% close to 10%) or 10 variables in M6 which has No_Eff_Units of 4 (13% a bit far from 10%). As a result, the associated acceptable range for Rv value should vary in an interval [2.9–4]. Such corrections in number of efficiencies are at the expenses of higher χ^2 value, i.e. less normality fitness but more managerial compliance. Moreover, if Rv gets smaller, the number of efficient units increases with a worse normality fit and a worse managerial compliance. This increase in the number efficiency units is desirable up to a managerial threshold limit. If Rv gets higher, the number of efficient units decreases with a better normality fit. However, the

Table 5 Various combinations of correlated input and output (I&O) variables

Variables		M1	M2	M 3	M 4	M 5	M 6	M 7	M 8	M 9	M 10	M 11	M 12	M 13	M 14
Input Variables	Input (1) Job Knowledge	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	□	□	□	□
	Input (2) Work Habits	✓	✓	✓	✓	✓	□	□	□	□	□	□	□	□	□
	Input (3) Teamwork and cooperation	✓	✓	✓	□	□	□	□	□	□	□	□	□	□	□
	Input (4) Interpersonal skills	✓	□	□	□	□	□	□	□	□	□	□	□	□	□
	Input (5) Dealing with Equipments	✓	□	□	□	□	□	□	□	□	□	□	□	□	□
	Input (6) Communication	✓	✓	✓	□	□	□	□	□	□	□	□	□	□	□
	Input (4&5)	□	✓	✓	✓	✓	□	□	□	□	□	□	□	□	□
	Input (3&6)	□	□	□	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	□
	Input (2 With 4&5)	□	□	□	□	□	✓	✓	✓	✓	✓	□	□	□	□
	Input (1 with 2, 4 &5)	□	□	□	□	□	□	□	□	□	□	✓	✓	✓	□
	Input (1, 2 , 4, 5 with 3&6)	□	□	□	□	□	□	□	□	□	□	□	□	□	✓
Output Variables	Output (1) Planning	✓	✓	✓	✓	✓	✓	□	□	□	□	□	□	□	□
	Output (2) General Practice Performance	✓	✓	✓	✓	□	□	□	□	□	□	□	□	□	□
	Output (3) Nursing Practice Performance	✓	✓	□	□	□	□	□	□	□	□	□	□	□	□
	Output (4) Technical Practice Performance	✓	✓	✓	✓	✓	✓	✓	□	□	□	□	□	□	□
	Output (5) Patient Education Performance	✓	✓	✓	✓	✓	✓	✓	□	□	□	□	□	□	□
	Output (6) Emergency Work Follow-up	✓	✓	□	□	□	□	□	□	□	□	□	□	□	□
	Output (7) Taking Responsibility	✓	✓	✓	✓	✓	✓	✓	✓	✓	□	□	□	□	□
	Output (8) Quality/Quantity of Work	✓	✓	✓	✓	□	□	□	□	□	□	□	□	□	□
	Output (9)	✓	✓	✓	✓	✓	✓	✓	✓	✓	□	□	□	□	□
	Output (3&6)	□	□	✓	✓	✓	✓	□		□	□	□	□	□	□
	Output (2&8)	□	□	□		✓	✓	✓	✓	✓	✓	✓	□	□	□
	Output (1 with 3&6)	□	□	□	□	□	□	✓	✓	□	□	□	□	□	□
	Output (4&5 with 1, 3 &6)	□	□	□	□	□	□	□	□	✓	✓	✓	✓	□	□
	Output (7 & 9)	□	□	□	□	□	□	□	□	□	✓	✓	□	□	□
	Output (4&5)	□	□	□	□	□	□	□	✓	□	□	□	□	□	□
	Output (2&8 with 7&9)	□	□	□	□	□	□	□	□	□	□	□	✓	□	□
	Output (1, 2 , 3,4, 5,6,7, 8, 9)	□	□	□	□	□	□	□	□	□	□	□	□	✓	✓

decrease in efficiency is not preferred from a managerial perspective due to few efficient units. Similarly from Table 6, the best VRS model is either M11 or M12 as they have the smallest χ^2 value of 1.4 with a corresponding of No_Eff_Units of 3 (i.e., 9%) which is relatively satisfying the (10%) managerial threshold. If the number of input and output variables (No_IO) is increased from 5 or 4 (M11 or M12) up to nine variables, the number of corresponding efficient units reaches 4 (13%). The best Rv value under VRS models varies from an interval [3.6 to 8]. Moreover, the number of efficient units in VRS seems to be more stable than that of CRS models. The two ranges of Rvs from the two DEA models intersect at an Rv value of 4 corresponding to a DEA Model with 8 variables.

Further a summary of results in terms of efficient units and average of efficiency scores are illustrated in Figs. 1 and 2. Figure 1 shows that the averages of DEA efficiency scores for the three DEA models results (CRS; Input-VRS and Output-VRS). They all have an increasing-trend as the number of variables increases with correspondingly weak discriminations. For instance, The CRS average values start from 67%, get stable in the middle at 84% (between 5 and 10 variables) and level at 87%, whereas VRS starts at a higher value and get stable after 7 variables onward. Figure 2 shows clearly the increase in stages in the number of efficient units. For Instance, the No_Eff_Units starts from 1, gets stable in the middle at 3 and 4 and level at 6. In summary, the main finding is that the ratio value *Rv* should

Table 6 DEA results for CRS and VRS input-oriented models based on different combinations of inputs and outputs listed in Table 5

Results Models	M 1	M 2	M 3	M 4	M5	M6	M 7	M 8	M 9	M 10	M 11	M 12	M 13	M 14
No_I_and_O	15	14	13	12	11	10	9	8	7	6	5	4	3	2
*RV*s	2.1	2.3	2.5	2.7	***2.9***	***3.2***	***3.6***	***4.0***	***4.6***	***5.3***	***6.4***	***8.0***	10.7	16.0
CRS-Means	0.88	0.87	0.87	0.87	0.87	0.85	0.84	0.84	0.83	0.78	0.76	0.72	0.69	0.67
Std. Dev.	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.14	0.15	0.15	0.15	0.14	0.14
χ^2	7.0	8.1	8.1	8.9	8.9	5.1	6.6	**1.4**	2.1	2.9	2.5	3.3	2.1	1.8
No_Eff_Units	6	6	6	6	***4***	***4***	***3***	***2***	1	1	1	1	1	1
VRS- Means	0.89	0.89	0.88	0.88	0.88	0.86	0.86	0.86	0.86	0.86	0.84	0.84	0.83	0.80
Std. Dev.	0.10	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.10	0.09
χ^2	9.6	9.6	7.8	9.3	9.3	8.9	8.9	3.3	3.3	3.3	**1.4**	**1.4**	4.8	2.9
No_Eff_Units	6	6	6	6	6	5	***4***	***3***	***3***	***3***	***3***	***3***	1	1

not be limited to the number of input and output variables but also it depends on whether a CRS or VRS model is used and the level of expected number of efficient units from managerial perspective.

Comparison of various performance evaluation approaches

From the section, the best CRS model could be considered as M8 since it has the smallest χ^2 value of 1.4 and number of efficient units (2 units or 6%). The DEA results from CRS model M8 and its variations VRS Input-oriented and VRS Output-oriented models are listed in Table 7 for illustrations of managerial implication and comparison with the currently practiced model. In Table 7, the first column represents indices of Nurses. The second block reports the efficiency score, the rank and the reference set for each Nurse from the CRS model. The third and fourth blocks represent the same but using the VRS input and output oriented DEA models, respectively. The last block "hospital rank" reports the hospital's total mark to each nurse, its associated normalized score and rank. The mark represents the managerial rating out of 100 for each Nurse. However, these marks are not comparable with DEA efficiency scores. Therefore; they are normalized by dividing each managerial mark by the highest obtained mark among all Nurses i.e. the mark of Nurse 10 of 92.38. The last column reports the hospital corresponding rank for each Nurse after normalization. A number of observations can be made on the results in Table 7.

First, *the average relative efficiency scores* using the input oriented DEA models (CRS and VRS) have values of 84% and 86% respectively, indicating that the Nurses can potentially complete their jobs with 14–16% less resource if they were all made efficient. On the high ranking, Nurse 4 is the most efficient one since it is appeared as peer 32 times (based on CRS model) followed by Nurse 10 with 2 times. However, the managerial ranking shows that Nurse 10 is ranked first and Nurse 4 is second. Moreover, DEA results show Nurse 5 is among the efficient fully efficient but ranked in the six position in the manual ranking. Also, Nurse 8 is ranked in 17th and 8th by input-oriented DEA models and it is in the 7th position by the current manual scheme. So far, the rankings are very different. Therefore, DEA can provide a corrective tool for ranking with a justification over the managerial one. On the lower ranking, both DEA and managerial rating results ranked Nurses 17 and 26 at the lowest performance of nurses.

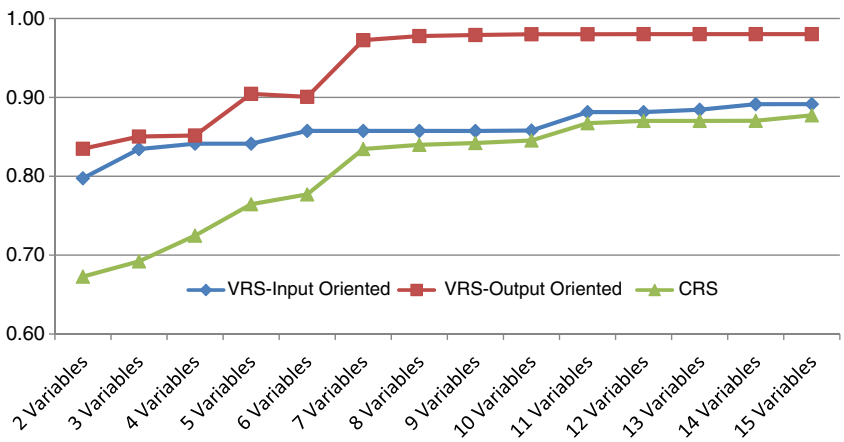

Fig. 1 Averages of DEA efficiency scores from the 14 VRS and CRS Models

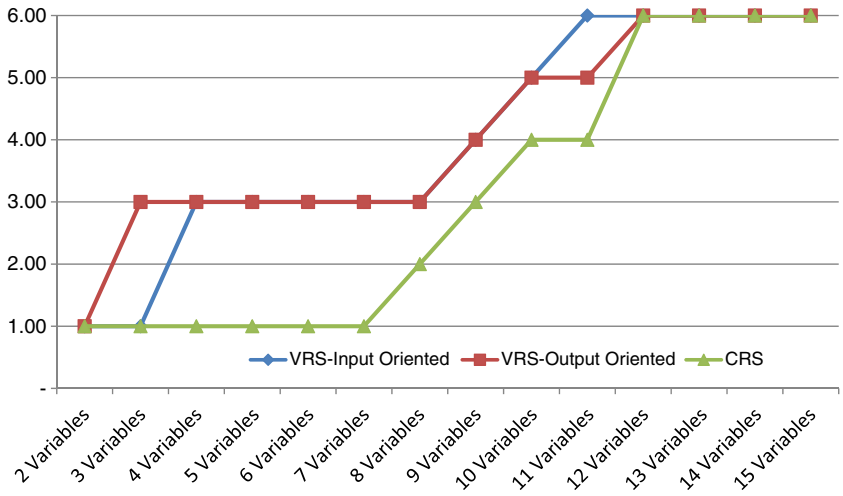

Fig. 2 Number of fully efficient nurses obtained from the 14 VRS and CRS Models

Table 7 Data envelopment analysis ranks versus hospital ranks

Nurse	DEA CRS-M8			DEA-VRS Input Oriented-M8			DEA-VRS Output Oriented-M8			Hospital Rank		
	Eff Score	Rank	Reference Set (λ)	Eff Score	Rank	Reference Set (λ)	Eff Score	Rank	Reference Set (λ)	Mark	Score	Rank
1	0.93	11	4	0.93	12	4	1.00	1	4	78.99	0.85	11
2	0.93	8	4	0.93	9	4	1.00	1	4	76.39	0.83	13
3	0.97	6	4	0.97	7	4	1.00	1	4	79.51	0.86	8
4	1.00	1*	4	1.00	1*	4	1.00	1*	4	91.11	0.99	2
5	1.00	1	4	1.00	1	4	1.00	1	4	82.1	0.89	6
6	0.84	18	4	0.84	19	4	1.00	1	4	75.87	0.82	17
7	0.93	8	4	0.93	9	4	1.00	1	4	79.16	0.86	9
8	0.87	17	4	0.87	18	4	1.00	1	4	81.64	0.88	7
9	1.00	1	4	1.00	1	4	1.00	1	4	88.33	0.96	3
10	1.00	1*	10	1.00	1*	10	1.00	1*	10	92.38	1	1
11	0.82	19	4	0.82	20	4	1.00	1	4	73.67	0.8	18
12	0.88	13	4	0.88	13	4	1.00	1	4	76.79	0.83	14
13	0.88	15	4	0.88	15	4	1.00	1	4	76.74	0.83	15
14	0.71	28	4 &10	0.88	17	4	0.79	30	4, 10, 24	72.17	0.78	20
15	0.88	14	4	0.88	14	4	1.00	1	4	74.02	0.8	19
16	0.79	24	4	0.79	25	4	1.00	1	4	70.73	0.77	21
17	0.49	31	4	0.64	31	4	0.75	32	4, 24	58.31	0.63	32
18	0.88	15	4	0.88	15	4	1.00	1	4	71.6	0.77	22
19	0.80	22	4	0.80	23	4	1.00	1	4	70.38	0.76	23
20	0.93	8	4	0.93	9	4	1.00	1	4	77.83	0.84	12
21	0.97	5	4	0.97	6	4	1.00	1	4	88.8	0.96	4
22	0.81	21	4	0.81	22	4	1.00	1	4	70.56	0.76	24
23	0.67	30	4	0.67	30	4	1.00	1	4	63.63	0.69	30
24	0.90	12	4	1.00	1*	24	1.00	1*	24	85.1	0.92	5
25	0.93	7	4	0.93	8	4	1.00	1	4	79.74	0.86	10
26	0.49	31	4	0.64	31	4	0.75	31	4, 24	60.39	0.65	31
27	0.75	25	4	0.75	26	4	1.00	1	4	70.03	0.76	25
28	0.74	27	4	0.74	28	4	1.00	1	4	66.86	0.72	29
29	0.80	22	4	0.80	23	4	1.00	1	4	68.48	0.74	27
30	0.70	29	4	0.70	29	4	1.00	1	4	67.9	0.73	28
31	0.75	25	4	0.75	26	4	1.00	1	4	68.99	0.75	26
32	0.81	20	4	0.81	21	4	1.00	1	4	76.73	0.83	16
Averagee	**0.84**			**0.86**			**0.98**				**0.82**	

1* efficient unit

1 weakly efficient unit

Second, *the efficiency scores obtained from the input oriented DEA model* based on CRS and VRS models and the managerial rating would be classified into four groups. The *first group* of *fully efficient set* of two nurses that are both CRS and VRS efficient, i.e., those Nurses obtained scores of 1 under each DEA model, namely Nurses: 4 and 10. The *second group of weakly efficient set* is formed by nurses with VRS efficiency scores of 1 and their CRS efficiency scores less than 1. This group is formed of a single Nurse 24 (considered in the 5th position in manual ranking). The *third group* of Nurses that are neither CRS nor VRS efficient; this group is subdivided into two sub-groups: (1) subgroup with either CRS or VRS efficiency scores less than 1 but higher than or equal the average efficiency score (0.85); (2) Subgroup with either CRS or VRS efficiency scores less than the average (0.85) but higher than 70%. The first sub-group includes 16 Nurses: 1; 2; 3; 5; 7; 8; 9; 12; 13; 14; 15; 18; 20; 21; 24 and 25, while the second sub-group includes 11 Nurses: 6; 11; 16; 19; 22; 27; 28; 29; 30; 31 and 32. The *fourth group* of Nurse with efficiency scores less than 70%, this group includes 3 Nurses: 17; 23 and 26. The suggested group would help management to create similar group and provide them with appropriate career development and appraising plans.

Third, the DEA rankings have uncovered a number of unfair cases which were ranked lower by the managerial rating appraisal, especially those weakly efficient Nurses. These Nurses are doing their job perfectly and could be potential superstars. These potential Nurses were uncovered by the DEA-VRS output-oriented model which found that those inefficient nurses by the DEA-input oriented VRS can be efficient under certain criteria. Hence they need to be trained to uncover their potentials. For instance, the current approach (managerial rating appraisal) gives nurse number 18 a rank of 22, but this nurse should be ranked in a better position as it is VRS-output efficient. It should be ranked in position 15 according to DEA results. However, this Nurse needs more training to improve his/ her performance from peers. Moreover, there are other closely ranked cases by the three methods. This closeness in ranking by DEA results and managerial one has created a trust by the management to use DEA analysis as an appraisal tool as it does not require any pre-setting of weights and provide more acceptance to nurses as portray them in their best performance.

Finally, since the different models have created different scores with different ranks. The significance of such differences is statistically investigated both in terms of scores and ranks. A correlation test was conducted to study the significance of difference of ranks for the DEA-CRS and VRS results and the Hospital ranks; the correlation result is relatively high 96% and 92% respectively. Also, the Friedman test was conducted to compare the significance differences of ranks. The Friedman analysis (Chi-Square (χ^2=31), degree of freedom=1 and p<0.01) provided a similar proof on the significance difference of the ranks.

Managerial implications of the DEA analysis

The DEA results provide a number of insights for mentoring and developing managerial plans to improve their Nurses performance. *First,* the professional work practices of the set of strongly efficient practices of nurses can be examined to find out their common best features. Looking at the positive weights assigned by nurses to favoured criteria in Table 8, one can see that Nurses assigned 8 times positive weights to input 1 (Job Knowledge), 11 times to input 2 (Team work and Communication) and 15 times to input 3. They also assigned positive weights 7 times to output 1 (Technical practice), 21 times for output 2 (Assess Educational Needs of Patients), 0 times for output 3 (Taking responsibility) 1 time for output 4 (Problem solving) and output 5 (General practice and quality of work). These features indicate their best strengths while assigning zero weights to performance criteria not serving their interests such as Output 9 (taking responsibility). The management here is invited to assess whether such criteria should be included in the evaluation or not. If they are essential to have, then the DEA model would allow the user to set lower bound restrictions on any weight so that the particular criteria would not be ignored in the evaluation

Second, the fully efficient set of Nurses and their identified best professional practices can be used as guidelines to inefficient Nurses. For instance, Nurse 17 obtained a score of 49% based on DEA-CRS analysis and 75% based on DEA-VRS results and has a reference set nurses (4 and 24) as indicated Table 7. To sustain performance and motivate such efficient group, the management may give them more authority, autonomy and control to do their jobs, extra salary, and holiday bonus.

Third, the weakly efficient Nurses group offers a great potential to the management. They may be given an option of more training to improve their skills and knowledge or enriching their job by adding more responsibilities and increase outputs while keeping the same level of inputs. Such flexibility comes from the fact they are positioned at the ends of efficient frontiers surface.

Fourth, the DEA provides guidelines for both weakly efficient and inefficient Nurses by projecting improvement for each Nurse on the frontiers surface formed by the established internal efficient benchmark set of Nurses. Table 9 provides DEA recommendations for one weakly efficient Nurse where % reduction in puts with negative sign and % increase in outputs with positive sign. For

Table 8 Optimal input weights (V) and output weights (U) for each nurse

Nurse	V(1)	V(2)	V(3)	U(1)	U(2)	U(3)	U(4)	U(5)
1	–	–	3.59	0.29	–	–	–	–
2	–	3.73	–	–	0.31	–	–	–
3	–	3.87	–	0.30	–	–	–	–
4	3.75	–	–	0.31	–	–	–	–
5	0.00	4.00	–	0.31	–	–	–	–
6	–	3.37	–	–	0.28	–	–	–
7	–	3.73	–	0.29	–	–	–	–
8	–	–	3.35	–	0.29	–	–	–
9	0.00	4.00	–	0.31	–	–	–	–
10	–	–	3.69	–	0.16	–	–	0.13
11	–	–	3.17	–	0.27	–	–	–
12	–	–	3.41	–	0.29	–	–	–
13	–	–	3.39	–	0.29	–	–	–
14	–	–	3.39	–	–	–	–	–
15	–	–	3.39	–	0.29	–	–	–
16	–	–	3.06	–	0.26	–	–	–
17	–	2.57	–	–	–	–	–	–
18	–	–	3.39	–	0.29	–	–	–
19	3.00	–	–	–	0.27	–	–	–
20	3.50	–	–	–	0.31	–	–	–
21	–	–	3.75	–	–	–	0.26	–
22	–	–	3.11	–	0.27	–	–	–
23	2.50	–	–	–	0.22	–	–	–
24	–	–	3.23	0.65	–	–	–	–
25	3.50	–	–	–	0.31	–	–	–
26	–	2.57	–	–	–	–	–	–
27	–	3.00	–	–	0.25	–	–	–
28	–	–	2.85	–	0.25	–	–	–
29	3.00	–	–	–	0.27	–	–	–
30	–	–	2.69	–	0.23	–	–	–
31	–	3.00	–	–	0.25	–	–	–
32	–	3.23	–	–	0.27	–	–	–

instance, Nurse 17 has to decrease its original score value of 0.50 on input 1 (Job Knowledge) to 0.21, since this input data was inverted due to isotonic property, this recommendation requires an increase in Job Knowledge score from 2 to 4.76, whereas since his/her efficiency score is higher (75%) based on VRS so input 1 should be increased from 2 to reach 2.38, the same for other variables.

Finally, the joint results of the analysis (CRS input and VRS output oriented DEA) could provide useful information to the managers. The Nurses according to their joint performance evaluation (Table 7) are grouped into four groups as Fig. 3. Nurses fall into four quadrants similar to the ones observed in the BCG matrix [27]: Superstar; to be Trained; Question Mark and Potential Star. *Question Mark group* are those Nurses that are neither efficient based on input oriented nor output oriented models the enhancement of this group performance cannot come from improvements in operations, since they are already inefficient on the operational side. *To be Trained group* are those Nurses that are efficient based on input-oriented CRS model, but not on VRS output-oriented model. Hence, their performance could be further improved if they attend more training courses in job knowledge, communication, interpersonal skill, etc, while *Superstar group* is formed of those Nurses that are fully efficient in both input and output oriented models. This group should be motivated in order to sustain their superior operational efficiency through giving them more responsibilities and control over their work. Finally, for the *Potential Star group* are lagging in relatively low efficiency score based on CRS input oriented

Table 9 Projection improvement for nurse 17

Inputs/ Outputs	Actual (Observed)	Projection (Target)	Difference	%
DEA CRS-Input Oriented				
I1	0.50	0.21	0.29	−0.59
I2 (3&6)	0.39	0.19	0.20	−0.51
I3 (2, 4 &5)	0.41	0.20	0.21	−0.52
O1 (4&5)	2.50	2.50	–	–
O2 (7)	2.00	2.31	0.31	0.15
O3 (9)	2.00	2.77	0.77	0.38
O4 (2&8)	2.00	2.91	0.91	0.46
O5 (1, 3& 6)	2.17	2.82	0.65	0.30
DEA VRS-Output Oriented				
I1	0.50	0.29	0.21	−0.42
I2 (3&6)	0.39	0.28	0.11	−0.29
I3 (2, 4 &5)	0.41	0.28	0.14	−0.33
O1 (4&5)	2.50	3.33	0.83	0.33
O2 (7)	2.00	2.67	0.67	0.33
O3 (9)	2.00	3.33	1.33	0.67
O4 (2&8)	2.00	3.52	1.52	0.76
O5 (1, 3& 6)	2.17	3.72	1.56	0.72

model and high score based on VRS output oriented model; therefore they should attend different training courses to be as efficient as Stars group. Although the above figure could be used by managers to motivate their Nurses, it is worth to note that the above grouping gives good discrimination between the Nurses performance. Using different oriented models provides manager with a flexible tool to evaluate their employees' performance. Accordingly managers can use the two oriented models to decide which training course is more suitable for each nurse: training to improve their work skills, knowledge, and communication; or / and improve planning skills, work quality, problem solving skills. Also, the input and output oriented evaluation model would be advised whenever the training budget is limited, therefore managers could regroup their nurses to include the full efficient (input and output efficient) and inefficient nurses in each shift. Hence managers will be able to replace the training course by learning from colleagues (internal learning).

Conclusion

The performance analysis of this study demonstrates that DEA approach can be used as an effective tool to the appraisal and evaluate Nurses performance using the

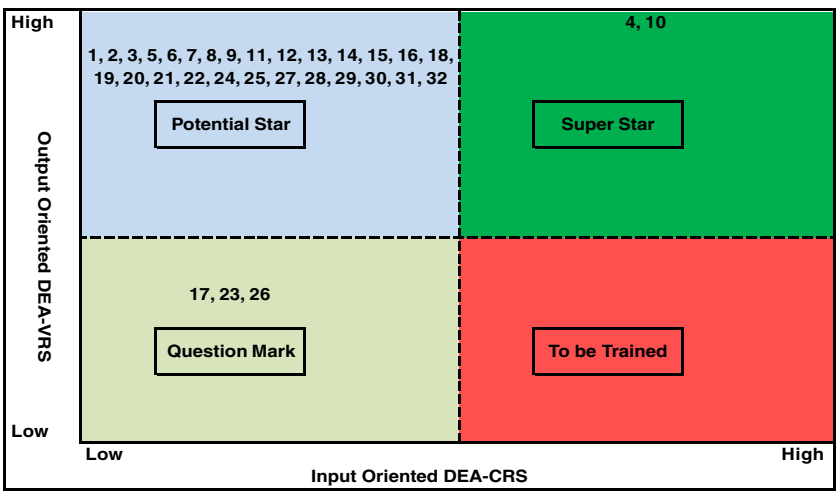

Fig. 3 Allocating of the nurses according to their DEA Performances

concept of relative efficiency scores. The DEA models also provided an efficient classification of nurses into three categories, fully efficient, weakly efficient and inefficient nurses. It indicated areas of weakness for each inefficient Nurses and automatically depicts the input and output variables that need future career development plans. Although, it identified the weak input and output factors for each Nurse, it projected the percentage degree of improvement required to achieve efficiency level. Such provided information would facilitate the mentoring process and help set goals for each nurse. It also identified the best professional practice internal benchmark to guide inefficient nurses and used a demonstration of nursing department core competencies. Additionally, it has a significant added value to the employee appraisal and evaluation process coming from the projected improvements of inefficient nurses and the identification of best internal practices. It can also help the human resources management in measuring the impact of any strategic managerial decision by comparing the average of the efficiency score before and after the decision.

The DEA results of the study were shared with the Nurse Director at Hospital G. The nurse director affirmed that the new model would have a significant impact on the performance management. On one hand it can increase the trust and satisfaction of nurses from the usage of such a transparent evaluation system. On the other hand, it provides a mentoring tool with clear recommendations that would resolve a lot of compensation and reward issues. The Nurse Director is willing to apply DEA models since it provides an improvement over the current performance evaluation process. Moreover, after a revision of input/output criteria, if the nursing management finds that the number of sub-criteria remains large compared to the number of nurses, a better aggregation technique can be based on the analytic hierarchy process to generate different weights by experts to aggregate inputs or outputs into fewer ones instead of using equal weights.

Furthermore, the DEA model can be easily integrated into other existing Human Resources database system where data information on appraisal forms can be stored, linked to the payroll and compensation medical system. Once access to the original evaluation data is assured, the DEA excel-based system will compute automatically evaluation analysis reports on efficiency scores, projections, rakings and correlations among input and output variables as opposed to the manual calculation in the current performance which is still in use at Hospital G. However, using the proposed DEA model entails the automation of the whole appraisal and evaluation process, makes it easier and faster, more reliable and organized, with better documentation of records and above all avoids manual human errors. Finally, this paper provides a new application (first to our knowledge) in the performance appraisal of nurses and can be recommended to the evaluation of employee in similar sectors.

Moreover, we showed that there are no simple rules of thumb to offer the DEA users guidance on the reliability of the obtained results. Our experimental results showed the ratio of the number of decision making units to the number of performance criteria should depends on whether an constant return to scale (CRS) or variable to scale DEA (VRS) model is used and the managerial expected number of efficient units. General guidelines on a reasonable range for the ratio are suggested. But the door is still open for more researchers to investigate further this issue. Finally, the above results were discussed with the Nurse Director, who is considering its real-life implementation as an effective and efficient strategic human resource management tool.

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