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Abstract

Purpose – The purpose of this paper is to develop a model based on data envelopment analysis (DEA) and program evaluation and review technique/critical path method (PERT/CPM) for determining prospective benchmarks.

Design/methodology/approach – The idea of determining prospective benchmark is needed for developing a model for future planning where inputs and outputs of systems are influenced by external factors such as economic conditions, demographic changes, and other socio-economic factors. In this paper, the PERT/CPM method estimates prospective inputs and outputs. On the other hand, in particular systems some measures play the role of both input and output. Such factors in DEA literature are called dual-role factors. This paper integrates PERT/CPM technique and the DEA.

Findings – The results of the proposed model depict that a present benchmark may not be a benchmark in future. A numerical example validates the proposed model.

Originality/value – This paper, for the first time, applies the PERT/CPM technique to incorporate the ideas for identifying prospective benchmarks. Moreover, the proposed model is an alternative solution for classifying inputs and outputs in DEA. Also, the proposed model is utilized in benchmarking green supply chain management.

Keywords Benchmarking, Data envelopment analysis

Paper type Research paper

Nomenclature

DMU_j, $j=1,\ldots,n$	decision making unit	λ_j	vector of DMU loadings for the DMU_o
DMU_o	decision making unit under evaluation	S_i^-	the ith input excess
$j=1,\ldots,n$	set of DMUs	S_r^+	the rth output shortfall
$i=1,\ldots,m$	set of inputs	S_{m+1}^-	the input excess (if dual-role behaves like an input)
$r=1,\ldots,s$	set of outputs		

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S^{+}_{s+1}	the output shortfall (if dual-role behaves like an output)
x_{ij}	the *i*th input of *j*th *DMU*
x_{io}	the *i*th input of DMU_o
$\tilde{x}_{ij}$	estimate of ith input of *j*th *DMU*
$\tilde{x}_{io}$	estimate of ith input of DMU_o
z_j	the dual-role factor of *j*th *DMU*
z_o	the dual-role factor of DMU_o
$\tilde{z}_j$	estimate of the dual-role factor of *j* th *DMU*
$\tilde{z}_o$	estimate of the dual-role factor of DMU_o
k	a zero-one binary variable
y_{rj}	the *r*th output of *j* th *DMU*
y_{ro}	the *r*th output of DMU_o
$\tilde{y}_{rj}$	estimate of *r*th output of *j*th *DMU*
$\tilde{y}_{ro}$	estimate of *r*th output of DMU_o
δ_j	$k\times\lambda_j$
ML_{ij}	the most likely estimate for *i*th input of *j* th DMU
ML_{rj}	the most likely estimate for *r*th output of *j* th DMU
OP_{ij}	the optimistic estimate for *i*th input of *j* th DMU
OP_{rj}	the optimistic estimate for *r*th output of *j* th DMU
PE_{ij}	the pessimistic estimate for *i*th input of *j* th DMU
PE_{rj}	the pessimistic estimate for *r*th output of *j* th DMU

1. Introduction

Over the last decade, there has been an increased pressure on enterprises to broaden the focus of sustainability and accountability in business performance beyond that of financial performance. Demands for sustainability management spring from a variety of sources, including societal mandates incorporated into regulations, fear of loss of sales, and a potential decline in reputation if a firm does not have a tangible commitment to corporate sustainability management (Lee and Farzipoor Saen, 2012). A supply chain (SC) is a system of organizations, people, technology, activities, information and resources involved in moving a product or service from supplier to customer. The SC activities transform natural resources, raw materials and components into a finished product that is delivered to the end customer (Nagurney, 2006). Green supply chain management (GSCM) has emerged as a key approach for enterprises seeking to become environmentally sustainable (Zhu *et al.*, 2005). GSCM philosophy focusses on how a firm utilizes its suppliers' processes, technology and capability, and integrating environmental concerns to enhance competitive advantages. GSCM focusses not only on products and production processes but also includes materials sourcing (Tseng and Chiu, 2013). Greening the SC, hence, can be defined as the process of incorporating environmental criteria or concerns into organizational decisions.

The value of greening SC depends largely on the nature of the organization. Governments view it as a useful tool for stimulating the development of environmentally friendly products to reduce overall environmental wastes and help economies to move along the path of sustainable development. Also, businesses tend to see greening the SC as a competitive advantage. Green supply chain (GSC) stimulates development of "greener" products and it decreases risks and costs of the SC as a whole (Gilbert, 2001). In spite of the advances in GSC, there are still a vast number of companies intending to implement GSC. Finding the benchmarks that have already implemented GSC can be a shortcut to utilize the experiences of best-practices.

Benchmarking is a search for the best-practices to imitate their performance (Shabani *et al.*, 2012). Benchmarking has rapidly become a standard practice among leading organizations. GSC benchmarking can be viewed as comparing company's green products, services, and processes that exist along the chain against the relevant metrics of successful firms or chains. Hence, benchmarking of GSC covers a range of characteristics such as processes, products, performances, and strategies.

Data envelopment analysis (DEA) is a widely accepted tool for calculating efficiency scores of decision making units (DMUs). As addressed by Stewart (2010), one of the standard outputs of DEA is the establishment of benchmarks for each inefficient DMU, with the implication that these may serve as targets toward which the DMU should desire. However, this sort of benchmarking in the standard DEA models is useless. In the standard DEA models, the benchmarks of the inefficient DMUs are determined based on historical data, i.e. standard DEA models play monitoring role and they do not take into account future planning. Future targets can meaningfully be set even for efficient DMUs. Efficient DMUs may be efficient in terms of current amounts of inputs and outputs, but they may still be inefficient in terms of future amounts. In other words, an efficient DMU may be selected as a benchmark at the present time, while it may not be a benchmark in future.

As Farzipoor Saen (2010b) explained, in some situations there is a strong argument for permitting certain factors to simultaneously play the role of both inputs and outputs. Remembering that the simple definition of efficiency is the ratio of output to input, an output can be defined as anything whose increase will cause an increase in efficiency. Similarly, an input can be defined as anything whose decrease will cause an increase in efficiency. However, there are some situations that decision maker is wavered to classify the input and output status of factors. Such factors are called dual-role factors. For example, as Farzipoor Saen (2010c) discussed, in supplier selection problem the factors such as ratings for service-quality experience and service-quality credence were considered dual-role factors. From the perspective of decision maker who intends to select the best supplier, such measures may play the role of proxy for "high quality of services," hence can reasonably be classified as outputs. On the other hand, from the perspective of supplier that intends to supply reverse logistics services, they can be considered as inputs that help the supplier in obtaining more customers.

The objective of this paper is to employ program evaluation and review technique/critical path method (PERT/CPM) to develop a novel DEA model for determining prospective benchmarks in the context of GSC in the presence of dual-role factor. This paper uses the PERT/CPM techniques for incorporating future benchmarks in the analysis.

To the best of knowledge of authors, there is not any reference that determines the prospective benchmarks in the context of GSC in the presence of the dual-role factor. This paper has some contributions as below:

- for the first time, proposed model is applied in the GSCM;
- for the first time, future estimates are incorporated into the model for prospective benchmarking;
- for the first time, benchmarking is performed in the presence of dual-role factors;
- the dual-role factor in this paper is considered as a discretionary factor;
- the estimates of experts are incorporated into the decision process by proposed model; and
- an application of the methodology has been performed on a set of data retrieved from 25 Iranian companies.

This paper is organized as follows. Literature review is given in Section 2. Proposed model is developed in Section 3. Section 4 presents a numerical example to validate the applicability of the proposed model. Managerial implications and concluding remarks are discussed in Sections 5 and 6, respectively.

2. Literature review

2.1 GSC

Hong *et al.* (2009) presented a framework that defines the interrelationships between strategic green orientation and business unit performance. Three factors including past green practices, implementation of innovative environment improvement program, and future commitment for environmental practices were explored through their study. They also emphasized on inter-organizational innovation practices such as strategic green orientation in terms of past, present, and future practices as well as on the factors that effectively implement such strategic direction and commitment. Although their framework is straightforward, but they did not present a tool for exploring future. Holt and Ghobadian (2009) examined the extent and nature of greening the SC and the factors that influence the breadth and depth of this activity. A series of constructs were presented in their paper to identify GSCM operational activities companies so as to benchmark themselves against. They also suggested which factors are driving these operational changes and how industry contingencies may be influential. However, their introduced factors were recognized only under the effect of past and utmost present data whereas potential futures have their own consequences. Eltayeb *et al.* (2010) examined the effects of four drivers including regulations, customer pressures, social responsibility, and expected business benefits on greening the SC. The drivers are associated with the future. These are the variables that originate from in progress activities.

Zhu and Liu (2010) developed a framework for telecommunication network companies on how to implement eco-design by benchmarking its parent foreign company. They found that top management commitments, awareness of employees, and training of eco-design tools are key aspects for such eco-planning. However, their framework does not take into account quantitative data for eco-design practices and performance improvements. Nunes and Bennett (2010) focussed on investigating and benchmarking green operations initiatives in the automotive industry. Their findings showed that the world's three major car manufacturers are pursuing various environmental initiatives involving the green operations practices such as green buildings, eco-design, GSC, green manufacturing, reverse logistics, and innovation. Gandhi *et al.* (2006) illustrated an approach for developing a framework of indicators for integrating environmental protection into corporate performance. However, the suggested indicators are regressive rather than forward-looking. Colicchia *et al.* (2011) provided a benchmarking instrument to evaluate and compare companies in terms of SC sustainability and highlight the main challenges that companies have to confront. They also investigated strategies undertaken by companies in the SC sustainability area. Additionally, Björklund (2010) developed a tool that can be applied to benchmark corporate social responsibility in purchasing. Their introduced tool helps companies in their structuring, categorizing, and presenting relevant data. All the foregoing studies examine the environmental performance from the aspects of past and present activities of the organization.

Lau (2011) discussed the development and use of a green logistics performance index for easy comparison of performance among industries and countries. In their work principal component analysis (PCA) was employed to derive the weights of indexes. Sarmiento and Thomas (2010) proposed a framework to apply analytic hierarchy process (AHP) in an internal benchmarking procedure used to identify improvement areas and challenges when firms attempt to adopt green initiatives with a SC perspective. Bai *et al.* (2010) introduced multi-SC activity overview rough set theoretic (RST) applications to aid management decision making with an especial focus on sustainability and GSCM. Zhu *et al.* (2010) presented a methodology to evaluate suppliers in terms of environmental criteria using portfolio analysis based on the analytical network process (ANP). Nevertheless, procedures such as PCA, AHP, RST, and ANP have a common limitation. They are based on some forms of subjective weight assignment. In fact, the weights allocations are under the influence of decision-maker(s) opinions. The problem becomes more complicated when the numbers of criteria are increased.

2.2 Dual-role factor

In conventional DEA it is assumed that the input vs output status of each of the chosen performance measures is known. In some situations, however, certain performance measures can play either input or output roles (Cook and Zhu, 2007). These performance measures in the DEA are called dual-role factors or flexible measures.

Remembering that the simple definition of efficiency is the ratio of output to input, an output can be defined as anything whose increase will cause an increase in efficiency. Similarly, an input can be defined as anything whose decrease will cause an increase in efficiency. Now consider the problem of evaluating the companies in order to recognize prospective benchmarks on the subject of the GSC which has a specific criterion such as green budget. The green budget is one area where governments as well as organizations can influence society's interaction with the environment – encouraging beneficial behavior, and discouraging environmental destruction. It may be found out that the green budget plays both input and output roles, simultaneously. The green budget can be considered as input, because it basically has a cost nature. On the other hand, green budget is a signal implying a company attempting to develop a GSC performance. Therefore, it is considered as an output. If the green budget is considered as an output, then increase in amount of it will increase the efficiency. Likewise, if it is considered as an input, then any decrease of it will increase the efficiency. Consequently, the green budget is considered as a dual-role factor.

To deal with such factors a number of studies have been done. Recently, Shabani *et al.* (in press) developed a DEA model for international market selection in the presence of dual-role factors. To determine the appropriate role for such a factor they utilized "ternary variables." Their proposed model assigns 0, 1, and 2 to the ternary variables. It means that dual-role factor plays input, equilibrium, and output role, respectively. However, to find the benchmark for inefficient DMUs dual formulation of the proposed model is needed. In fact, extracting the envelop form is problematical while some of the variables are integer. Shabani *et al.* (2011) introduced another DEA model entitled "non-binary arithmetic operator dual-role (NAOD)" under free disposability assumption for selecting the refrigerated containers in cold chain management. In their study genetic algorithm is applied to validate the proposed model. Although, they considered a partial role for dual-role factors, but the NAOD model is a non-linear programming (NLP) problem and does not lead to global optimal solutions. Cook *et al.* (2006) presented a methodology for dealing with dual-role factors and classified DMUs into three groups according to whether such a factor is behaving like an output, an input, or is in equilibrium. Their model's limitation is to consider only a dual-role factor while there may be several dual-role factors in different situations.

Farzipoor Saen (2010c) presented a model for selecting third-party reverse logistics (3PL) providers in the presence of multiple dual-role factors. His proposed model modified the limitation of Cook *et al.*'s (2006) model. Based on this model, Azadi and Farzipoor Saen (2011b), Farzipoor Saen (2010a, b, c; 2011a, b, c) and Yang *et al.* (2010) extended several dual-role models in the presence of stochastic data, imprecise data, and weight restrictions and applied them to assess 3PL providers, international market, advertising media, technology, and production system. Nonetheless, Mahdiloo *et al.* (2011) mentioned that the conventional models (such as Cook *et al.*, 2006; Farzipoor Saen, 2010c) deal with dual-role factor as non-discretionary (uncontrollable) criteria, whereas there might be dual-role factor which is under control of management. They introduced an algorithm to fix up the mentioned drawback. A serious flaw in their algorithm is to determine the role of the dual-role factor through double calculations; once considers the factor as an input and another time as an output.

Hatefi and Jolai (2010) extended a method based on translog output distance function for classifying inputs and outputs and evaluated the performance of DMUs. They applied Monte Carlo simulation to evaluate the presented method. However, their method is complex for modeling. Cook and Zhu (2007) modified the standard constant returns to scale DEA model to accommodate flexible measures. Their introduced model is a mixed integer linear programming (MILP). Toloo (2009) claimed that the Cook and Zhu's (2007) model may produce incorrect efficiency scores due to a computational problem as a result of introducing a large positive number into the model. Therefore, he introduced a revised model that does not need such a large positive number. The revised model of Toloo (2009) in fact is a special case of that of Cook and Zhu (2007), and is infeasible in many real cases. Another significant drawback from either the Cook and Zhu's (2007) model or Toloo's (2009) model is that they are very optimistic models and always overestimate the efficiency (Amirteimoori and Emrouznejad, 2012). Amirteimoori and Emrouznejad (2011) proposed a pair of alternative models in which each flexible measure is separately treated as either input or output variable to maximize the technical efficiency. Their proposed model is very similar to the one developed by Mahdiloo *et al.* (2011). However, their models have two limitations. First, their models classify dual-role factors by double calculations. Second, in each model one aspect of dual-role factor is assumed to be uncontrollable. In other words, when output-oriented model is applied, input aspect is considered as uncontrollable factor, and when input-oriented model is applied, output aspect is considered as uncontrollable factor.

Considering all abovementioned points, the purpose of the current research is to introduce an original model to accurately assign role to dual-role factors.

3. Proposed model

Charnes-Cooper-Rhodes (CCR) model developed by Charnes *et al.* (1978), evaluates the proportional efficiency θ, but it does not take into account the input excesses and output shortfalls that are represented by non-zero slacks. This is a drawback because θ does not include the non-zero slacks. Therefore, the Additive model was proposed by Charnes *et al.* (1985) for treating the slacks (i.e. the input excesses and output shortfalls) directly in the objective function. The Additive model has the same production possibility set as the CCR. Moreover, both input and output orientations of the CCR model are combined into a single model by the Additive model. The envelop form of the Additive model is given as Model (1):

$$\max \sum_{r=1}^{s} S_r^+ + \sum_{i=1}^{m} S_i^-,$$
$$\text{s.t.}$$
$$\begin{aligned} &\sum_{j=1}^{n} \lambda_j x_{ij} + S_i^- = x_{io}; \quad i = 1,\ldots,m, \\ &\sum_{j=1}^{n} \lambda_j y_{rj} - S_r^+ = y_{ro}; \quad r = 1, \ldots, s, \\ &\sum_{j=1}^{n} \lambda_j = 1, \\ &\lambda_j, S_i^-, S_r^+ \geqslant 0 \forall i, r, j. \end{aligned} \tag{1}$$

Suppose that one of the criteria has the nature of both profit and cost. In other words, this criterion plays the role of both input (cost) and output (profit), simultaneously. Such a criterion in the DEA literature is called dual-role factor or flexible measure. Expressions (2) and (3) construct the mathematical form of a dual-role factor as follows:

$$\sum_{j=1}^{n} \lambda_j z_j + s_{m+1}^- = z_o; \tag{2}$$

$$\sum_{j=1}^{n} \lambda_j z_j - s_{s+1}^+ = z_o; \tag{3}$$

if one directly adds these expressions into the model for performance measurement, there will be some complications in the results. First, the results demonstrate that all DMUs are efficient. In other words, the discrimination power of the model will be drastically decreased and all the DMUs are restricted to be on the efficient frontier. The reason is that in the lack of constraints such as "Assurance Region" or "Cone-Ratio" which keep a tight rein on the selection of benchmarks, the DMUs become free to determine which outputs and inputs to be emphasized, so that the efficiency score becomes maximum. Second, these expressions imply that role of the dual-role factor is in equilibrium, i.e., the input side is neutralized by output side, and vice versa.

To obviate above-mentioned drawbacks and determine a specific role for the dual-role factor, a new binary variable k is defined and is incorporated into the second and third constraints. Therefore, with minor changes, following constraints are obtained:

$$\sum_{j=1}^{n} k \lambda_j z_j + S_{m+1}^- = k z_o; \tag{4}$$

$$\sum_{j=1}^{n} (1-k) \lambda_j z_j - S_{s+1}^+ = (1-k) z_o; \tag{5}$$

$$k \in \{0, 1\}.$$

If the variable k takes unit value, then (5) is removed and consequently the dual-role factor plays input role. In contrast, if the variable k takes zero value, then (4) is removed and consequently the dual-role factor plays output role. The constraints (4) and (5) may be rewritten as follows:

$$\sum_{j=1}^{n} k\lambda_j z_j + S_{m+1}^{-} = kz_o; \tag{6}$$

$$\sum_{j=1}^{n} \lambda_j z_j - \sum_{j=1}^{n} k\lambda_j z_j - S_{s+1}^{+} = z_o - kz_o; \tag{7}$$

$$k \in \{0, 1\}.$$

Now, Expressions (6) and (7) are incorporated into the Models (1) and (8) is obtained as follows:

$$\max \sum_{r=1}^{s} S_r^{+} + \sum_{i=1}^{m} S_i^{-},$$

$$\text{s.t.}$$

$$\sum_{j=1}^{n} \lambda_j x_{ij} + S_i^{-} = x_{io}; \quad i = 1, \ldots, m,$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} - S_r^{+} = y_{ro}; \quad r = 1, \ldots, s,$$

$$\sum_{j=1}^{n} k\lambda_j z_j + S_{m+1}^{-} = kz_o; \tag{8}$$

$$\sum_{j=1}^{n} \lambda_j z_j - \sum_{j=1}^{n} k\lambda_j z_j - S_{s+1}^{+} = z_o - kz_o;$$

$$\sum_{j=1}^{n} \lambda_j = 1,$$

$$k \in \{0, 1\},$$

$$\lambda_j, S_i^{-}, S_r^{+}, S_{m+1}^{-}, S_{s+1}^{+} \geqslant 0, \forall j, i, r.$$

NLP is a formulation in which a set of unknown real variables are defined by some non-linear constraints and/or a (non-) linear maximizing or minimizing objective function. Solving a NLP is difficult. It is clear that Model (8) is a non-linear problem. It can be linearized by change of variables $\delta_j = k\lambda_j$, $j = 1, \ldots, n$ and incorporating following constraints into the Model (8):

$$0 \leqslant \delta_j \leqslant k, \tag{9}$$

$$\delta_j \leqslant \lambda_j \leqslant \delta_j + (1-k), \tag{10}$$

therefore, the following MILP is obtained:

$$
\begin{aligned}
&\max \sum_{r=1}^{s} S_r^+ + \sum_{i=1}^{m} S_i^-,\\
&\text{s.t.}\\
&\sum_{j=1}^{n} \lambda_j x_{ij} + S_i^- = x_{io}; \quad i = 1, \ldots, m,\\
&\sum_{j=1}^{n} \lambda_j y_{rj} - S_r^+ = y_{ro}; \quad r = 1, \ldots, s,\\
&\sum_{j=1}^{n} \delta_j z_j + S_{m+1}^- = kz_o;\\
&\sum_{j=1}^{n} \lambda_j z_j - \sum_{j=1}^{n} \delta_j z_j - S_{s+1}^+ = z_o - kz_o;\\
&\sum_{j=1}^{n} \lambda_j = 1,\\
&0 \leqslant \delta_j \leqslant k; \quad j = 1, \ldots, n,\\
&\delta_j \leqslant \lambda_j \leqslant \delta_j + (1-k); \quad j = 1, \ldots, n,\\
&k \in \{0, 1\},\\
&\lambda_j, S_i^-, S_r^+, S_{m+1}^-, S_{s+1}^+ \geqslant 0, \quad \forall j, i, r.
\end{aligned}
\tag{11}
$$

Note that if in a linear mathematical optimization, some of the variables are integer, it is called a MILP problem. Therefore, a MILP is the minimization or maximization of a linear objective function subject to linear constraints as given in Model (11).

The idea of prospective benchmark detection implies a need for developing a model for future planning where inputs and outputs of systems are influenced by external factors such as economic conditions, demographic changes, and other socio-economic factors.

As a well-known term in the field of operations research, the PERT/CPM method has been developed as a technique for project scheduling. This technique quantifies knowledge about the uncertainties in durations of activities. The PERT is stated in the form of "most likely," "optimistic," and "pessimistic" approximations for each activity. In this paper, the PERT/CPM technique is considered as a control tool for manager that estimates the quantities of each input and output. At this juncture and inspired by the work of Azadi and Farzipoor Saen (2011a), this method is employed to estimate $\tilde{x}_{ij}$ and $\tilde{y}_{rj}$ as amounts of inputs (x_{ij}) and outputs (y_{rj}) measures in the coming time. A decision maker who is involved in future planning, is asked to estimate the following three parameters on each input, output, and dual-role factor of the jth DMU:

(1) the most likely estimate for input (ML_{ij}) and output (ML_{rj});

(2) the optimistic estimate for input (OP_{ij}) and output (OP_{rj}); and

(3) the pessimistic estimate for input (PE_{ij}) and output (PE_{rj}).

This study converts the three estimates into the expected values for each input and output. The expected value for the ith input of jth DMU is as follows:

$$\tilde{x}_{ij} = \frac{(OP_{ij}+4ML_{ij}+PE_{ij})}{6}, \tag{12}$$

that is equivalent to:

$$\tilde{x}_{ij} = \frac{\left[(OP_{ij}/2)+2ML_{ij}+(PE_{ij}/2)\right]}{3}, \tag{13}$$

The expected value for the rth output of jth DMU is as follows:

$$\tilde{y}_{rj} = \frac{(OP_{rj}+4ML_{rj}+PE_{rj})}{6}, \tag{14}$$

that is equivalent to:

$$\tilde{y}_{rj} = \frac{\left[(OP_{rj}/2)+2ML_{rj}+(PE_{rj}/2)\right]}{3}, \tag{15}$$

In addition, the expected value for the dual-role factor can be estimated in the same way. Finally, by incorporating $\sim xij$, $\sim yrj$ and $\sim zj$ into the Models (11), (16) is formed as follows:

$$\begin{gathered}
\max \sum_{r=1}^{s} S_r^+ + \sum_{i=1}^{m} S_i^- \\
\text{s.t.} \\
\sum_{j=1}^{n} \lambda_j \tilde{x}_{ij} + S_i^- = \tilde{x}_{io}; \quad i = 1, \ldots, m \\
\sum_{j=1}^{n} \lambda_j \tilde{y}_{rj} - S_r^+ = \tilde{y}_{ro}; \quad r = 1, \ldots, s \\
\sum_{j=1}^{n} \delta_j \tilde{z}_j + S_{m+1}^- = k\tilde{z}_o; \\
\sum_{j=1}^{n} \lambda_j \tilde{z}_j - \sum_{j=1}^{n} \delta_j \tilde{z}_j - S_{s+1}^+ = \tilde{z}_o - k\tilde{z}_o; \\
\sum_{j=1}^{n} \lambda_j = 1; \\
0 \leqslant \delta_j \leqslant k; \quad j = 1, \ldots, n, \\
\delta_j \leqslant \lambda_j \leqslant \delta_j + (1-k); \quad j = 1, \ldots, n, \\
k \in \{0, 1\}, \\
\lambda_j, S_i^-, S_r^+, S_{m+1}^-, S_{s+1}^+ \geqslant 0, \quad \forall j, i, r.
\end{gathered} \tag{16}$$

Definition 1. A DMU, DMU_o, is said to be efficient DMU if and only if the value of objective function becomes zero, i.e. $S_r^{+*}, S_i^{-*}, S_{m+1}^{-*}, S_{s+1}^{+*} = 0$.

Ultimately, Expression (17) is proposed to obtain the efficiency score of DMU$_j$ as follows:

$$E_j^* = \frac{1-\frac{1}{m+k}\left(\sum_{i=1}^{m} \frac{S_i^{-*}}{x_{ij}} + \frac{S_{m+1}^{-*}}{z_j}\right)}{1+\frac{1}{s+(1-k)}\left(\sum_{r=1}^{s} \frac{S_r^{+*}}{y_{rj}} + \frac{S_{s+1}^{+*}}{z_j}\right)}, \quad j = 1, \ldots, n \tag{17}$$

where $S_i^{-*}, S_r^{+*}, S_{m+1}^{-*}$, and S_{s+1}^{+*} denote optimum solutions of Models (11) or (16). Note that if one utilizes Model (16), quantities x_{ij}, y_{rj}, and z_j should be replaced by $\tilde{x}_{ij}, \tilde{y}_{rj}$, and $\tilde{z}_j$, respectively:

Definition 2. The optimal score of (17) is a value between [0,1].

Definition 3. A DMU, DMU_o, is said to be efficient DMU if and only if the efficiency score obtained from (16) becomes unit. Otherwise, it is said to be an inefficient DMU.

4. An illustration of the proposed model

To validate the applicability of the proposed model and determine the prospective benchmarks, this section provides a numerical example. Table I presents the data set of 25 Iranian companies. The data set have been taken from reports published in Green Innovation: Projects Festival (2008) and Pioneers of Excellence (2008). This example shows how decision maker(s) estimates future levels of inputs, outputs, and dual-role factors.

In this paper, criteria related to the GSC are identified on the basis of extensive literature review and consultation with academicians and industrial professionals. The used performance measures are wastes (Tseng, 2013; Shabani *et al.*, 2012), transportation cost (Wang *et al.*, 2011), energy cost (Tseng, 2013), green purchasing (Tseng, 2013), and green budget (Wang *et al.*, 2011; Shang *et al.*, 2010).

The inputs are wastes, transportation cost, and energy cost. The outputs are green purchasing and recycling revenue. As mentioned in Section 2, the green budget plays both the input and the output roles, simultaneously. Therefore, the green budget is considered as a dual-role factor.

Companies are considered as DMUs. To estimate prospective benchmarks, one of the decision makers of each company is requested to estimate the most likely (ML_{ij} or ML_{rj}), optimistic (OP_{ij} or OP_{rj}), and pessimistic (PE_{ij} and PE_{rj}) levels of inputs, outputs, and dual-role factor. These estimates are given in Table II. For instance, consider the DMU no. 1. As Table I addresses, recycling revenue of this DMU is 6.14 percent of total revenue. The decision maker of this company estimates 8.3, 9.33, and 12.33 percent of growth in recycling revenue in terms of pessimistic estimate, most likely estimate, and optimistic estimate, respectively. The expected value of inputs ($\tilde{x}_{ij}$) is calculated by the Equations (12) or (13). Also, the Equations (14) or (15) are used to provide the expected value of outputs ($\tilde{y}_{ij}$). Note that, since a dual-role factor plays both input and output role, to calculate expected value of the dual-role factor there are no differences among the results of using the Expressions (12)-(15). These values are provided in Table III.

Finally, Table IV presents the results of running the Models (11) and (16). Table IV has two main parts. In the first part, results of the Model (11) are given. The Model (11) is run on the data set of Table I. The results indicate the efficiency scores of current

DMU	Inputs: Wastes x_{1j} (%)	Inputs: Transportation cost x_{2j} (%)	Inputs: Energy cost x_{3j} (%)	Dual-role factor: Green budget z_j (%)	Outputs: Green purchasing y_{1j} (%)	Outputs: Recycling revenue y_{2j} (%)
1	12.62	21.97	14.11	5.65	22.47	6.14
2	18.26	22.74	12.01	5.92	18.61	6.08
3	19.76	17.99	13.41	5.90	17.15	6.87
4	18.00	21.88	6.49	8.80	17.16	7.42
5	18.60	15.05	9.99	6.07	23.63	8.03
6	10.96	21.10	10.87	7.14	22.81	7.43
7	12.65	19.44	13.77	5.86	17.72	6.34
8	10.34	15.31	12.38	9.47	19.76	4.72
9	13.87	22.02	7.39	7.24	24.12	5.42
10	12.71	22.59	10.95	9.33	22.65	6.84
11	15.07	22.26	6.02	8.24	24.95	7.27
12	19.85	16.09	8.48	7.39	18.79	4.56
13	13.94	17.62	12.49	5.56	22.86	4.09
14	11.58	21.04	9.09	7.31	22.32	4.43
15	19.51	21.51	11.35	9.52	20.58	5.34
16	18.64	16.22	14.46	5.95	17.34	5.25
17	16.97	21.08	14.34	5.81	19.56	5.74
18	14.29	21.13	13.21	5.18	22.78	5.85
19	12.62	22.74	11.11	8.10	21.43	8.71
20	13.11	19.07	10.60	8.45	21.18	4.27
21	18.01	18.85	7.12	8.83	22.04	6.15
22	18.65	18.22	6.11	5.24	22.23	5.30
23	17.95	20.03	11.35	7.35	22.52	7.04
24	18.01	23.08	11.88	6.94	21.67	6.19
25	15.22	20.62	12.75	5.75	24.27	8.45

Table I.
The data set of 25 Iranian companies

levels of companies. As a result, DMUs 4, 5, 6, 8, 11, 12, 13, 14, 19, 22, and 25 are introduced as current benchmarks (according to *Definitions 1 and 3*). For example, DMU no. 14 has zero objective value or the efficiency score 1, i.e. this DMU is an efficient unit. Moreover, the value of k for DMU no. 14 is unit which means green budget for this DMU behaves like an input. However, the objective of this paper is to find prospective benchmarks. Therefore, Model (16) is run on the data set of Table III. The second part of Table IV provides the results. The DMUs 4, 5, 6, 8, 9, 11, 19, 22, and 25 are considered as prospective benchmarks, since they are efficient. The rest of DMUs are inefficient, as well. Consider DMUs 12, 13, and 14. Currently, these DMUs are efficient. Although, the estimated efficiency scores 0.848, 0.719, and 0.834, respectively, for DMUs 12,-14 addressing they will not be considered as benchmarks in future. Besides, k value for DMU no. 14 becomes zero. Therefore, the green budget is considered as an output in the future and any increase in its level will increase the efficiency score. On the other hand, DMU no. 9 which is an inefficient DMU with efficiency score 0.984 is estimated to be a prospective benchmark since its efficiency score becomes unit.

In Table IV additional information is given. To improve the efficiency scores of inefficient DMUs, the values of s_1^-, s_2^-, and s_3^- stand for excess usage of wastes,

Table II. The estimates of inputs, outputs, and dual-role factor

	Inputs									Dual-role factor			Outputs					
	Wastes			Transportation cost			Energy cost			Green budget			Green purchasing			Recycling revenue		
DMU	PE_{1j}	ML_{1j}	OP_{1j}	PE_{2j}	ML_{2j}	OP_{2j}	PE_{3j}	ML_{3j}	OP_{3j}	$PE_{4\text{ or }3j}$	$ML_{4\text{ or }3j}$	$OP_{4\text{ or }3j}$	PE_{1j}	ML_{1j}	OP_{1j}	PE_{2j}	ML_{2j}	OP_{2j}
1	8.66	5.35	2.90	19.80	19.75	16.34	13.08	10.92	8.43	7.97	11.04	12.87	28.18	29.57	35.74	8.30	9.39	12.33
2	15.20	12.00	8.88	20.26	20.27	16.80	10.28	9.00	8.31	8.36	10.69	12.89	23.84	28.45	32.29	8.31	10.77	11.75
3	17.32	11.45	9.80	16.39	14.39	12.45	12.15	10.62	6.99	8.62	10.17	11.97	22.94	25.78	28.45	9.10	10.48	13.04
4	13.40	10.98	8.27	19.77	19.45	15.11	5.48	2.52	2.92	11.47	13.63	15.46	23.43	27.00	28.90	9.90	12.23	14.40
5	13.93	12.29	9.34	13.24	11.82	9.64	8.43	6.41	3.73	9.05	11.64	13.16	29.85	30.46	35.34	10.83	11.91	14.35
6	6.56	2.29	1.92	19.39	18.71	15.55	9.65	7.80	7.07	9.21	12.78	16.37	29.61	32.13	34.93	9.68	10.78	14.04
7	8.29	4.85	3.18	17.24	15.45	13.41	11.86	10.84	7.76	8.28	11.71	15.32	23.92	25.63	28.88	8.85	10.67	11.38
8	6.08	1.35	1.22	13.39	11.93	9.80	10.74	9.38	7.36	12.01	14.48	18.39	25.64	26.75	33.24	6.96	9.37	10.85
9	10.75	6.46	4.30	20.01	19.93	16.55	5.91	4.05	0.49	9.62	12.54	15.15	30.25	33.22	37.88	8.17	9.74	11.77
10	10.41	3.72	3.69	21.50	17.82	16.42	9.63	8.25	7.14	11.35	13.90	16.35	29.61	32.46	35.59	8.85	9.94	13.66
11	11.11	7.71	5.68	19.94	17.29	16.95	4.18	3.08	2.93	10.31	13.98	16.37	30.08	31.57	38.64	10.11	12.16	13.83
12	14.89	12.67	10.04	14.89	13.51	9.80	6.72	4.60	2.61	9.97	11.52	13.73	24.31	27.52	31.56	6.77	8.25	11.08
13	9.34	8.94	4.90	15.10	13.99	11.60	10.87	9.28	5.76	7.66	10.53	11.59	29.21	31.28	35.37	6.33	8.29	10.68
14	9.48	4.60	2.22	18.58	18.45	15.04	7.14	6.43	3.85	9.57	11.43	16.36	28.87	30.92	35.60	6.93	7.60	11.37
15	17.46	11.42	9.55	20.42	16.61	16.10	10.16	8.56	6.69	11.71	15.09	17.66	27.15	27.06	31.66	7.43	9.49	11.87
16	15.02	9.33	9.12	13.88	13.78	9.57	13.17	12.09	8.43	8.94	10.53	14.71	23.83	24.41	30.24	7.96	10.13	11.68
17	13.73	10.42	7.34	19.76	17.75	15.23	13.24	10.77	8.74	8.80	10.10	15.12	25.24	26.32	33.40	8.07	8.99	11.19
18	11.77	5.19	4.30	18.88	17.12	14.42	11.56	11.12	9.76	8.10	10.80	13.78	27.86	31.71	36.42	8.12	10.54	11.94
19	10.49	7.01	3.40	20.63	17.80	16.54	9.42	8.49	5.68	10.83	13.88	16.72	27.86	29.73	34.52	10.71	11.94	14.14
20	9.24	7.33	4.03	16.55	14.31	13.89	9.59	8.47	6.70	10.86	13.51	16.00	27.46	29.89	33.01	6.53	7.60	10.23
21	15.46	12.41	8.71	17.12	15.48	13.12	5.25	4.09	3.23	11.16	13.26	18.49	27.94	29.25	34.70	8.17	10.70	12.77
22	15.00	12.07	9.47	17.12	13.33	12.36	5.07	3.54	2.65	7.50	11.11	12.00	28.29	30.34	33.26	7.80	8.64	10.76
23	13.25	10.13	8.50	18.73	15.81	14.63	9.72	8.32	7.05	9.95	12.50	13.56	29.29	32.25	35.25	9.66	11.13	14.02
24	13.70	10.70	8.53	21.09	20.86	17.33	10.76	9.58	7.15	8.96	11.52	16.16	26.98	29.33	33.17	8.80	9.62	12.24
25	10.23	9.52	6.21	17.78	16.37	13.75	10.80	9.82	8.15	8.54	10.99	15.06	29.43	30.92	35.91	11.04	12.22	13.67

	Inputs			Dual-role factor	Outputs	
DMU	Wastes $\tilde{x}_{1j}$	Transportation cost $\tilde{x}_{2j}$	Energy cost $\tilde{x}_{3j}$	Green budget $\tilde{z}_j$	Green purchasing $\tilde{y}_{1j}$	Recycling revenue $\tilde{y}_{2j}$
1	5.49	19.19	10.86	10.84	29.34	9.70
2	12.02	19.69	9.10	10.67	27.68	10.53
3	12.15	14.40	10.27	10.21	25.31	10.68
4	10.93	18.78	3.08	13.57	26.41	12.20
5	12.07	11.69	6.30	11.46	30.36	12.14
6	2.94	18.30	7.99	12.78	31.71	11.14
7	5.15	15.41	10.50	11.74	25.34	10.49
8	2.12	11.82	9.27	14.72	26.57	9.21
9	6.82	19.38	3.76	12.49	32.73	9.82
10	4.83	18.20	8.30	13.88	31.98	10.38
11	7.94	17.68	3.24	13.77	31.32	12.10
12	12.60	13.12	4.62	11.63	26.98	8.47
13	8.33	13.78	8.96	10.23	30.93	8.36
14	5.02	17.90	6.12	11.94	30.58	8.12
15	12.12	17.16	8.52	14.95	27.08	9.54
16	10.24	13.10	11.66	10.96	24.32	10.03
17	10.46	17.66	10.85	10.72	26.14	9.20
18	6.14	16.96	10.96	10.85	31.07	10.37
19	6.99	18.06	8.17	13.85	29.42	12.10
20	7.10	14.62	8.36	13.48	29.49	7.86
21	12.30	15.36	4.14	13.78	29.03	10.62
22	12.12	13.80	3.65	10.66	29.99	8.85
23	10.38	16.10	8.34	12.25	31.76	11.36
24	10.84	20.31	9.37	11.87	28.94	9.92
25	9.09	16.17	9.70	11.26	30.67	12.27

Table III. The expected values of 25 Iranian companies

transportation cost, and energy cost, respectively. The shortfalls of green purchasing and recycling revenue are shown by s_1^+ and s_2^+, respectively. Also, if the green budget plays the role of input, its excess is shown by s_4^-, and if it plays the role of input, s_3^+ represents its shortfall, i.e. $s_4^- \times s_3^+ = 0$.

The results of current and prospective efficiency scores are given in Figure 1. Figure 2 summarizes all the discussions in this paper, as well.

5. Managerial implications

The implications of the proposed approach are important from national and business points of view. First, this paper introduced a new benchmarking tool. It helps organizations on their sustained efforts toward enhancing the social responsibility. The tool makes in-depth insight for organizations desiring to recognize the fields in which their strengths and weaknesses lie. The proposed model may also support governments in formulating green policies on extending the social responsibility. Second, managers can use the proposed model to plan some corrective actions and revise their GSC strategies. Third, applying the proposed method enables managers to take into account the trends related to the future. Theories such as chaos theory, non-linear science, and standard evolutionary theory, which have been utilized to estimate the future, allow analysts to comprehend many complex systems. However,

Table IV. The results

	Results of the Model (11)											Results of the Model (16)									
DMU	E_j^*	Value of objective function	k	S_1^{-*}	S_2^{-*}	S_3^{-*}	S_1^{+*}	S_2^{+*}	S_4^{-*}	S_3^{+*}	E_j^*	Value of objective function	k	S_1^{-*}	S_2^{-*}	S_3^{-*}	S_1^{+*}	S_2^{+*}	S_4^{-*}	S_3^{+*}
1	0.713	10.791	0	0	2.881	4.855	0	0.018	0	3.036	0.750	13.988	0	0	3.977	5.082	0.416	1.183	0	3.330
2	0.587	19.510	0	3.190	0.480	5.990	6.340	1.190	0	2.320	0.588	22.410	0	4.080	2.010	5.860	5.790	1.570	0	3.100
3	0.663	17.007	0	4.706	0	4.383	6.004	0	0	1.915	0.651	20.797	0	6.802	0	3.860	6.260	0	0	3.875
4	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
5	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
6	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
7	0.715	12.169	0	0	0	4.575	4.935	0	0	2.660	0.738	13.674	0	0	0.539	4.369	6.056	0.225	0	2.485
8	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
9	0.984	2.724	0	0	0.404	0	0	1.514	0	0.806	1	0	1	0	0	0	0	0	0	0
10	0.845	6.668	1	0	2.876	0.282	0.348	0.727	2.435	0	0.869	4.518	1	0	0.134	2.106	0.430	1.123	0.726	0
11	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
12	1	0	0	0	0	0	0	0	0	0	0.848	5.866	1	0.607	0	0	2.984	1.682	0.593	0
13	1	0	1	0	0	0	0	0	0	0	0.719	9.266	0	0.526	0	2.858	0	2.927	0	2.956
14	1	0	1	0	0	0	0	0	0	0	0.834	6.539	0	0	2.335	0	0	2.270	0	1.934
15	0.598	17.920	1	0.910	6.460	1.360	3.050	2.690	3.450	0	0.611	18.460	1	3.821	0	5.014	5.680	2.563	1.381	0
16	0.645	16.753	0	7.195	0	3.064	3.334	0	0	3.160	0.597	17.453	0	6.213	0	3.903	3.991	0	0	3.346
17	0.603	18.188	0	2.703	0	7.240	4.509	1.097	0	2.639	0.546	21.225	0	2.540	0	7.589	5.152	2.890	0	3.053
18	0.657	11.734	0	0	0.016	6.141	1.314	0.999	0	3.263	0.710	11.228	0	0	1.092	5.855	0.230	0.836	0	3.214
19	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
20	0.682	6.216	1	0	0	0	1.694	3.122	1.400	0	0.709	9.463	0	2.199	0	1.971	1.776	2.731	0	0.786
21	0.854	5.124	1	0.687	0	0	1.564	0.607	2.266	0	0.865	6.551	1	2.487	0	0	1.965	0.901	1.197	0
22	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
23	0.840	8.919	1	0	4.465	1.285	1.040	0.939	1.189	0	0.696	10.056	0	3.877	0	3.515	0.931	0	0	1.733
24	0.657	15.280	0	2.940	0.820	5.860	3.280	1.080	0	1.300	0.553	20.270	0	2.900	2.630	6.130	4.530	2.180	0	1.900
25	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0

the application of these techniques is difficult in practice. But, the proposed approach for identifying prospective benchmarks is a simple approach. Fourth, the proposed model allows organizations to examine multiple criteria to discover main eco-friendly criteria along with operational performance measures. Finally, the proposed model determines whether outlays on greening the SC play input role or output role.

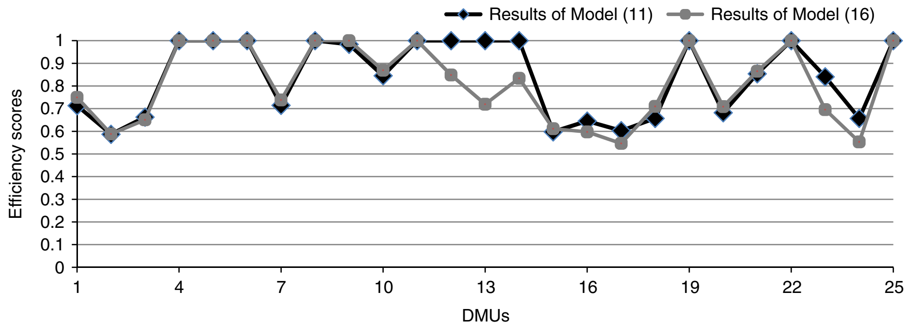

Figure 1. The efficiency scores of the Models (11) and (16)

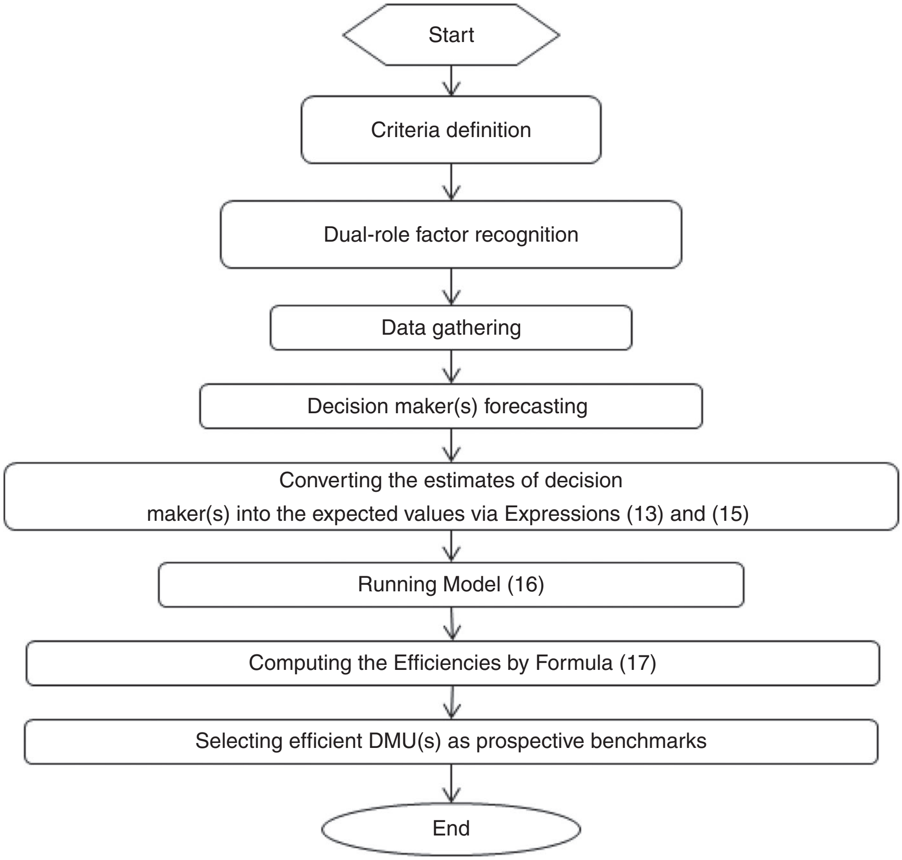

Figure 2. Computations process

6. Concluding remarks

With increasing awareness of environment protection, firms are enforced to implement environmental practices to enhance green image (Lin, 2013). Therefore, GSC is becoming a major component of corporate environmental management strategies. When the motivation for GSCM is for business opportunity or to respond to external restraints, then firms are not likely to be concerned about the impact of the strategy on the suppliers' environmental behavior. On the other hand, if the motivation for GSCM is based on leadership commitment to sustainable development or the desire to promote sustainable development generally, then the question of impact on supplier behavior becomes very important (Gilbert, 2001).

Firms that seriously want to promote environmental sustainability will need to recognize standards of greening. Benchmarking may be a search to find the best practices in GSC. Up to now, lots of researches have been done to explore methodologies for benchmarking. However, selected benchmarks have been identified based upon the data set of earlier periods and they might not be known as benchmarks in future.

To determine the prospective benchmarks, this paper proposed a new model. The model benefits from DEA as well as PERT/CPM technique. It uses the PERT/CPM technique to estimate future levels of criteria. Then, the estimates are incorporated into the proposed model and prospective benchmarks would be identified. Besides, the proposed model deals with the dual-role factor.

More researches can be done based on the results of this paper. For instance, an interesting idea is to develop a DEA model based on artificial neural network (ANN) to estimate input and output values. The ANN is a mathematical model applied to find patterns in data to predict the future. As a result, management is able to determine prospective benchmarks. Also, the future is always accompanied by uncertainty. Incorporating stochastic data, imprecise data, and fuzzy data to determine prospective benchmarks is an interesting topic of research.

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Further reading

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