



A literature review of sustainable supplier evaluation with Data Envelopment Analysis

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ABSTRACT

This paper summarizes findings about papers involving supplier selection and evaluation using Data Envelopment Analysis (DEA) published between 2009 and 2018. It reviews how DEA, one of the most frequently used methods, supports the supplier selection and evaluation process and related management decisions. Its novelty stems from the fact that such a type of review has only been carried out in a much broader context, thus the present approach can reveal potentially new opportunities for development and application. A systematic literature review was completed involving 54 papers that propose the use of some form of DEA for supporting supplier-management-related decisions. The paper uses descriptive and multivariate statistics to cluster the reviewed papers. Although a large number of papers were published in the period under examination, most of them still focus on supplier selection. However, a limited number of papers were identified which are more practice oriented and support strategic decision making in supplier management. Papers considering sustainability tend to focus only on green factors, but in most cases it means an additional criterion in the evaluation. Sustainability problems do not generate substantially new DEA model versions.

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1. Introduction

Methods for supporting firms' purchasing decisions are dealt with extensively in the business related literature. Research has shown for decades that the work of purchasers is becoming increasingly complex (De Boer et al., 2001; Hong and Kwon, 2012; Luzzini et al., 2014), evidently urging a more systematic and transparent approach to purchasing-related decision making. This situation justifies the fact that contemporary papers offer a range of methods and techniques that may support purchasing decision makers in their most important task: managing the supply base. The importance of methodological development is also increasing due to the opportunities offered by information technology and Internet of Things (IoT) development (Ghadimi et al., 2019). However, to exploit such opportunities it is important to connect purchasing knowledge with methodological advances.

This paper reviews how one of the most frequently used methods, Data Envelopment Analysis (DEA), supports the supplier selection and evaluation process and related management

decisions, and structures knowledge of its potential applications. Its novelty stems from the fact that such a review has only been carried out in a much broader context (Soheilrad et al., 2018). The aim of this paper is to examine how DEA is integrated with purchasing and supply management: namely we identify what purchasing tasks DEA is used to handle, and what resources (what kind of literature) articles rely on to identify the purchasing problems they are intended to solve. As the issue of sustainability gets more and more attention, we will also look at how the identified papers integrate it to their DEA model from purchasing and methodological point of view. As the importance of information technology in optimizing and supporting management decisions is growing, the role of teamwork and interdisciplinary thinking is becoming better recognized. Connecting purchasing management knowledge with mathematical knowledge is essential for ensuring that methodological developments can be utilized.

This paper is structured as follows: first, it assesses the results of literature reviews about supplier evaluation. In Section 3, DEA methodology is briefly presented. Then, a detailed analysis of the methodology of the literature review is described (Section 4) a presentation of basic descriptive data about the identified papers the coding scheme is introduced. Section 5 investigates the identified papers according to their research priority and also uses multivariate statistical analysis to identify clusters. Section 6 concludes.

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2. 2. Reviews about supplier management and supplier selection

To structure knowledge about supplier selection, a large number of literature reviews have been published. The large-scale review of [Wetzstein et al. \(2019\)](#), based on co-citation network analysis, extracts clusters that are identified as involving 1) the conceptual foundations of the field; 2) modelling of the procurement environment; 3) handling group-decision making and imprecise input data; 4) computational research; 5) green/sustainable research; or, 6) risk-based supplier selection. In an earlier review, [Wetzstein et al. \(2016\)](#) identified six streams of research, namely: 1) approaches (methods or techniques) for supplier selection (SS); 2) criteria for supplier selection; 3) green and sustainable SS; 4) strategy oriented SS; 5) Research and Development (R&D) oriented SS; and, 6) operations-oriented SS.

As literature reviews have revealed ([Giunipero et al., 2019](#)), one important stream of reviews focuses on methodology for supporting supplier evaluation. It is recognized that a large number of methodologies are used to support purchasing-related decision making, with Analytic Hierarchy Process (AHP) and DEA identified as the most common approaches (e.g. [Ho et al., 2010](#); [Agarwal et al., 2011](#); [Wu and Barnes, 2011](#); [Chai et al., 2013](#)), although many recent publications combine the former to create more a consistent technique or to link interconnected purchasing decisions. [Aissaoui et al. \(2007\)](#) focused on multilevel supplier selection by reviewing methods that connect the tactical and operational decisions of supplier choice and order allocation.

The topic of green and sustainable supplier evaluation has also attracted contributions in review papers. Result indicate that studies focusing on all three dimensions of sustainability are scarce, environmental and economic considerations are dominating the research ([Rajeev et al., 2017](#); [Chen et al., 2017](#)). Green purchasing is often considered as an important subset of green supply chain ([Green et al., 2012](#)) and identify relationship with firm performance ([Dubey et al., 2013](#)) [Zsidisin and Siferd \(2001\)](#) defines environmental purchasing for an individual firm as the set of purchasing policies held, actions taken, and relationships formed in response to concerns associated with the natural environment. These concerns relate to the acquisition of raw materials, including supplier selection, evaluation and development; suppliers' operations; inbound distribution; packaging; recycling; reuse; resource reduction; and final disposal of the firm's products.

A significant proportion of sustainable purchasing and supply management papers adopt stakeholder theory, institutional theory and resource-based perspectives ([Johnsen et al., 2017](#)). Supply chain collaboration was identified as a topic which is gaining attention ([Chen et al., 2017](#)). [Tseng et al. \(2019\)](#) finds that there is a growing trend of applying mathematical optimization models for enhancing decision making in pursuit of environmental performance and the study also finds a consistent growth in the evaluation of green supply chain management practices and performance. Literature reviews also analyzed the methodologies developed to support sustainability in supplier evaluation. [Govindan et al. \(2015\)](#) found that between 1997 and 2011 the most widely used multi-criteria decision making approach was AHP, while [Zimmer et al. \(2016\)](#) concluded that mathematical analytical models were most frequently used in the literature (AHP, Analytic Network Process (ANP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and DEA). This indicates that the techniques applied in green supplier selection are similar to those generally used in supplier selection, although several new environmental performance criteria were recognized in the review papers ([Govindan et al., 2015](#); [Zimmer et al., 2016](#); [Nielsen et al., 2014](#); [Hassini et al., 2012](#); [Glock et al., 2017](#)).

Connecting purchasing management and the available methods is essential, as this is how the new problems related to the more complex and strategic issues of purchasing and supply management can be addressed. A fundamentally important paper by [De Boer et al. \(2001\)](#) investigated supplier evaluation methods in a framework that reflects the diversity of purchasing situations and the phases of supplier selection. The related model highlighted four phases: namely, problem definition, formulation of criteria, qualification, and choice. This idea was present in later reviews, but many of the latter added other phases such as the post-evaluation of suppliers ([Igarashi et al., 2013](#)), and supplier monitoring and supplier development ([Zimmer et al., 2016](#)). Thus, recognition of the strategic role of purchasing increases the importance of activities that go beyond selection, which is how the pre-qualification and post-qualification activities mentioned above came to the fore. The increasing sophistication of the strategic contribution of supply over time also promotes activities aimed at increasing sustainable competitive advantage, allowing purchasing professionals to focus on new forms of supplier relationships, supply management, advanced planning, and value-added activities ([Tchokogue et al., 2017](#)). Supply base strategy development usually relies on mapping suppliers, and responses may focus on coping with complexity (e.g. standardization, local/regional sourcing, improving capabilities) or coping with dependence ([Bygballe and Persson, 2015](#)). In line with this, the purchasing and supply management literature indicates the existence of many supply-base-related decisions and activities. [van Raaij \(2016\)](#) highlights supplier development, performance evaluation, and supplier relationship management. Supplier segmentation can also support the decision to invest in supplier relationships and promote the choice of appropriate governance structures ([Day et al., 2010](#)).

These reviews stimulated the idea of the current paper, the aim of which is to review how Data Envelopment Analysis supports supplier management, the evaluation process, and related management decisions. Its novelty stems from the fact that such a review has only been carried out in a much broader context (e.g. [Soheilirad et al., 2018](#) investigated how DEA supports supply chain management). General reviews of DEA are also available, but how the former can be used in supplier evaluation has not yet been clarified. Bringing together the features of the method and linking it with purchasing problems directs attention to areas that are already the focus of methodological development and can reveal areas where DEA is potentially applicable and deserving of further improvement.

3. The basic DEA method in purchasing decisions

Decisions about purchasing and supply are becoming more and more complex as the function becomes more strategic, increasing the need and the opportunity for methodological support for such decisions. DEA is widely used in business and economic decision making ([Velasquez and Hester, 2013](#)). To investigate how it is applied in purchasing and supply decisions, we briefly introduce DEA from a methodological point of view.

The basic method of DEA was initiated by [Charnes et al. \(1978\)](#). It is a linear programming nonparametric technique for evaluating the relative efficiency of comparable entities (Decision making units (DMUs)). It can be used to evaluate the relative efficiency of DMUs according to multiple inputs and outputs. DEA is designed to produce the maximum outputs or use the minimum inputs by treating a DMU as a black box; i.e., by ignoring internal structures. The model offered by [Charnes et al. \(1978\)](#) is a hyperbolic programming model under linear conditions. A general-solution-type kind of model was first investigated by [Martos \(1964\)](#), who examined the problem as a special case of a linear programming model.

DEA can be used as a general framework to evaluate suppliers in materials- and supply management in the absence of criteria weights. Assume that a purchaser evaluates p number of suppliers. The number of input criteria is n , and the number of output criteria m . The evaluation of supplier i is defined using vectors $(\mathbf{x}_i, \mathbf{y}_i)$, where vector \mathbf{x}_i is the value of the input (e.g. management) criteria and vector \mathbf{y}_i is the output (e.g. sustainability) criteria. The aim of DEA is to construct the weights for the input and output criteria. The weights are vectors \mathbf{v} and \mathbf{u} for the input and output criteria.

The output-oriented DEA Charnes–Cooper–Rhodes (DEA-CCR) model can be formulated in the following format, assuming that we seek to examine the efficiency of the first decision-making unit:

$$\mathbf{u} \cdot \mathbf{y}_1 / \mathbf{v} \cdot \mathbf{x}_1 \rightarrow \max \quad (1)$$

s.t.

$$\mathbf{u} \cdot \mathbf{y}_j / \mathbf{v} \cdot \mathbf{x}_j \leq 1; j = 1, 2, \dots, p. \quad (2)$$

$$\mathbf{u} \geq \mathbf{0}, \mathbf{v} \geq \mathbf{0}. \quad (3)$$

Model (1)–(3) is the basic model of DEA, which can be reformulated in a linear programming model in the following form:

$$\mathbf{u} \cdot \mathbf{y}_1 \rightarrow \max \quad (4)$$

s.t.

$$\mathbf{v} \cdot \mathbf{x}_1 = 1, \quad (5)$$

$$\mathbf{u} \cdot \mathbf{y}_j - \mathbf{v} \cdot \mathbf{x}_j \leq 0; j = 1, 2, \dots, p. \quad (6)$$

$$\mathbf{u} \geq \mathbf{0}, \mathbf{v} \geq \mathbf{0}. \quad (7)$$

This last model is one possible formulation of a basic DEA model (1)–(3); i.e., an output-oriented model because the counter (output) of the first supplier is maximized and the denominator (input) normalized. If the denominator is minimized and the counter is normalized, the DEA model is called input oriented. Weights (\mathbf{u}, \mathbf{v}) are not applied for further examination in the basic model, although there exist some generalizations which use the calculated weights.

Models (4)–(7) can easily be solved with commercial software – e.g. by using Microsoft Excel Solver.

To summarize, a main advantage of DEA models in purchasing and supply management is that DEA can uncover relationships that may not be revealed by other methods. DEA can be used wherever efficiencies need to be compared (Sexton et al., 1986; Stolp, 1990; Liu et al., 2013), and this is exactly what purchasing managers need in the case of the many supplier evaluation/management activities specified in the literature (e.g. prequalification, segmentation, supplier development, etc.). There are some drawbacks of DEA. One of them is the number of DMUs. Cooper et al. (2007) recommended that the number of DMUs analyzed should be at least the maximum of the multiplication of numbers of input and output, or three times the sum of number of input and number of output criteria. In spite of all drawbacks, due to its relative simplicity and easy-to-access computer support, it is well suited to corporate use.

Recent publications focus on how DEA can be used in various industries. De et al. (2020) measured the impact of lean and sustainability oriented innovation on sustainability performance of small and medium sized enterprises. Kalantary et al. (2018) develop a model to assess sustainability in a spare parts manufacturer supply chain. Zhou et al. (2018) introduce a DEA model for evaluating industrial production and environmental management

system. Zhai et al. (2019) measure the efficiency of an energy supply chain with two-stage frontier-shift DEA.

4. Methodology

A systematic review is recognized as an efficient tool for evaluating an extensive literature (Mulrow, 1994; Fink, 2019). To implement this, we utilized the six-step approach suggested by Durach et al. (2017) for systematic literature reviews in supply chain management. The six step will be the following:

1. Define research question (Section 4.1)
2. Determine the characteristics required of primary studies (Section 4.2)
3. Retrieve sample of potentially relevant literature (Section 4.3)
4. Selection of pertinent literature (Section 4.4)
5. Coding scheme application (Section 4.5)
6. Analysis of the papers (Section 5)

4.1. Define research question (RQ)

As outlined in the previous section, numerous literature reviews that have analyzed supplier selection from different perspectives have been published. Most of these reviews aimed at creating a comprehensive picture of some aspects of supplier valuation (methods applied, criteria, citation links, etc.). In this paper we have chosen a different approach. Focusing on DEA, we looked at how published papers proposed to support supplier evaluation with the aim of discovering trends in use and potential for further research.

4.1.1. RQ1: How is DEA integrated into purchasing and supply management?

- a What is the research priority of the identified papers?

Supplier evaluation attracts continuously increasing attention in scientific publications. To address how DEA is integrated into purchasing and supply management, we assumed that a methodological development can only truly be integrated into a management area if it can identify a professional problem and demonstrate that it is relevant to the literature in the particular management area using references.

- b What supplier-related activities are considered to be supported by DEA?

Purchasing practice and literature often use a three-level model to describe purchasing activities. Van Weele (2009) classified such activities as having a long-term (strategic), medium-term (tactical) or short-term (operational) impact. As some activities may have a short-, medium- or long-term impact we rather relied on an understanding that helped to categorize activities according to their goal. Fig. 1 summarizes those purchasing activities which rely on supplier evaluation; it was assumed that the latter could be supported by DEA methodology.

Tactical-level activities were defined in our model as those that involve purchasing activities aimed at managing the evaluation of suppliers as part of the bidding/tendering process to meet a particular need. Supplier selection is an important element of this process. Some publications consider such selection as a one-time decision. However, as (for example) the review of De Boer et al. (2001) highlighted, it might also involve a four-step process. The last two steps (qualification and final selection) are manageable

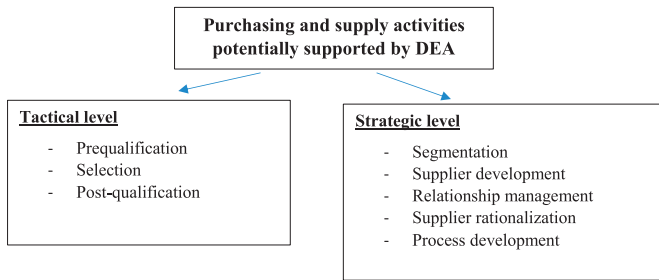


Fig. 1. Purchasing activities potentially supported by methodology.

using quantitative methods. Some publications identify another step known as post-evaluation or vendor rating to check whether suppliers have met expectations and to monitor the performance of active suppliers. (Wu and Barnes, 2011; Igarashi et al., 2013; Luzzini et al., 2014). Accordingly, the analysis for this paper considered a three-step approach related to tactical-level supplier evaluation: qualification/prequalification (shorting the suppliers), selection (choice of supplier) and post-qualification (checking supplier performance). It was assumed that most of the identified publications would focus on these levels.

Strategic purchasing activities were considered in this paper as those which are designed to manage the potential supply base in order to maximize potential advantages, mobilize difficult-to-duplicate external resources, and manage risk. Those activities were included in the research model which require the evaluation of suppliers. Relying on the results of Bygballe and Persson (2015) and Tchokogué et al. (2017), the following activities which incorporate supplier evaluation were identified: supplier segmentation, supplier development, relationship management, supplier rationalisation, and process development. The assumption was that these activities can be appropriately supported by DEA. Because this is a relatively new area of purchasing and supply management and is less well known in the broader management literature, we assumed that fewer papers would address such topics, but those which did would be more familiar with the purchasing literature.

Operative-level activities were considered as those that define the details of an order within a given supplier relationship (call time, quantity, composition, order allocation, etc.) As most of these activities are related to inventory management, it was assumed that literature about supplier evaluation would not focus on these activities.

4.1.2. RQ2: What is the focus of the papers under examination?

a Is there a link between the methods and the problem?

The research question examines what groups can be identified based on the link between the professional problem and the methodology. We assumed that methodological and purchasing developments would be somewhat different, although a cluster analysis could refine this expectation and provide us with a more structured picture of the research focus of the analyzed papers.

b How does sustainability fit into the focus?

The issue of sustainability is commonly addressed in the methodology-related, purchasing and supply management literature. We assumed that the majority of the papers we examined would include environmental topics. We investigated how this factor relates to the methodology and to which supply management problems.

4.2. Determine the characteristics required of primary studies

The next step of the process was to develop criteria for determining whether a publication could provide information regarding the research question. We searched for articles that included a qualitative model of DEA to support an evaluation of a supplier's performance or capabilities in order to facilitate a supplier-related decision or support supplier management activities. We also considered whether the article included a description of the proposed DEA model to be an important criterion.

4.3. Retrieve sample of potentially relevant literature

The next step was to identify a dataset for this study that was replicable, transparent, and included a broad spectrum of high-quality articles from leading journals. For this task we used the Scopus database. We searched academic papers published in peer-reviewed journals in the English language, excluding conference papers, reports, notes, etc. (A similar approach was followed in papers such as Spina et al., 2016; Giunipero et al., 2008). The following five terms were used: "Data envelopment analysis", and "supplier evaluation", or "supplier selection" or "vendor evaluation" or "vendor selection". Articles containing these terms in the title, key words or abstract were included in the initial search. The search was carried out on January 8, 2019. The time period was defined to cover articles from 2009 to 2018, which was considered to be a large enough range to provide a longitudinal perspective. As a result, we identified 164 papers. Each paper identified during the literature search was first evaluated for possible relevance based on its title and abstract: we excluded 20 papers which failed to satisfy the original criteria (paper develops or applies qualitative DEA model to support supplier-related decisions).

Next, we followed the approach of Wetzstein et al. (2016, 2019) to guarantee that only papers from quality journals were included in the dataset for this study: we utilized the German VHB JOURQUAL 3 ranking and British ABS 2018 ranking. Wetzstein et al. also utilized those journals which were present on both lists and which reached a quality ranking of at least 'C' on the VHB list and a minimum score of '2' in the ABS ranking. This reduced the number of articles to 33. As this approach excluded a large number of papers and those journals which were not ranked on one of the lists we decided to include those journals which were highly ranked on either of the two lists. As a result, we identified 55 papers.

4.4. Selection of pertinent literature

At this stage, we reviewed the full text of the papers. The texts were thoroughly read and then individually evaluated to meet the criteria (to check if they dealt with supplier assessment and used the DEA model, and that the papers contained a detailed description of the suggested DEA model). The final database contained 54 articles.

4.5. Coding scheme application

At this stage the articles underwent content analysis to help categorize the papers according to the research priorities. To assure inter-rater reliability, each of the authors independently categorized the papers. Articles that were differently categorized were re-examined by both authors and discussed until unanimity was reached. Based on this system of categorization it was possible to complete the analysis; results are presented in Section 5.

We coded the 54 articles into six categories. The first three dimensions aim to grasp how the methodology is integrated with supply management, while the other three dimensions focus on the methodology.

a Research goal

First, the research goal of the reviewed papers was analyzed. The main categories used to classify the surveyed articles were:

- Methodological problems: these papers focus on a methodological problem (e.g. negative or unreliable data). The goal was to develop a solution to the defined problem. The articles discuss such methodological problems in a purchasing context, but this context could simply be replaced by another business problem (e.g. facility location).
- Methodological problem with purchasing orientation. These papers also focus on a methodological problem, but identify some purchasing-related issues and seek solutions to them.
- Purchasing problem: these papers define a purchasing management problem and develop a solution.

b Literature background

The nature of the referenced literature shows what knowledge base the articles build on. Here, we examined how many purchasing-related references each article contains. The categories were the following:

- Scarce: the paper contains 0–4 substantive purchasing references; an overwhelming proportion of references are methodology related
- Few: the paper contains 5–9 substantive purchasing references; most references are methodology related
- More: the paper contains 10–14 substantive purchasing references, but the majority of these references are methodology related
- Many: the paper contains more than 14 substantive purchasing references and the use of purchasing- and methodology-related literature is balanced.

c Level of purchasing activity

For the classification, we observed the level at which the DEA application could be linked (Here, we decided on the classification based on what the article uses the DEA method for.)

- Strategic purchasing activities are those activities which are aimed at helping manage the potential supply base in order to maximize potential advantages and manage risk (e.g. supplier segmentation, supplier development, etc.).
- Tactical-level activities are those that involve the use of purchasing activities to meet a particular need (e.g. tendering process, contracting).
- Operational-level activities are those that can be linked to the satisfaction of a particular claim within an existing contractual framework (e.g. ordering).

d Use of methodology

This categorization concerns which attribute of the basic DEA model is highlighted in the paper.

- Measurement of efficiency: the goal of the analysis is to evaluate suppliers and differentiate between efficient and nonefficient suppliers (DMUs).
- Ranking: the aim of the model is to develop a rank order of suppliers according to their efficiency. (This requires an extension of the basic DEA model.)

- Identification of factor weights: the basic DEA model calculates weights and the paper develops the factor weights for another analysis (e.g. for a scoring model).
- e Quality of data in the model

The quality and nature of the data that is available may affect the outcome of the calculations, so it should be taken into account.

- Deterministic data: in these papers data is assumed to be fully available and known.
- Undesirable data: the paper assumes that data may be different in the sense that some is desirable (more is better) and some undesirable (less is better). Such data can be deterministic.
- Imprecise data: data are not fully available or are uncertain.
- Fuzzy data: there is information about the data, but the borders of the data are not fully known.
- Stochastic data: the probability distribution of the data is known.

f Integration of sustainability aspects

Sustainability (especially green) aspects are frequently addressed in the literature. It is of relevance to analyze how papers incorporate this topic.

- No mention: sustainability aspects are not taken into account.
- Mention, but no handling: criteria are mentioned but the nature of the criteria or their effect on the results is not underlined.
- Handling in the model: the nature of the criteria or the effects on the results are considered in the paper.

The six dimensions are the variables used in a multivariate statistics analysis.

5. Statistical analysis of the papers

To answer our research questions about how DEA supports supplier-management-related decisions, descriptive statistics about the identified papers will first be presented, followed by some findings from cross tabulation. Next, multivariate statistical tools are applied to reveal how methodological improvements were connected in the papers to supply management priorities.

5.1. Descriptive statistics concerning the database

Regarding the number of published papers, academic interest slightly increased over the time period under investigation, confirming the relevance of DEA in supplier evaluation. As [Table 1](#) reveals, in most years the number of publications identified was around five, except for in 2018, when 11 articles were identified, which is twice the average.

The 54 articles in our database were spread over 28 journals. Thirteen journals published at least two papers over the examined period (See [Table 1](#)). It is worth comparing these results with those of the more general review of [Wetzstein et al. \(2019\)](#). The latter authors found in their literature review (while studying supplier selection) that 85% of the identified papers were published in 15% of the journals. Our sample about DEA compared to the study of [Wetzstein et al. \(2019\)](#) was much less concentrated: 72% of the papers were published in 46% of all papers. This difference may stem from the different approach to VHB and ABS rankings: while [Wetzstein et al. \(2019\)](#) included only journals positively ranked on both lists, we included journals that were positively listed in one of the rankings. (We decided to include Expert Systems with Application, Sustainability, Operational research, Information

Table 1
Papers published per journal and year.

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
International Journal of Production Research	2			3	1					6
Expert Systems with Applications	1	2	1			1				5
Journal of Cleaner Production		1							2	4
Sustainability (Switzerland)									1	3
International Journal of Operational Research				2						1
International Journal of Production Economics						2	1			3
Annals of Operations Research										2
Computers and Industrial Engineering										2
Decision Sciences	1				1					2
European Journal of Operational Research				1				1		2
Journal of the Operational Research Society							1			1
Omega (United Kingdom)						1		1		2
Transportation Research Part D: Transport and Environment									2	2
Others:	0	1	2	0	3	3	2	2	1	1
Σ :	4	4	3	6	5	7	4	4	6	11

Technology and Management, Enterprise Information Systems, Journal of Business Economics and Management, Journal of the Operational Research Society, International Journal of Integrated Supply Management.)

5.2. Research priorities of the papers

Simple comparison of the dimensions tells us a lot about the priorities of the examined articles. First of all, it was expected that the research goal would be connected to the referred-to literature. The reviewed literature contained narrative literature reviews. These sections of the articles were prepared with the aim of presenting the theoretical foundations and context of the research questions and helping bring the research questions into focus.

The most important message from the table (Table 2) is that the majority of the articles we identified do not rely heavily on purchasing literature. More than a third of the articles hardly contained any substantive reference to purchasing. Moreover, it seems that the articles with a methodological focus were primarily those ones which did not look for a connection with the purchasing literature. We consider here those papers which contained only a few references (most of which involved very general mention of the importance of supplier selection, or some general statements about selection criteria). The conclusion is that at in about 50 percent of the papers the relevance of the suggested methodology was not confirmed by the purchasing and supply management literature review.

Purchasing management literature has long emphasized the strategic role of this function. As part of this evolution, purchasing focuses not just on short-term tactical decisions, but also on supplier management tasks involving helping purchasing to manage risks, optimise costs, and generate a source of long-term competitive advantage.

Comparison of the research goal and level of activity (Table 3) reveals that although the purchasing literature emphasizes the importance of strategic tasks, the proportion of papers that are engaged in the development of a methodology for supporting the tactical tasks of supplier selection is significant. We also find it interesting to highlight that two-thirds of the articles that involve

purchasing problems focus on the strategic level.

Similar results are also found in terms of a comparison of level of purchasing activity and literature background (Table 4). Articles that deal with the strategic level are better supported by literature than publications that address the tactical level.

In order to organize the research focus of the papers in the sample, the purchasing levels were further subdivided into activities and linked to the use of DEA methodology. As only one paper discussed the operative level (the focus was on order allocation), strategic and tactical decisions were highlighted. To address the research question about DEA in purchasing, these activities were connected with the 'use of methodology' factor. Results are presented in Table 5. In some cases, it was difficult to infer from the text of the article exactly what the purpose of supplier evaluation was in the article, in which case we tried to identify this from the description of DEA.

Most of the identified papers (31/54) focused on supplier selection, and almost all of them (29/31) used DEA to rank suppliers, thereby supporting the selection of suppliers. Almost half of them scarcely referred to the purchasing and supply management literature, and only 5 of the 31 included a substantial number of purchasing-related references. Papers with sound purchasing-related references typically defined purchasing problems (e.g. Sarkis (2014) focused on Key Performance Indicators (KPI) determination in sustainable supplier selection).

However, many papers took a more novel approach and used DEA to support advanced supply management practices. The number of the former was relatively small, but they evenly supported the identified activities. All of them used DEA to measure efficiency, which is related to the basic logic of this method. Only one paper used DEA to identify weights. The theoretical background of the addressed problem was much more well-founded: 9 of the 12 papers had a high number of purchasing and supply management references. The three papers which had fewer Purchasing and Supply Management (PSM) references focused on supplier development and presenting data analyses of real corporations. This practical orientation might have helped them to identify PSM-related problems.

Table 2
Cross-tabulation: Research goal and literature background.

	Scarce	Few	More	Many
Methodological problems	16	4	0	0
Methodological problems with purchasing orientation	2	12	2	0
Purchasing problem	1	3	9	5
Σ :	19	19	11	5

Table 3

Cross-tabulation: Research goal and level of purchasing activity.

	Strategic	Tactical	Operative	
Methodological problems	1	18	1	20
Methodological problems with purchasing orientation	0	16	0	16
Purchasing problem	11	7	0	18
	12	41	1	

Table 4

Cross-tabulation: Level of purchasing activity and literature background.

	Scarce	Few	More	Many	
Strategic	1	2	5	4	12
Tactical	17	17	6	1	41
Operative	1	0	0	0	1
	19	16	17	5	

Finally, to obtain an answer to research question RQ2/b the issue of sustainability was analysed.

To investigate how sustainability orientation of the paper related to supply management problem the following cross-table was completed (Table 6).

Nineteen of the 54 papers (35.2%) dealt with sustainability to some extent (most of them simply included green criteria into the evaluation) while only eight papers (14.81%) addressed the issue directly (offered methodological solutions). Among sustainability aspects, environmental issues dominate in the papers. Only a few papers considered social aspects (e.g. Rashidi and Saen, 2018, Shi et al., 2015; Hatami-Marbini et al., 2017; Izadikhah et al., 2018).

Our research question was also aimed at analysing the integration of sustainability issues into purchasing decisions so that a comparison with the previous dimensions could shed light on possible relationships. Sustainability aspects were mostly considered in models aimed at supporting the tactical level (16 papers out of the 41 papers; 41.46%), while only two (out of 12) papers considered it at the strategic level. Data of Table 6 reflects that the level of purchasing activity in focus of the investigated papers is not closely connected to sustainability orientation of the papers.

It was also investigated that how sustainability orientation of a paper relates to the methodological aim of the paper (Table 7).

The interpretation of the data is that no direct connection can be identified between the methodological aim and sustainability orientation of the investigated papers. DEA usage does not influence whether sustainability considerations are involved in method

developments in the field of supplier evaluation. This also means that integrating sustainability problems into DEA does not mean the need to develop significantly new model versions. The papers with sustainability orientation frequently addressed data problems. The issue of negative or undesirable (e.g. Izadikhah et al., 2018; Hatami-Marbini et al., 2017) and imprecise (Yu and Su, 2017) data were highlighted, whereas reduction is the goal for most environmental criteria. To capture green aspects, some methods proposed a combined methodology (e.g. the use of FA-DEA-AHP to incorporate the low-carbon concept in He and Zhang, 2018).

5.3. Multivariate statistical analyses of the dimensions

On the basis of Section 4, we coded the 54 articles as follows:

- 1 *Research goal* of the article: methodology (1), methodology and purchasing (2), and purchasing (3),
2. *Cited purchasing background*: scarce (1), a few (2), more (3), and many (4),
3. *Level of management decision (decision level)*: operative (1), tactical (2), and strategic (3),
- 4 *Use of methodology*: measurement of efficiency (1), ranking (2), and search for factor weights (3),
- 5 *Quality of data* in the model: deterministic data (1), undesirable data (2), imprecise data (3), fuzzy data (4), and stochastic data (5),
- 6 *Handling of sustainability*: no (1), mention, but not handling (2), and handling in the model (3).

With this coding we built a database with six dimensions as variables measured on ordinal scales.

We applied three multivariate statistical methods to reveal the relationships between dimensions and identify groups of papers. First, correlation analysis was used to examine the linear connections between the variables. Then, with the help of factor analysis we analyzed the number of latent factors that could be used to explain the variance in the database. Finally, we examined

Table 5

Cross-table: Methodology and level of purchasing activity.

	Tactical			Strategic				
	Pre-qualification	Selection	Post-qualification	Segmentation	Supplier development	Relationship management	Supplier rationalisation	Process development
Methodology measuring efficiency for ranking identifying weights	8	1	2	2	3	2	2	3
		29						
		1						

Table 6

Cross-table: Sustainability and level of purchasing activity.

	Strategic level	Tactical level	Operative level	Total
No sustainability	10	24	1	35
Mention of sustainability	0	11	0	11
Handling in the model	2	6	0	8
Total	12	41	1	

Table 7
Cross-table: Sustainability and methodological aim.

	Measuring efficiency	Ranking	Identifying weights	Total
No sustainability	16	18	1	35
Mention of sustainability	4	7	0	11
Handling in the model	4	4	0	8
Total	24	29	1	54

which processed articles could be grouped through cluster analysis.

The correlation matrix of the variables is presented in Table 8. The correlation matrix shows that the linear relationship is moderate between the first four variables (i.e. research goal, cited purchasing background, decision levels, and use of methodology). In addition, these relationships proved to be significant. However, the other two variables (quality of data, and handling of sustainability) are only weakly linearly correlated with each other and with the other four variables. Since the level of significance was not determined to be significant, we conclude that there is no relationship between these two variables and between the other four variables.

Based on the correlation matrix, we examined how many factors could be used to describe our model. We found that 65.1 percent of the variance could be explained by two latent factors. With the rotated component matrix, we can see which factors are strongly correlated to the variables (i.e., which factors are explained by the variables). Table 9 shows that the first four variables (research goal, cited purchasing background, decision levels, and use of methodology) are strongly correlated with the first factor. This explains about 44.5 percent of the variance based on rotation with VARIMAX. The other two variables (quality of data, and handling of sustainability) are responsible for 20.6 percent of the residual variance. The results of a Kaiser-Meyer-Olkin test (at 0.700) indicate that the factor model is moderately compliant, which is satisfactory.

The 54 articles included in the sample were divided into groups using quick cluster analysis, which indicated that five groups were appropriate. Groups of papers were the following: see Table 10.

The quick cluster process also allowed us to define the cluster centres of groups from the cluster model by which groups can be characterized. Table 11 presents the distribution of the papers within the clusters.

Cluster 5 is characterized as containing those methodological papers that focus on a ranking problem and deterministic data. In Cluster 4 there are papers with a purchasing orientation focusing on supplier management. Cluster 3 contains papers focusing on ranking problems with fuzzy data. In Cluster 2 are mainly papers with a purchasing focus and a strong purchasing literature background with attention to data quality. Cluster 1 contains papers that focus on standard purchasing situations with reference to sustainability.

Table 8
Correlation matrix of variables.

		Purchasing literature background	Level of purchasing	Use of Methodology	Quality of Data	Sustainability
Research Goal	Pearson Correlation	.783 ^a	.565 ^a	-.452 ^a	-.085	.158
	Sig. (2-tailed)	.000	.000	.001	.539	.255
Purchasing literature background	Pearson Correlation	.543 ^a	-.405 ^a	.005	.172	.172
	Sig. (2-tailed)	.000	.002	.971	.214	.214
Level of purchasing	Pearson Correlation		-.494 ^a	-.089	-.114	-.114
	Sig. (2-tailed)		.000	.524	.410	.410
Use of Methodology	Pearson Correlation			.270 ^b	-.040	-.040
	Sig. (2-tailed)			.048	.776	.776
Quality of Data	Pearson Correlation				.125	.125
	Sig. (2-tailed)				.366	.366

^a Correlation significant at the 0.01 level (2-tailed).

^b Correlation significant at the 0.05 level (2-tailed).

Table 9
Rotated component matrix.

	Component	
	1	2
Research Goal	.883	.148
Purchasing literature background	.859	.238
Operative Tactical Strategic	.781	-.193
Use of Methodology	-.702	.291
Quality of Data	-.170	.715
Sustainability	.140	.724

These results reinforce the previous findings that methodology-oriented papers and purchasing-oriented papers may be differentiated: Clusters 1, 3 and 5 represent methodological papers, while Clusters 2 and 4 represent purchasing-oriented papers.

6. Conclusions

This study was designed to review papers that used DEA for supplier evaluation that were published from 2009 to 2018 in high quality journals accessible from the Scopus database. Our analyses showed that DEA has attracted sustained attention, except for in 2018, when 11 papers were published, which is more than twice the average of previous years (4.8 papers per year).

This review extends the existing literature by providing an overview of work that has been done to develop models for supplier evaluation to support the selection or management of the supply base. The research question investigated how DEA is integrated into purchasing and supply management, and what the focus of the related papers is.

Results also confirmed our assumptions that methodology-oriented papers and purchasing and supply management literature are not well interconnected. Most of the papers were published in operations-research oriented journals, and many of them had no or only a few purchasing and supply management references to justify the relevance of the aim of the paper. On the other hand, many purchasing-oriented papers which cited relevant literature did not address complex methodological issues. Several literature reviews earlier indicated that in the purchasing and supply management literature methodological papers

Table 10
Clusters identified with quick cluster analysis.

Clusters	Papers
1. (4 papers)	20, 27, 28, 54
2. (3 papers)	19, 42, 51,
3. (8 papers)	2, 3, 4, 8, 21, 24, 30, 35
4. (16 papers)	6, 7, 11, 12, 15, 23, 25, 26, 37, 38, 39, 40, 41, 47, 49, 53
5. (23 papers)	1, 5, 9, 10, 13, 14, 16, 17, 18, 22, 29, 31, 32, 33, 34, 36, 44, 43, 45, 46, 48, 50, 52

Table 11
Final cluster centres.

	Cluster				
	1	2	3	4	5
Research Goal	2	3	1	3	1
Purchasing literature background	2	4	2	3	1
Operative Tactical Strategic	2	3	2	3	2
Use of Methodology	2	1	2	1	2
Quality of Data	3	4	4	1	1
Sustainability	3	2	1	1	1

predominate, which often suggests complex methodologies for dealing with the issue of supplier selection and evaluation. The results of this literature review came to similar conclusion concerning the application of DEA to supplier evaluation. However, it also indicated a more complex problem: methodological improvements are scarcely supported by the purchasing- and supply-related literature. Part of the problem is that the presence of management problems as described in the papers and the relevance of the solutions are not justified. The second problem is that as a consequence of the weak interrelations between the two fields, when new problems appear in purchasing and supply management they can lack methodological support. A positive result of the present study is that it has identified a number of articles that are already linked to strategic purchasing practices and relate to a more advanced level. Methodologically, these papers often do not use the most sophisticated tools, but they are forward-looking because of their approach. These articles are much more relevant to the current trends and literature of the purchasing profession, and they suggest opportunities for further application.

It is a common tendency that groups of researchers, not individuals, prepare articles. The inclusion of methodologies in purchasing and supply management is a challenge that fits this trend well: ideally, research teams in which methodological experts and purchasing researchers work together could address the issue. The massive development of information science gives us the opportunity to handle the related problems.

With regard to research questions about how sustainability fits into the focus of the papers, we observe that while a large proportion of papers do address this issue, most of them only consider environmental problems. This may be because purchasing organisations have more influence on these problems than social ones, or because the potential environmental influence of purchasing decisions can be more easily modelled than the social effects. This topic should be the focus of new research, similar to the question 'which challenges do environmental issues pose to methodological development?' (Due to the few applications among the investigated papers, only hints are made here.)

The literature review has shown that in recent years, a large number of articles have dealt with the use of DEA in supplier evaluation. However, only a small part of this articles presented a practical application, suggesting that the adoption of DEA is still low in the industry. It might be the aim of a further research to identify the causes of this low adoption rate.

This research has some limitations. Although two researchers were involved in the content analysis, the classifications of the papers at certain points remained subjective. Moreover, the multivariate statistical analyses relied on the six dimensions as measured on ordinal scales, which to some extent involves subjective judgement.

In conclusion, there are many opportunities for future investigation and methodological developments in a number of areas in relation to this research. We hope that these results will encourage scholars with a methodological and purchasing background, and even practitioners, to examine how to synthesize their knowledge.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Gyöngyi Vörösmarty: Conceptualization, Formal analysis, Investigation, Writing - original draft, Supervision. **Imre Dobos:** Conceptualization, Methodology, Formal analysis, Writing - review & editing.

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Appendix A. The investigated papers

List of abbreviations

ABS	Association of Business Schools
AHP	Analytic Hierarachy Process
ANP	Analytic Network Process
DEA	Data Envelopment Analysis
DEA-CCR model	DEA Charnes-Cooper-Rhodes model
DMU	Decision Making Unit
IoT	Internet of Things
KPI	Key Performance Indicator
PSM	Purchasing and Supply Management
R&D	Research and Development
SS	Supplier selection
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
VHB	Verband der Hochschullehrer für Betriebswirtschaft e.V

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