



A systematic review on supplier selection and order allocation problems

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Abstract

The supplier selection and order allocation are two key strategic decisions in purchasing problem. The review presented in this paper focuses on the supplier selection problems (SSP) and order allocation from year 2000 to 2017 in which a new structure and classification of the existing research streams and the different MCDM methods and mathematical models used for SSP will be presented. The review was examined in three aspects: the summaries of the existing evidence concerning the problems, the identification of gaps in the current research to help determine where further investigation might be needed and positioning new research activities.

Keywords Supplier selection · Single sourcing · Order allocation · Optimization · Multi-criteria decision making · Multiple sourcing

Introduction

The supplier selection problem (SSP) is a procurement decision-making problem that consists of the definition of methods and the models to analyze and measure the performance of a set of suppliers in order to improve customer's competitiveness. This decision is more complex because the diversity of quantitative and qualitative criteria assigns on evaluation and decision-making process. Various decision-making techniques have been proposed in the literature to remove this problem, particularly those of multi-criteria analysis which use both quantitative and qualitative data. Additionally, in the function supply, the decision of choosing the best suppliers consists in deciding whether we shall use single- or multiple-sourcing strategies during the acquisition of a given material resource. Also, the supplier selection and order allocations are two key strategic decisions in purchasing problem. Then, these decisions are more complex and

various techniques have been proposed in the literature to solve these problems.

Several taxonomies and review literature papers devoted to the supplier selection problem such as De Boer et al. (2001); Aissaoui et al. (2007); Ho et al. (2010); Chai et al. (2013); Wetzstein et al. (2016).

In recent year, the number of researcher's work is interesting in supplier selection with order allocation is increased, but a few of systematic reviews consider this issue. For these reasons, our intention is to present a rigorous review of scientific literature, by presenting a classification of these works for a large period (17 years) which was not taken into consideration in the other surveys.

This study proposes a new structure and classification of the existing research streams and the different methods used for SSP and order allocation as well as identifying gaps in the current research and delineating future research avenues with the aim of relating the existing quantitative methods to empirical research.

The main contribution of this paper is to provide a comprehensive literature review of supplier selection with order allocation during the last 17 years, which shows a significant increase in research work published in this field. In this study, we will apply the classification framework developed by Denyer and Tranfield (2009) in order to advance our understanding of the field of supplier selection and order allocation and to facilitate to the researchers to discover

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meaningful information concerning this subject. Also, this new classification seeks to identify any new trends in this field and highlight any gaps that would benefit from future research efforts, including MCDM methods and optimization models. Finally, this survey aims to enhance our ability to discover important knowledge in this large number of literature.

Given this evolving research field, this paper analyzes research in international scientific journals that focus on this field and build a relevant framework for classifying the most papers published since 2000 until to 2017. Consequently, we provided a bibliography of 270 published papers in order to answer the following questions: which journals are mostly touched on this problem? Which multi-criteria decision-making methods are frequently applied in the process of supplier selection? Which mathematical models are prevalently used to formulate the supplier selection and order allocation problem? Which techniques are frequently used to solve these models? What are the limitations of these methods and models?

In this paper, we present the most popular methods and models used in these problems. Firstly, we summarize the most characteristics about the supplier selection process and we tried to classify the different multi-criteria decision methods of collecting papers in two categories: single criterion and outranking synthesis approaches. Secondly, we present an extensive review and analysis of the decision models of a multiple-sourcing problem in the supplier selection. Moreover, a classification of mathematical models according to the objective function is a single-objective function or multiple-objective functions. Finally, we tried to analyze the hybrid methods used in supplier selection and order allocation problems.

The remainder of this paper is organized as follows: Section “[Research methodology](#)” presents the research methodology used in the topic of supplier selection and order allocation. Section “[Analyzing and reporting](#)” concerns about analyzing and reporting. Section “[Observations and remarks](#)” presents an observation and discussion about the most prevalently used methods and journals by years.

Research methodology

In this study, we describe the systematic review for classifying the published papers about 2000 until to 2017 in this topic. Systematic review is defined by Denyer and Tranfield (2009) as “a specific methodology that locates the existing studies, selects and evaluates contributions, analyses and synthesizes data, and reports the evidence in such a way that allows reasonably clear conclusions to be reached about what is and is not known.”

The introduction of the use of systematic evaluation processes in particular of systematic literature review will help to obtain an objective summary of research evidence concerning this topic by producing better-quality reviews and evaluations.

The systematic reviews review the primary data which can be either quantitative or qualitative and synthesize the findings of previous research investigating the same or similar questions.

The systematic reviews use a systematic approach to search, select and appraise the produced evidence, and they employ explicit rigorous and accountable methods to inform new research questions.

In this paper, we based on the five-step procedure proposed by Denyer and Tranfield (2009) describe the systematic review:

Step 1 Formulate the questions: we follow the CIMO logic proposed by Denyer et al. (2008) to formulate clear questions whose purpose is to establish the focus of the study and to frame the inclusion criteria. This logic of the CIMO is as follows: “in this class of problematic Contexts, use this Intervention type to invoke these generative Mechanism(s), to deliver these Outcome(s)” (Denyer et al. 2008).

Applying the ICMO logic, we formulate the design proposition to identify the four main elements:

If a buyer aims to take a decision concerning a supplier selection and order allocation problem which characterized by multiple criteria and multiple suppliers (C), it should use a multi-criteria decision-making method and the mathematical optimization (I) based on the opinion of one or group decision-makers in order to rank suppliers according to their importance and the definition of the different objectives and constraints to take the optimal decision of order allocation (M) in order to select the best suppliers and distribute the order quantity between them (O).

Step 2 Locating studies: This step aims to locate, select and appraise the relevant researches as much as possible.

Relevant papers were targeted using electronic academic databases including science direct, IEEE Xplore, Springer link Journals, Emerald, Taylor and Francis and so on. These papers are searched in the search databases using the following keywords: “vendor selection,” “supplier selection,” “supplier evaluation,” multi-criteria supplier selection “order allocation,” “order lot-sizing,” “optimization supplier selection” and covering major journals in the fields of “Management Science,” “Operations Research,” “Purchasing



Table 1 Distribution of articles in major journals in the period 2000–2017

Journal	Total	Percentage %
Expert Systems with Applications	64	23.70
International Journal of Production Economics	35	12.96
European Journal of Operational Research	26	9.62
Applied Mathematical Modelling	15	5.55
Computers and Industrial Engineering	15	5.55
International Journal of Production Research	12	4.44
Omega: The International Journal of Management Science	9	3.33
Others	94	34.81

Management” and “supply chain management and logistics” from 2000 to 2017 (up to September 2017).

Step 3 Study selection and evaluation: this step defines the inclusion and exclusion criteria to focus on relevant papers.

This survey was taken to identify papers that had been published in high-ranking journals in order to increase the validity of this systematic literature review.

To ensure the relevance of the papers, we consider only English papers. We read as first research 400 abstracts on this topic. We extended the master’s thesis, doctoral dissertation, textbooks and unpublished articles and non-English papers. We ended up with 300 papers in total.

An article is included in this survey if it is thoroughly based on pre-selection methods, MCDM methods, order allocation models and methods and hybrid methods of the supplier selection problem. As a result, 270 articles are reviewed attempting to be as exhaustive as possible. This scope makes to researchers the most valuable information and an extensive search concerning the supplier selection problem and order allocation. In addition, we excluded researches devoted to green supplier selection and sustainable supplier selection.

Step 4 Analysis and synthesis: in this step, we extract and store the important information about the studied problem from the collection of the most relevant papers.

We used the designed questions proposed in Step 1 to extract the relevant information. The results obtained in this step are the description and the classification of the papers.

Step 5 Reporting and using the results: in this last step, a systematic review should be structured in a similar manner to a report of empirical research which includes an introduction, methodology, findings and conclusion.

The first three steps have been well discussed in research methodology. Now, we focus on analysis and reporting in the following sections.

Analyzing and reporting

Table 1 presents the distribution of the papers based on the name of journal in which the 270 papers specific to the problem of supplier selection and order allocation. The lapse of time of these papers is between 2000 and 2017 for identifying the trends in the chronological progression of research on problem of supplier selection and order allocation.

Since 2000, the number of publications in the domain of the SSP and order allocation has grown increasingly. Figure 1 shows that the most number of published papers in this domain are in the period 2009–2013, especially in 2011 so that we find 40 published papers and the important method used is the TOPSIS which is a qualitative technique (see Fig. 1).

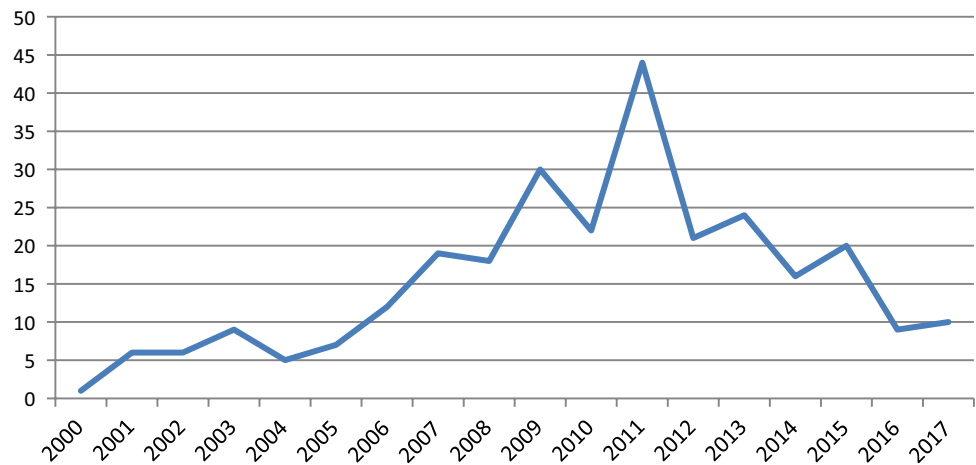
In addition, the most techniques used in this period for solving SSP are qualitative techniques such as TOPSIS and AHP. Overall, the multi-criteria nature of the supplier selection problem is the main reason that explain the usage of these MCDM approaches.

Problem context-based classification

In the function supply, the decision of choosing the best suppliers consists in deciding whether we shall use single- or multiple-sourcing strategies during the acquisition of a given material resource.

Supplier selection (single sourcing)

In this decision, one supplier can satisfy all the buyer’s needs and the buyer makes only one decision: which supplier is the best. Gary Dickson in 1966 is the first of the pioneers who became interested in the topic. He defined this problem as follows: «The vendor selection problem is associated with

Fig. 1 Distribution of papers by year

deciding how one vendor should be selected from a number of potential alternatives.» (Dickson 1966).

In this problem, the purchasing department makes the decision about whether one or more suppliers are selected from a number of alternatives and for the completion of an activity or the provision of a product. In the case where several activities are carried out, we talk about the problem of the supplier selection if the activities are treated independently (no synchronization between activities, no precedence constraints).

Order allocation problem (multiple sourcing)

In purchasing problem, we talk about “order allocation problem” where the activities are subject to precedence constraints.

In multiple sourcing, as no supplier can satisfy all the buyer’s requirements, more than one will be selected. In this situation, the buyer purchases the same items from more than one supplier, and the total demand is split among them. The order quantity is split among suppliers for a variety of reasons such as cost, quality and capacity. This decision consists in combining the supplier selection with the order allocation problem. In this decision, more questions arise: What order quantity should be allocated to each supplier? Which order should be assigned to each supplier? And which period, in the planning horizon, should be used?.

Methodology-based classification

Pre-selection of potential suppliers’ methods

The aim of this phase is to reduce the number of suppliers for the final selection using the multi-criteria decision-making method. Therefore, the purpose of this phase is to rule out the inefficient candidates and reduce the set of all the

Table 2 Classification of pre-selection methods

No.	Criteria	Number of articles	Percentage %
1	Categorical	1	3.84
2	Linear weighted average method	2	7.69
3	DEA	13	52
4	Cluster analysis	03	11.53
5	CBR	06	23.07
Total		25	

suppliers to a small range of acceptable ones. It is a simple step in evaluating suppliers and developing a list of potential key suppliers based on a set of factors, such as experience, financial ability, managerial ability, reputation and work history. In the following paragraphs, we will discuss the supplier pre-qualification approaches, and Table 2 summarizes the using of these methods:

Categorical methods The main papers using the categorical method in the supplier selection problem are those of Khaled et al. (2011).

Linear weighted average method Amid et al. (2006) solved a fuzzy multi-objective linear model supplier selection problem in a supply chain by applying an asymmetric fuzzy-decision-making technique. Ng (2008) constructed a weighted linear program for the multi-criteria supplier selection problem by using a transformation technique that could solve the problem without applying an optimizer.

Data envelopment analysis (DEA) Liu et al. (2000) proposed a simplified DEA model to evaluate the supplier’s performance as the basis of 3 inputs, price index, delivery performance and distance factor, and 2 output criteria which are the supply, variety and quality. Narasimhan et al. (2001) proposed factors to apply the DEA to evaluate the suppliers of a multi-national corporation in the telecommunication



industry. Talluri and Baker (2002) used the DEA method with two input and four output factors to evaluate the potential stakeholders (suppliers, manufacturers, retailers and distributors). Talluri and Narasimhan (2004) proposed the DEA for an effective supplier sourcing based on the cross-efficiencies and statistical methods in clustering the supply base. Garfamy (2006) applied the DEA by focusing on the total cost of ownership (TCO) to measure the overall performances of suppliers. Saen (2006) developed an innovative method based on the DEA model to evaluate the technology suppliers on mainly three factors, in which there is a qualitative factor—amount of know-how transfer. In the research of Seydel (2006), the DEA is used to solve the supplier selection problem. Talluri et al. (2006) proposed a chance-constrained DEA approach to evaluate the performance of the suppliers taking into consideration the stochastic performance measures. Wu et al. (2007) proposed an augmented imprecise DEA approach for the selection of the suppliers. Wu and Blackhurst (2009) proposed a methodology called the augmented DEA to evaluate and select the best supplier. This method enhanced the discriminatory power over the basic DEA models to rank the suppliers. Songhori et al. (2011) proposed a structured framework to solve the supplier's selection with order allocation problem for their firm using DEA. Falagario et al. (2012) proposed a tender evaluation method based on the DEA method and related concept of cross-efficiency. Karsak and Dursun (2014) proposed a new fuzzy multi-criteria group decision-making method for supplier selection combined quality function deployment (QFD) and data envelopment analysis (DEA).

Cluster analysis Hong et al. (2005) applied a clustering method to find out the best suppliers on the basis of: preparation, pre-qualification and final selection, so, they could maximize the revenue while satisfying the customer's needs. Bottani and Rizzi (2008) presented a hybrid method using the cluster analysis and the AHP. Ha and Krishnan (2008) introduced a hybrid method which incorporates multiple techniques into the supplier's evaluation process in order to select the most competitive one(s) in the supply chains.

Case-based reasoning method (CBR) Choy and Lee (2002) proposed a generic model of CBR integrating customer relationship management (CRM) and a supply chain management (SCM). The model was applied to a consumer product manufacturing company, which maintained a database of past suppliers and their attributes. Like in the work of Choy and Lee (2002, 2003) and Choy et al. (2002), Choy et al. (2003) applied the CBR-based methodology for the supplier selection problem. Humphreys et al. (2007) integrated both the case base reasoning and the decision support components including multi-attribute analysis which presents a framework to measure the supplier's environmental performance.

Table 3 Classification of MCDM methods

Abbreviations	Number of articles	Local percentage %	Global percentage %
<i>Single-criterion synthesis approach</i>			
Number total of papers = 122			
AHP	47	38.52	17.40
ANP	21	17.21	7.78
MAUT	2	1.63	0.74
SMART	4	3.27	1.48
TOPSIS	26	21.31	9.62
VIKOR	7	5.73	2.59
SIR	1	0.81	0.37
BWM	2	1.63	0.74
<i>Outranking synthesis approach</i>			
ELECTRE	6	4.91	2.22
PROMETHEE	6	4.91	2.22

Multi-criteria decision-making methods

This phase consists in determining the method for the final selection of suppliers and the allocation of final-order quantities among them. In this step, several methods have been used in the literature to evaluate and select the suppliers and many researches classified these methods in various categories. De Boer et al. (2001) positioned the qualitative methods in step formulation of the problem and criteria but the quantitative methods are involved in the final stages of the qualification and selection of the suppliers. Ho et al. (2010) classified the techniques of the supplier's selection into individual and integrated approaches. Then, Chai et al. (2013) selected and reviewed 123 journal articles, between 2008 and 2012, which were used in the supplier' evaluation and selection. They classified 26 techniques into three categories, namely Multi-criteria decision-making (MCDM) techniques, mathematical programming (MP) techniques and artificial intelligence (AI) techniques.

In this study, we classify the MCDM approaches used to solve the supplier selection problem into two categories such as (1) single-criterion synthesis approach and (2) outranking synthesis approach (see Table 3).

Single-criterion synthesis approach The key multi-criteria decision-making methods within this approach include: MAUT, SMART, UTA, TOPSIS, AHP and GP.

Analytic Hierarchic Process (AHP) Akarte et al. (2001) developed a web-based AHP system to evaluate the casting suppliers on 18 criteria, six objectives and twelve subjective and divided them into four groups. Tam and Tummala (2001) applied the AHP approach to a real case study to examine its feasibility in selecting a vendor for a telecommunication system. Muralidharan et al. (2002) proposed a



five-step AHP-based model which incorporated nine criteria to select the suppliers. Chan (2003) developed an interactive selection model using the AHP method to facilitate the selection of suppliers. Liu and Hai (2005) used Noguchi's voting and ranking method to solve the supplier selection based on the AHP method. Hou and Su (2007) proposed an AHP-based decision support system to identify the appropriate suppliers of components in a mass customization environment. Chan and Chan (2010) used an AHP method to solve the supplier selection problem in the apparel industry. Peng (2012) used the AHP method to evaluate and select logistics outsourcing service suppliers and applied an actual case. Chen and Wu (2013) proposed a modified failure mode and effect analysis (MFMEA) method to select new suppliers from the supply chain of risk perspective. Deng et al. (2014) proposed a D-AHP method for the supplier selection problem, which extends the classical analytic hierarchy process (AHP) method, based D numbers, that is a new, effective and feasible representation of uncertain information. Dweiri et al. (2016) proposed a decision support model for supplier selection based on analytic hierarchy process (AHP) using a case of automotive industry in a developing country of Pakistan.

The many papers integrated AHP with other approaches to evaluate the performance of suppliers and select the best supplier are those of: Chen and Huang (2007), Saen (2007b), Sevklı et al. (2007), Ha and Krishnan (2008), Çebi and Bayraktar (2003), Wang et al. (2004, 2005), Yang and Chen (2006), Xia and Wu (2007), Lin et al. (2011), Rezaei and Davoodi (2012), Kar (2015) and Segura and Maroto (2017).

The proposed approaches integrated with fuzzy set in AHP method are: Kahraman et al. (2003), Chan and Kumar (2007), Bottani and Rizzi (2008), Yang et al. (2008), Chan et al. (2008), Lee (2009), Chamodrakas et al. (2010), Sen et al. (2010), Zeydan et al. (2011), Yucenur et al. (2011), Chen and Chao (2012), Shaw et al. (2012), Yu et al. (2012), Rezaei and Ortt (2013), Junior et al. (2014), Rezaei et al. (2014), Ayhan and Kilic (2015), Lee et al. (2015), Beikkhakhian et al. (2015), Bruno et al. (2016), Tavana et al. (2016), Büyükközkcan and Göçer (2016, 2017).

Analytic Network process (ANP) Sarkis and Talluri (2002) applied the ANP method to help decision makers select the best supplier by taking into account the organizational factors and strategic performance metrics, which consist of seven evaluating criteria. Bayazit (2006) proposed an ANP method to select the right supplier by identifying ten evaluating criteria that were categorized into supplier's performance and capability clusters. Gencer and Gürpınar (2007) implemented an ANP model for an electronic company to evaluate and select the most appropriate supplier as the basis of various evaluating criteria. Lin et al. (2010) proposed a hybrid MCDM technique to cope with the complex and interactive supplier selection problem in determining the

structural relationships and the interrelationships among all the evaluation dimensions. Wan et al. (2017) used ANP and ELECTRE II in interval 2-tuple linguistic environment for solving supplier selection problems with two-level criteria. The authors developed a 2-tuple linguistic ANP (TL-ANP) approach to derive criteria and sub-criteria weights.

The papers using the fuzzy ANP are those of: Lin (2009), Amin and Razmi (2009), Razmi et al. (2009a), Onüt et al. (2009), Yucenur et al. (2011), Xiao et al. (2012) and Lin (2012). The researches combined ANP with other methods such as Demirtas and Üstün (2008, 2009), Ustun and Demirtas (2008), Tseng et al. (2009), Razmi and Rafiei (2010), Lin et al. (2011), Aouadni et al. (2013) and Ghadikolaei and Parkouhi (2017).

Multiple-attribute utility theory (MAUT) There is one research that used this method in SSP, Sanayei et al. (2008) which presented an effective model using both MAUT and LP to solve the supplier selection problem. Segura and Maroto (2017) applied a multiple-criteria supplier segmentation approach based on PROMETHEE and multi-attribute utility theory (MAUT)

Simple Multi-Attribute Rating Technique (SMART) Barla (2003) conducted a five-step approach based on the SMART for the supplier evaluation and selection in a glass manufacturing company. Huang and Keska (2007) presented a comprehensive set of 101 metrics collected from the literature for the supplier selection. Other papers integrated the SMART with other approaches, for example, Seydel (2005) and Chou and Chang (2008).

Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) Shyur and Shih (2006) present an effective model using both ANP and modified TOPSIS, to accommodate the criteria with interdependencies in supplier selection problem. Junior et al. (2014) presented a comparing study between the fuzzy AHP and the fuzzy TOPSIS methods to solve the problem of supplier selection. Wood (2016) applied fuzzy and intuitionistic fuzzy TOPSIS with flexible entropy weighting to evaluate and select supplier considering criteria relevant to an oil and gas facilities development project. Aouadni et al. (2017) developed the cardinal data TOPSIS method (TOPSIS-CD method) and the meaningful mixed data TOPSIS method (TOPSIS-MMD method) which suggest novel reference points and extend the TOPSIS method to mixed data. These two extended methods applied to a multi-attribute supplier selection problem. Aouadni et al. (2017) developed the cardinal data TOPSIS method (TOPSIS-CD method) and the meaningful mixed data TOPSIS method (TOPSIS-MMD method) which suggest novel reference points and extend the TOPSIS method to mixed data.

The different papers that used the hybrid fuzzy TOPSIS method for the supplier selection problem are those of: Chen et al. (2005, 2006), Boran et al. (2009), Onüt et al. (2009),



Razmi et al. (2009b), Guneri et al. (2009), Awasthi et al. (2010), Dalalah et al. (2011), Zeydan et al. (2011), Kara (2011), Deng and Chan (2011), Chen (2011a, b), Jolai et al. (2011), Yucel and Guneri (2011), Liao and Kao (2011), Lin et al. (2011), Govindan et al. (2013), Kilic (2013), Junior et al. (2014), Roshandel et al. (2013), Lee et al. (2015), Igoualene et al. (2015) and Wood (2016).

VIKOR method Combined with fuzzy set Chen and Wang (2009) and Sanayei et al. (2010) used the fuzzy VIKOR method to evaluate the best supplier. Shemshadi et al. (2011) extended the VIKOR method with a mechanism to extract and deploy objective weights based on Shannon's entropy concept for solving supplier selection. Hsu et al. (2012) select the best vendor for conducting the recycled material based on a hybrid MCDM model combining DEMATEL-based on ANP (called DANP) with VIKOR method. You et al. (2015) proposed an extended VIKOR method for group multi-criteria supplier selection with interval 2-tuple linguistic information. Wu et al. (2016) used extended VIKOR under linguistic information for solving supplier selection in nuclear power industry. Ghadikolaei and Parkouhi (2017) used fuzzy analytic network process and grey VIKOR techniques to solve supplier selection problem.

SIR method Chai et al. (2012) proposed a novel intuitionistic fuzzy SIR method to solve the uncertainty group multi-criterion decision-making problem and applied their method in the supplier selection problem.

Best–worst method (BWM) Rezaei et al. (2015a, b) proposed an integrative approach that includes capabilities and willingness as two dimensions for evaluating and subsequently segmenting suppliers. The results of that segmentation are then used as the main basis for supplier development. Rezaei et al. (2016) used the best–worst method to solve supplier selection life cycle approach integrating traditional and environmental criteria.

Outranking synthesis approach In the literature of evaluating and selecting the best supplier, the outranking methods are: ELECTRE and PROMETHEE.

ELimination and Choice Expressing Reality (ELECTRE) Almeida (2007) applied the ELECTRE method to solve an outsourcing contract problem, when dealing with outsourcing vendor selection. Liu and Zhang (2011) proposed a novel method to deal with the supplier selection of supply chains that combines entropy weight and an improved ELECTRE-III method. As an example, we mention: Montazer et al. (2009) and Sevkli (2010). Wan et al. (2017) presented an interval 2-tuple ELECTRE II (IT-ELECTRE II) approach to deal with the case of criteria being not compensated in supplier selection problem. Zhong and Yao (2017) proposed an ELECTRE I-based multi-criteria group decision-making method with interval type-2 fuzzy numbers applied to solve supplier selection problem.

Preference Ranking Organisation METHod for Enrichment Evaluations (PROMETHEE) Dulmin and Mininno (2003) used PROMETHEE 1, 2 to solve the supplier selection problem. This approach would be able to deal with several conflicting performance criteria. Araz and Ozkarahan (2007) developed a new multi-criteria sorting method based on PROMETHEE for the supplier evaluation problem. Chen et al. (2011b) used group fuzzy PROMETHEE to solve the real case of the supplier selection problem. After that, PROMETHEE was utilized for ranking the alternatives. Chai et al. (2012) proposed an extended PROMETHEE approach based on superiority and inferiority method. Krishankumar et al. (2017) proposed a new extension to PROMETHEE outranking method under intuitionistic fuzzy set environment for solving supplier selection problem with linguistic preferences.

Segura and Maroto (2017) used PROMETHEE method to develop portfolios with suppliers that should be partners of the company, as well as to identify other types of relationships, such as long-term contracts, market policies or to highlight those to be removed from their portfolio.

Order allocation methods

In the order allocation problem, the decision maker needs to make more than one decision: What product to order? What quantity to order and from which supplier(s)? In which periods?. Different from single sourcing, in the case of supplier's unreliability or supplier's default, multiple sourcing allows a buyer to order from others suppliers the defect quantity without the need for searching and negotiating with a new supplier.

However, this process involves higher costs than those of single sourcing, owing to the need for managing more than one contract/supplier and the loss of scale economies. In the multiple-sourcing strategies, there are other models of supplier selection where the decision maker has to choose: What to buy and When. As a result, in the multiple-sourcing strategies, two other types can be made to classify the different models. The first type concerns the number of different purchased items, and the second concerns the scheduling horizon (see Table 4, 5 and 6).

Single- and multiple-item models The decision “what to buy” is among the most important decisions in the purchasing operation. In this case, the decision maker has to determine the number of items purchased. In this section, we particularly distinguish two important features: single or multiple products ordered and the presence of any form of quantity discount offered by the vendors.

Single- and multiple-period models The third important decision of the supplier selection problem is “in which peri-

Table 4 Review of single- and multiple-item models in SSP

	Review
Single-item model	Ghodsypour and O'Brien (2001), Talluri and Narasimhan (2003), Kumar et al. (2004, 2006), Liu et al. (2006), Faez et al. (2009), Xia and Wu (2007), Liao and Rittscher (2007a), Demirtas and Üstün (2008), Yu and Tsai (2008), Glickman and White (2008), Ozgen et al. (2008), Ustun and Demirtas (2008), Burke et al. (2008), Sanayei et al. (2008), Kheljani et al. (2009), Guneri et al. (2009), Sawik (2010), Sanayei et al. (2010), Wang and Yang (2009), Lin (2009), Ebrahim et al. (2009), Kokangul and Susuz (2009), Demirtas and Üstün (2009), Amid et al. (2009), Wu et al. (2010), Mendoza and Ventura (2010), Yücel and Guneri (2011), Lin et al. (2011), Amid et al. (2011), Mafakheri et al. (2011), Hajji et al. (2011), Meena et al. (2011), Xu and Ding (2011), Lin (2012), Shaw et al. (2012), Mendoza and Ventura (2012), Glock (2012), Arikani (2013), Choudhary and Shankar (2013), Ruiz-Torres et al. (2013), Hammami et al. (2014), Lee et al. (2013), Sawik (2013), Ekici (2013), Mohammaditabar et al. (2015), Mazdeh et al. (2015)
Multiple-item model	Crama et al. (2004), Basnet and Leung (2005), Kawtummachai and Van Hop (2005), Narasimhan et al. (2006), Wang and Che (2007), Wadhwa and Ravindran (2007), Rezaei and Davoodi (2008), Bottani and Rizzi (2008), Wang (2008), Che and Wang (2008), Shen and Yu (2009), Lee et al. (2009), Onüt et al. (2009), Amin and Razmi (2009), Yücel et al. (2009), Osman and Demirli (2010), Chang and Lee (2010), Amin et al. (2011), Ozkok and Tiryaki (2011), Li and Zabinsky (2011), Kara (2011), Rezaei and Davoodi (2011), Yang et al. (2011), Jolai et al. (2011), Woo and Saghiri (2011), Bichler et al. (2011), Shi et al. (2011), Xu and Yan (2011), Mansini et al. (2012), Senyigit and Soylemez (2012), Manerba and Mansini (2012), Yu et al. (2012), Esmaeili et al. (2013), Esfandiari and Seifbarghy (2013), Sawik (2013), Gorji et al. (2014), Scott et al. (2015), Cárdenas-Barrón et al. (2015), Ayhan and Kilic (2015), Yu and Wong (2015) and Turk et al. (2017)

ods?" when the buyer decides to define the planning horizon of procurement. Thereby, we have concluded that the techniques developed in the multiple-sourcing strategies can be classified in two models. The single-period models do not consider the inventory management over time, and the multiple-period models consider inventory management by determining an order allocation.

Besides, the suppliers sometimes offer discounts, so that price reductions are designed to induce large orders. Quantity discounts have received significant attention in

Table 5 Review of single- and multiple-period models in SSP

	Review
Single-period model	Ghodsypour and O'Brien (2001), Talluri and Narasimhan (2003), Kumar et al. (2004), Crama et al. (2004), Kawtummachai and Van Hop (2005), Kumar et al. (2006), Faez et al. (2009), Narasimhan et al. (2006), Liao and Rittscher (2007a), Xia and Wu (2007), Wadhwa and Ravindran (2007), Wang and Che (2007), Sanayei et al. (2008), Burke et al. (2008), Ozgen et al. (2008), Glickman and White (2008), Yu and Tsai (2008), Demirtas and Üstün (2008), Wang (2008), Bottani and Rizzi (2008), Che and Wang (2008), Shen and Yu (2009), Onüt et al. (2009), Amin and Razmi (2009), Kheljani et al. (2009), Sawik (2010), Guneri et al. (2009), Wang and Yang (2009), Lin (2009), Ebrahim et al. (2009), Kokangul et al. (2009), Amid et al. (2009), Yücel et al. (2009), Wu et al. (2010), Mendoza and Ventura (2010), Chang and Lee (2010), Amin et al. (2011), Yücel and Guneri (2011), Lin et al. (2011), Amid et al. (2011), Ozkok and Tiryaki (2011), Li and Zabinsky (2011), Yang et al. (2011), Hajji et al. (2011), Woo and Saghiri (2011), Bichler et al. (2011), Meena et al. (2011), Shi et al. (2011), Xu and Yan (2011), Xu and Ding (2011), Lin (2012), Shaw et al. (2012), Mendoza and Ventura (2012), Mansini et al. (2012), Senyigit and Soylemez (2012), Glock (2012), Manerba and Mansini (2012), Yu et al. (2012), Arikani (2013), Ruiz-Torres et al. (2013), Hammami et al. (2014), Esmaeili et al. (2013), Ekici (2013), Esfandiari and Seifbarghy (2013), Sawik (2013) and Mohammaditabar et al. (2015)
Multiple-period model	Ghodsypour and O'Brien (2001), Basnet and Leung (2005), Liu et al. (2006), Liao and Rittscher (2007a, b), Rezaei and Davoodi (2008), Ustun and Demirtas (2008), Demirtas and Üstün (2009), Osman and Demirli (2010), Mafakheri et al. (2011), Kara (2011), Rezaei and Davoodi (2011), Jolai et al. (2011), Choudhary and Shankar (2013), Lee et al. (2013), Sawik (2013), Gorji et al. (2014), Mazdeh et al. (2015), Cárdenas-Barrón et al. (2015), Soto et al. (2017), Ghaniabadi and Mazinani (2017) and Turk et al. (2017)

the literature of the supplier selection problem for decades. As a result, the decision of suppliers' selection will be more complicated in the presence of discount schemes. The models developed in the literature which take into account the discounts quantity are as follows: Chauhan and Proth (2003), Crama et al. (2004), Goossens et al. (2007), Burke et al. (2008), Kokangul and Susuz (2009), Zhang (2010), Kang and Lee (2010), Mansini et al. (2012), Lee



Table 6 Classification of order allocation models

Models types	Number of articles	Percentage local %	Percentage global %
Number total of papers	175		
Single-item models	47	26.85	17.40
Multiple-item models	41	23.42	15.18
Single-period model	66	37.71	24.44
Multiple-period models	21	12	7.78

et al. (2013), Choudhary and Shankar (2013, 2014), Mazdeh et al. (2015), Ayhan and Kilic (2015), etc.

Single-objective optimization models By considering the literature of published works for multiple-sourcing supplier selection, we can distinguish two groups of techniques used to model the supplier selection problem (SSP) such as (1) single-objective optimization and (2) multi-objective optimization. In the single-objective models, only one criterion is considered as the objective function, while the other criteria, such as quality and lead-time, are modeled as constraints. These models can be divided into the following categories: linear programming, linear/nonlinear mixed programming, etc.

Linear programming (LP) Talluri and Narasimhan (2003) are the first researchers who considered the performance variability measures in evaluating different suppliers by developing two linear programming models to maximize and minimize the performance of a supplier against the best target measures set by the buyer. Ng (2008) developed a weighted linear programming model to help decision makers or buyers to solve the supplier selection problem, with an objective of maximizing the supplier's score. Che and Wang (2008) used a linear programming to model the supplier's selection and order quantity allocation problems to find the fundamental purchasing configuration that will best minimize the T-score total utility function of total products.

Integer programming (IP) Talluri (2002) developed a binary integer linear programming model to evaluate the alternative supplier bids based on ideal targets of bid attributes set by the buyer and to select an optimal set of bids by matching the demand and capacity constraints. Hong et al. (2005) proposed a model based on mixed integer linear programming (MILP) for the supplier selection problem. The main objective of this model is to determine the optimal number of suppliers and the order quantity. Basnet and Leung (2005) presented a mixed linear programming model that combines the supplier selection with the traditional inventory lot sizing. Liu et al. (2006) developed an integer programming to solve the distributed planning problem. Glickman and White (2008) developed a mixed integer

linear programming (MILP) model to find out a solution for the supplier selection problem when multiple products are transported via truckload and less than truckload shipment to a number of distributed centers. Rezaei and Davoodi (2008) proposed a mixed integer programming model in which they introduced imperfect items and storage capacity in the lot sizing with the supplier selection problem. Keskin et al. (2010) considered the inventory-related costs and decisions of the stores. Mansini et al. (2012) developed an integer programming-based heuristics to solve the supplier selection problem with quantity discounts and truckload shipping. Choudhary and Shankar (2013) proposed an integer linear programming model to determine the timings of procurement, lot sizes, suppliers and carriers to be chosen so as to incur the least total cost over the planning horizon. Palak et al. (2014) proposed a mixed linear programming in order to minimize the total supply chain costs. Cárdenas-Barrón et al. (2015) proposed a novel approach to find a solution of the multi-product multi-period inventory lot sizing with supplier selection problem. Ayhan and Kilic (2015) provided a two-stage approach integrating both the F-AHP technique and the MILP model to solve the supplier selection problem in multi-item/multi-supplier environment with all-unit quantity discount allowed. Adeinat and Ventura (2015) developed a mixed integer nonlinear programming to search the replenishment policy and optimal selling price in a supply chain for a particular type of product defined by a single retailer and multiple potential suppliers. Ghaniabadi and Mazinani (2017) developed a mixed integer linear programming to solve the dynamic lot-sizing problem with supplier selection, backlogging and quantity discounts.

Nonlinear programming (NLP) Ghodsypour and O'Brien (2001) formulated a mixed integer nonlinear programming (MINLP) model to solve the supplier selection problem. Crama et al. (2004) described the purchasing decisions faced by a multi-plant company. They formulated a nonlinear mixed binary programming to solve cost-minimization problem. Kheljani et al. (2009) proposed a number of mixed integer nonlinear programming models to model the supplier selection problem. Keskin et al. (2010) proposed a MINLP model for the supplier selection with inventory problem of a multi-store firm. Esmaeili et al. (2013) investigated a nonlinear binary programming to integrate a multi-item supplier selection model. Ekici (2013) applied a mixed integer nonlinear programming model for the supplier selection under capacity constraint and multiple criteria. Mohammaditabar et al. (2015) analyzed the selected suppliers and prices that are agreed on in decentralized supply chains. Mazdeh et al. (2015) developed a mixed integer nonlinear programming (MINLP) model for the dynamic lot-sizing problem with supplier selection and quantity discounts. Pazhani et al. (2016) proposed a mixed integer nonlinear programming model to determine the optimal inventory policy for the

stages in the supply chain and allocation of orders among the suppliers considering inventory replenishment, holding and transportation costs simultaneously. Ahmad and Mondal (2016) developed a mathematical model based on mixed integer nonlinear programming (MINLP) to solve dynamic supplier selection problem (DSSP). Soto et al. (2017) addressed the multi-period inventory lot-sizing problem with supplier selection and inventory shortage, and it considers both all-units and incremental quantity discounts.

Dynamic programming (DP) Li et al. (2009) considered a supply contracting problem in which the buying firm faces non-stationary stochastic price and demand. Tsai et al. (2010) proposed an approach to model the supplier selection problem in a dynamic environment. Hajji et al. (2011) developed a dynamic stochastic optimization model for the joint supplier selection, replenishment and manufacturing control problem. Ventura et al. (2013) developed a mixed integer nonlinear programming model to determine an optimal inventory policy that coordinates the transfer of materials between consecutive stages of the supply chain from period to period while properly placing the purchasing orders to the selected suppliers and satisfying customer demand on time. Choi (2013) proposed a two-phase optimal supplier selection scheme in which the first phase filters the inferior suppliers and the second phase helps to select the best supplier among the set of non-inferior suppliers by multistage stochastic dynamic programming. Mazdeh et al. (2015) developed single-item dynamic lot-sizing problem with supplier selection and quantity discounts. Ahmad and Mondal (2016) solved a dynamic supplier selection problem (DSSP) under two-echelon supply network with assembly of the part-product. Ghaniabadi and Mazinani (2017) studied the dynamic lot-sizing problem with supplier selection, backlogging and quantity discounts.

Stochastic programming (SP) Xu and Nozick (2009) formulated a two-stage stochastic program and a solution procedure to optimize the supplier selection to hedge against disruptions. Awasthi et al. (2009) considered a supplier selection problem for a single manufacturer/retailer when a demand is random. Zhang and Zhang (2011) developed a mixed integer programming model to model the supplier selection and purchasing problem with fixed selection cost and limitation on minimum and maximum order sizes under stochastic demand. Kara (2011) proposed an integrated methodology for the supplier selection problem based on two-stage stochastic programming model and fuzzy TOPSIS methods in this methodology. Li and Zabinsky (2011) developed a scenario-based two-stage stochastic programming (SP) model and a chance-constrained model for the supplier selection which considered the case of multiple plants with multiple products. Yang et al. (2011) proposed a stochastic demand of multi-product supplier selection model with service level and budget constraints using

genetic algorithm. Ruiz-Torres et al. (2013) considered the supplier's order allocation problem in the context of a classic transportation network with multiple supply sources and a set of separate demand points, where each supplier not only has limited capacity, but also a probability of failure to supply the required quantity. Sawik (2013) proposed a portfolio approach and developed a mixed integer programming model with conditional value-at-risk for the selection and protection of suppliers and the order allocation quantity and emergency inventory in the supply chains with disruption risks. Guo and Li (2014) studied the supplier selection and order allocation problem in a multi-echelon system under a stochastic demand. Hammami et al. (2014) proposed a mixed integer stochastic programming model for the supplier selection in the global context. Sawik (2014) formulated a stochastic mixed integer programming approach to the integrated supplier selection and customer order scheduling in the presence of supply chain disruption risks, for a single- or dual-sourcing strategy. Scott et al. (2015) proposed a hybrid method based on AHP, QFD and stochastic optimization for selecting the appropriate suppliers and allocating order between them. Torabi et al. (2015) proposed a two-stage stochastic programming model for solving supplier selection and order allocation problem to build the resilient supply base under operational and disruption risks.

Fuzzy linear programming Guneri et al. (2009) presented an integrated fuzzy and linear programming approach to the supplier selection problem in the supply chain. Hsu et al. (2010) proposed an approach for the selection of suppliers which is capable of handling fuzzy data but was not seriously treated by the researchers. Amin et al. (2011) proposed a decisional method to select the suppliers based on two phases. In the first phase, they applied a quantified SWOT analysis (strengths, weaknesses, opportunities and threats) to evaluate the suppliers. In the second phase, they developed a fuzzy linear programming model to determine the order quantity. Chen et al. (2011a) developed an approach to tackle multiple-criteria group decision-making problems in the context of interval-valued intuitionistic fuzzy sets.

Multi-objective optimization models In this section, we are interested in the multi-objective optimization that is an area of multiple-criteria decision making combined with the mathematical optimization involving more than one objective function to be simultaneously optimized. For the supplier selection problem, we classify the multi-objective optimization models in the following categories:

Multiple-objective linear programming (MOLP) Narasimhan et al. (2006) constructed a multi-objective programming model to select the optimal suppliers and determine the optimal order quantity. Sodenkamp et al. (2016) integrated multi-criteria decision method and linear programming for

developing to support collaborative multi-objective supplier selection and order allocation decisions.

Multiple-objective mixed integer programming (MIP) Xia and Wu (2007) incorporated into the supplier selection the multi-objective mixed integer programming model with the AHP. Sawik (2010) established single- and multi-objective mixed integer programming models, where the selection of suppliers is based on price and quality of the purchased parts and reliability of on time delivery. Feng et al. (2011) introduced a multiple-objective 0–1 programming model for the supplier selection problem. Rezaei et al. (2015a, b) proposed a mixed multi-objective programming to solve lot sizing with supplier selection for an assembly system.

Multiple-objective nonlinear programming (NLP) Cakravastia and Takahashi (2004) developed a multi-objective nonlinear model for the negotiation process by generating a set of effective alternatives in each negotiation period. Furthermore, Rezaei and Davoodi (2011) developed two multi-objective mixed integer nonlinear models for multi-period lot-sizing problems involving multiple products and multiple suppliers. Esfandiari and Seifbarghy (2013) modeled the supplier quota allocation problem as a multi-objective nonlinear optimization problem, while the demand was dependent on the offered price by the suppliers.

Dynamic multiple-objective programming Liao and Rittscher (2007a) developed a multi-objective programming model, integrating supplier selection, procurement lot sizing and carrier selection decisions for a single purchasing item over multiple planning periods while the demand quantities are known but inconstant, i.e., dynamic demand conditions. Ware et al. (2014) developed a multi-objective mixed integer nonlinear program (MINLP) to address the dynamic supplier selection problem (DSSP):

Stochastic multiple-objective programming For the stochastic multiple-objective programming, Liao and Rittscher (2007b) formulated a multi-objective programming model for the supplier selection under stochastic demand conditions. Ravindran et al. (2010) developed a multi-objective optimization model for the supplier selection problem which accounted for value-at-risk type of disruption due to natural events and miss-to-target type of risk of quality. Xu and Ding (2011) used a chance-constrained MOLP model with bi-random coefficients to model the supplier selection problem. Senyigit and Soylemez (2012) considered the lot sizing with the supplier selection problem in multi-echelon multi-product defective supply chain network with stochastic demand.

Fuzzy multiple-objective programming Amid et al. (2006) presented a fuzzy multi-objective linear programming model for supplier selection when the input data are vagueness and imprecision. Kumar et al. (2006) proposed a fuzzy programming model for the vendor selection problem in a supply chain as a “fuzzy multi-objective integer programming

vendor selection problem” formulation. Recently, Wu et al. (2010) have presented a fuzzy multi-objective programming model to decide on the supplier selection taking risk factors into consideration. Ozkok and Tiryaki (2011) proposed a compensatory fuzzy approach to solve the multi-objective linear supplier selection problem with multiple-item (MLSSP-MI) by using Werners’ “fuzzy AND” operator. Haleh and Hamidi (2011) developed a fuzzy linear programming model to optimize a fuzzy MCDM model to allocate orders to the suppliers in a supply chain under uncertainty over a multi-period time horizon. Yucel and Guneri (2011) developed a weighted additive fuzzy programming approach for multi-criteria supplier selection. Arikan (2013) studied the multiple-sourcing supplier selection problems as a fuzzy multi-objective linear programming problem. Dursun and Karsak (2013) considered the QFD planning, which incorporates two interrelated HOQ matrices, as a fuzzy multi-criteria group decision tool and employed the fuzzy weighted average (FWA) method. Similarly, Lin (2012), Yu et al. (2012), Shaw et al. (2012), as well as Amin and Zhang (2012), Moghaddam (2015) used the multi-objective fuzzy linear programming to solve the supplier selection problem. The fuzzy multiple-objective mixed integer linear programming is developed by Razmi et al. (2009a), Wang and Yang (2009), Amid et al. (2009) and Nazari-Shirkouhi et al. (2013).

Bi-objective optimization Sawik (2011a, b, c) considered the risk-neutral and risk-adverse objective functions separately and simultaneously in a bi-objective optimization problem. Mafakheri et al. (2011) proposed a two-stage multiple-criteria dynamic programming approach for the supplier selection and order allocation. In the first stage, they employed the AHP to rank the suppliers and in the second stage, they integrated the supplier ranks into an order allocation model that aims to maximize a utility function and minimize the total supply chain costs. Turk et al. (2017) proposed bi-objective model to solve inventory planning with supplier selection.

Goal programming (GP) Karpak et al. (2001) proposed a goal programming (GP) model to evaluate the suppliers through three objectives identified such as quality, cost and delivery performance. Kumar et al. (2004) used the multi-objective model containing three fuzzy goals and some crisp constraints for the supplier selection problem. They also applied the goal programming approach to solve this model. Osman and Demirli (2010) proposed a bilinear goal programming model to represent the strategic reconfiguration and to formulate the supplier selection problem. Chen (2011a, b) integrated multiple MP techniques among which GP is an important component. Lee et al. (2009) and Liao and Kao (2011) reduced real-world SS problems to a formulation of multi-choice GP. Sadeghieh et al. (2012) developed a genetic algorithm (GA)-based grey GP



Table 7 Classification of mathematical models in SSP

Multiple-sourcing models	Models types	Number of articles	Percentage local %	Percentage global %
Total number of papers		103		
Single-objective programming	Linear programming	03	2.91	1.11
	Integer Programming	15	14.56	5.56
	Nonlinear programming	11	10.67	4.07
	Dynamic programming	08	7.76	2.96
	Stochastic programming	13	12.62	4.81
	Fuzzy programming	04	3.88	1.48
Multi-objective programming	Multiple-objective linear programming	02	1.94	0.74
	Multiple-objective mixed integer programming	04	3.88	1.48
	Multiple-objective nonlinear programming	03	2.91	1.11
	Dynamic multiple-objective programming	02	1.94	0.74
	Stochastic multiple-objective programming	04	3.88	1.48
	Fuzzy multiple-objective programming	17	16.50	6.29
	Bi-objective programming	05	4.85	1.85
	Goal programming	12	11.65	4.44

Table 8 Classification of order allocation methods

Multiple-sourcing methods	Methods	Number of articles	Percentage local %	Percentage global %
Total number of papers		42		
Exact methods	Branch and bound	03	7.14	1.11
	Branch and cut	01	2.38	0.37
	Benders decomposition method	01	2.38	0.37
Artificial intelligence method	Genetic algorithm	14	33.33	5.18
	Neural network	10	23.80	3.70
	Grey system theory	05	11.90	1.85
	Particle swarm optimization	04	9.52	1.48
	Ant colony algorithm	01	2.38	0.37
	Scatter search algorithm	01	2.38	0.37
	Evolutionary algorithm	02	4.76	0.74

approach. Aouadni et al. (2013) developed the imprecise GP model with satisfaction function to explicitly incorporate the preferences of the buyer in all the decision-making to solve the supplier selection problem. Finally, Choudhary and Shankar (2014) used a goal programming model for joint decision making of inventory lot size for the supplier selection and the carrier selection. Jadidi et al. (2015) proposed an improved multi-choice goal programming (MCGP) approach for solving supplier selection problem. Moghaddam (2015) used a Monte Carlo simulation model integrated with fuzzy goal programming to determine the best set of suppliers and the optimal order allocation in reverse logistics with demand uncertainty. Igoulalene et al. (2015) combined the fuzzy consensus-based neat OWA

and goal programming model to solve multi-criteria group decision-making supplier selection problem. Table 7 classifies the different mathematical models in SSP.

The math models may be solved in different ways. The approaches used in solving them are outlined in the following section. We classify the solving mathematical models in two main categories such as exact methods and artificial intelligence (AI) methods (see Table 8).

Exact method *Branch-and-bound method* Basnet and Leung (2005) used an enumerative search algorithm and a heuristic to solve a multi-period inventory lot-sizing scenario, where there are multiple products and multiple suppliers. Goossens et al. (2007) studied the procurement

problem faced by a buyer who needs to purchase a variety of goods from suppliers applying a total quantity discount policy. They performed computational experiments by comparing three exact algorithms: a min-cost flow-based branch-and-bound approach (using the network solver of Ilog Cplex 8.1), a linear programming based branch-and-bound approach (using the MIP solver of Ilog Cplex 8.1) and a branch-and-cut approach (also using the MIP solver of Ilog Cplex 8.1). Zhang and Zhang (2011) addressed the supplier selection and purchase problem under stochastic demand. The problem is modeled as a mixed integer programming (MIP), and a branch-bound algorithm is proposed to solve it.

Branch-and-cut method In 2012, Manerba and Mansini provided a branch-and-cut method to solve the capacitated total quantity discount problem (Capacitated TQDP) where the quantity available for a product from a supplier is limited.

Benders decomposition method Osman and Demirli (2010) developed a bilinear goal programming model to represent the strategic reconfiguration and the supplier selection problem. The Benders decomposition algorithm is used to handle the complexity of this model.

Artificial intelligence (AI) techniques In the literature of the supplier selection, the major artificial intelligence techniques are genetic algorithm (GA), neural network (NN), rough set theory (RST) and grey system theory (GST).

Genetic algorithm (GA) The literature that considered typical GA for the supplier selection problem includes: Wang and Che (2007), Liao and Rittscher (2007a), Che and Wang (2008), Rezaei and Davoodi (2008), Yang et al. (2011) and Lee et al. (2013). Moreover, Xu and Ding (2011) designed a bi-random simulation-based GA. Che (2010) provided a heuristic algorithm combining guided GA and Pareto GA. In addition, Wang (2008), as well as Sadeghieh et al. (2012) utilized GA as an element to construct their decision model to solve the supplier selection problem. Rezaei and Davoodi (2011) applied a non-dominated sorting GA (NSGA II) to solve the multi-objective nonlinear programming model for a joint pricing, lot sizing and supplier selection model. Deng et al. (2014) formulated a multi-objective optimization problem for the supplier selection and a product line design, and it is solved by using NSGA II. Simić et al. (2015) presented a novel hybrid model for supplier assessment and selection, based on hybrid solution including genetic algorithm (GA) and harmony search algorithm (HSA). Du et al. (2015) proposed a hybridization of Pareto genetic algorithm (PGA) with multi-intersection and similarity crossover (MSC) strategy to solve the bi-objective program of the life cycle supplier selection of CoPS (LSS&CoPS) problem.

Neural network (NN) The neural network was used in the SSP are: Keskin et al. (2010), Luo et al. (2009), Celebi

and Bayraktar (2008), Wu (2009a), Lee and Ouyang (2009), Keskin et al. (2010), Guneri et al. (2011), Aksoy and Öztürk (2011), Kar (2015) and Tavana et al. (2016).

Grey System Theory (GST) The reviewed literature introduced GST for SSP from two perspectives: the decision information in the form of grey values (Bai and Sarkis 2010; Sadeghieh et al. 2012) and grey relational analysis (GRA) (Golmohammadi and Mellat-Parast 2012; Li et al. 2008; Wu 2009b).

Particle swarm optimization (PSO) Kuo et al. (2010) proposed decision support system composed of three components such as the collection of quantitative data, a combined particle swarm optimization (PSO) and fuzzy neural network (FNN) to derive the rules for qualitative data, and a decision integration model for integrating both the quantitative data and fuzzy knowledge decision to achieve the optimal decision an intelligent supplier decision support system. Assadipour and Razmi (2012) developed PSO algorithm to find good feasible solutions to the problem of inventory lot sizing and supplier selection for an assembly system, where the supplier's available capacities are assumed as ambiguous dynamic parameters. Xiao et al. (2012) developed a novel evaluation framework to select the supplier's considering risk by integrating fuzzy cognitive map (FCM) and fuzzy soft set to solve the supplier selection problem. The PSO algorithm was used to train fuzzy cognitive maps and obtain the weight of each criterion. Kuo et al. (2015) proposed an integrated artificial immune network and particle swarm optimization to distribute the order quantity between the key suppliers at minimum cost.

Ant colony algorithm (ACA) Tsai et al. (2010) used an attribute-based ant colony system for the supplier evaluation.

Scatter search algorithm Ebrahim et al. (2009) used the scatter search algorithm for supplier selection and order lot sizing under multiple price discount environment.

Evolutionary algorithm (EA) Soto et al. (2017) combined evolutionary and local research to solve lot sizing with supplier selection, inventory shortage and quantity discounts. Turk et al. (2017) utilized multi-objective evolutionary algorithm (MOEA) to minimize the conflicting objectives of supply chain operation cost and supplier risk.

Hybrid methods

In the last decade, numerous integrated approaches to the supplier selection have been proposed. We mentioned among these integrated methods the combination between MCDM methods, such as Hsu et al. (2012) combined ANP and VIKOR method. Onüt et al. (2009) combined ANP and TOPSIS methods. Shirinfar and Haleh (2011) used fuzzy ANP, fuzzy TOPSIS and fuzzy PROMETHEE. Furthermore, there are other types of hybridization as: Yang and Chen (2006) integrated AHP and grey relational analysis. Kar



Table 9 Review of hybrid methods in SSP

Methods	Technique	Additional features of decision approaches and literature
Certitude hybrid approach	AHP, GP	Lexicographic goal programming (Çebi and Bayraktar (2003)) Product-driven supply chain selection (Wang et al. (2004, 2005))
	ANP, LP	Benefit, opportunity, cost and risk model (Demirtas and Üstün (2008))
	ANP, GP, LP	Benefit, opportunity, cost and risk model (Demirtas and Üstün (2008)) Benefit, opportunity, cost and risk model (Demirtas and Üstün (2009))
	ANP, TOPSIS, LP	Imprecise GP integrated the decision maker's preference (aouadni et al. (2013))
	ANP, NLP	Case study related to manufacturing enterprise (Lin et al. (2011))
	MAUT, LP	Mixed integer NLP (Razmi and Rafiei (2010))
	ANP, VIKOR	Maximize total additive utility (Sanayei et al. (2008))
	TOPSIS, Max–Min GP	Recycled materials (Hsu et al. (2012))
	AHP, MAUT, PROMETHEE	Normalized goal programming (Jadidi et al. (2014))
	ANP, ELECTRE II	Supplier segmentation (Segura and Maroto (2017))
Fuzzy hybrid approach	AHP, LP	Supplier selection in interval 2-tuple linguistic environment (Wan et al. (2017))
	AHP, MOP, LP	Fuzzy weighted average used in Fuzzy QFD (Dursun and Karsak (2013))
	AHP, GP	Fuzzy compromise programming (Wang and Yang (2009))
	AHP, MOP	Multiple goal programming (Lee et al. (2009))
	MOP, LP, ANP	Low carbon SCM (Shaw et al. (2012))
	ANP, NLP	Soft time window (Yu et al. (2012))
	ANP, DEMATEL	Fuzzy multi-objective LP (Lin (2012))
	TOPSIS, LP	Fuzzy TOPSIS (Kara (2011))
	SP, TOPSIS	Network formation and pairwise comparisons (Razmi et al. (2009a)) Group fuzzy TOPSIS integrated with fuzzy LP (Razmi et al. (2009b))
	TOPSIS, GP	LP model under fuzzy environments (Gureri et al. (2009)) Group weighted additive fuzzy programming (Yucel and Gureri (2011))
	TOPSIS, MILP	Supplier selection in multi-item/multi-supplier environment (Kilic (2013))
		Supplier evaluation and demand allocation (Singh(2014))

(2015) presented a hybrid approach for group decision support for the supplier selection problem based on the fuzzy set theory, analytic hierarchy process and neural networks. Ha and Krishnan (2008) integrated AHP, DEA and artificial neural network; Saen (2007a) and Sevkli et al. (2007) integrated AHP and DEA, etc. In this paper, we are interested in summarizing the hybridization methods between MCDM method and the optimization models to evaluate and select the suppliers and determine the order allocation among them. Then, we provide an overall summary of these methods in Table 9.

Observations and remarks

Figure 2 presents the classification of the MCDM method based on years. Since 2007, there was a considerable growth in the number of articles applied MCDM methods on the supplier selection problem. There are clear that the AHP method is the most frequent method applied in this field. The total number of articles that used the AHP method published since 2000 is 38.52%. Another interesting result shows that the TOPSIS method is the important method used in 2011. The usage of MCDM method has decreased since 2013, but lots of attention was paid to hybrid method, mathematical models and artificial method in recent 5 years.

The distribution of the mathematical models by years is shown in Fig. 3. This clearly illustrates the orientation toward mathematical modeling and the artificial



Fig. 2 Distribution of the MCDM methods by years

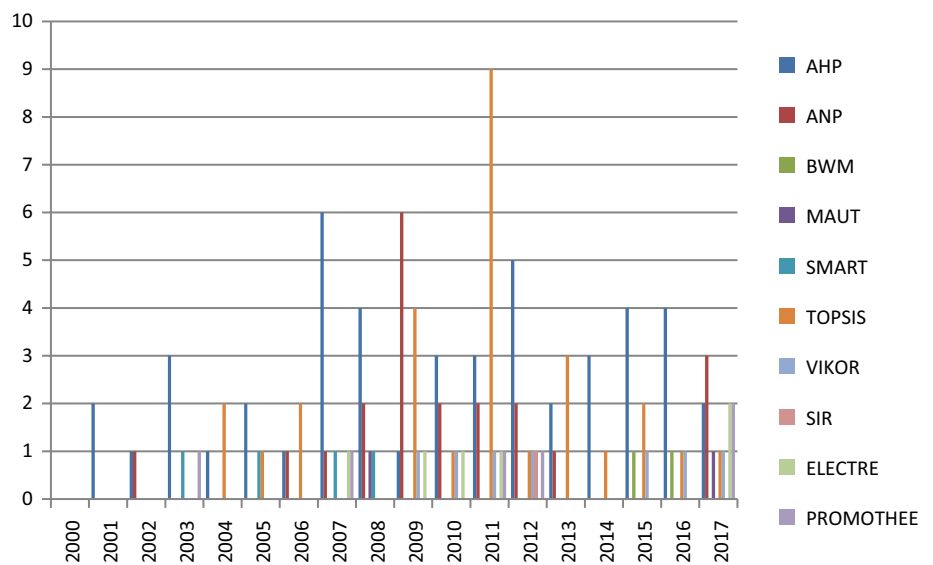
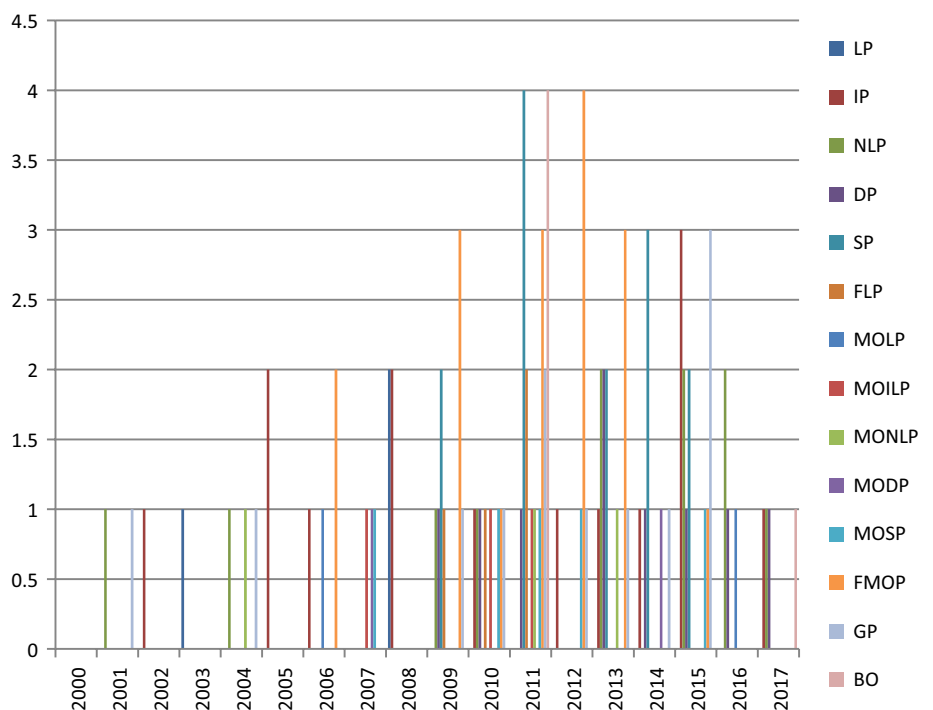


Fig. 3 Distribution of the mathematical models based on years



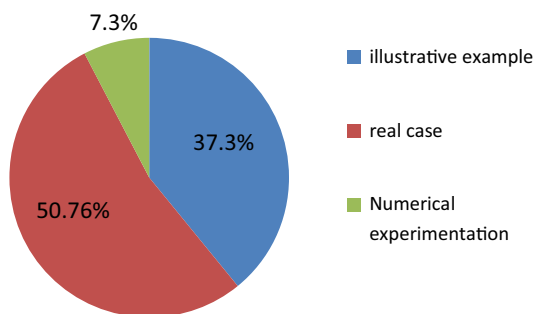
intelligence techniques in this field, especially in the last 5 years. Since 2010, the number of articles that used the mathematical tools for solving this issue is increased. The fuzzy multiple-objective programming is the popular mathematical models used for the modeling of the SSP and order allocation. As a result, it should be noted that the use of exact and artificial methods is limited despite the tendency of authors to this research axis. The genetic algorithm (33.33%) is more implemented than the other AI method and the exact method.

Overall, among the objectives of this survey is to find out the most popular method adopted in supplier selection and order allocation literature. As found in the previous sections, the MCDM approaches (122 papers or 45.18%) remain more popular than the mathematical programming (103 or 38.14%) and AI approaches (42 papers or 15.55%) as a tool for solving this problem. We summarize in Table 10 the strengths and weaknesses of the different methods.

It we found that 50.76% of these models have been applied in real-world cases and the most of them in manufacturing companies (40 articles) (see Fig. 4).

Table 10 The strengths and weaknesses of supplier selection methods

Methods		Strengths	Weaknesses
MCDM		Quick and easy to use Takes into account qualitative and quantitative criteria Considers the dependency between criteria	Depends on human judgment No possibility to introduce constraints in the model pairwise comparison matrices is a complex task Non-meaningfulness of the resulting rankings in mixed data contexts
Mathematical programming	Mono-objective	Finds optimal solution Possibility of introducing new constraints in model	Doesn't take into consideration human judgment Difficult to measure qualitative criteria Computing optimal solution might be time-consuming in the case of NP-hard problems
	Multi-objective	Criteria do not necessarily have a common dimension, finds several solutions We can introduce new constraints	Difficulty to take into account human judgment Doesn't obtain optimal solution Difficult to analyze the result Computing near solution might be time-consuming in the case of NP-hard problems
Exact methods		Provides optimal solution High quality of solution	Doesn't take into consideration human judgment difficulty to solve large size instances
Artificial intelligence		Offers a flexible knowledge base Takes into account qualitative criteria	The collection of knowledge about suppliers and access to expertise is long and difficult Very expensive

Application of research papers from 2000 to 2017**Fig. 4** Distribution of the application models

Conclusion and future directions

This paper attempted to review papers published in the period 2000–2017 about supplier selection and order allocation issues. There are 270 international journals studied in this survey, which are accessible via the database system Web of Science. As can be seen, most papers have been published in journals with strong quantitative traditions. The majority of these papers appear in Expert Systems with Applications (64 articles), International Journal of Production Economics (35 articles) and European Journal of Operational Research (26 articles) and others (these are listed in Table 1).

The first aim of this survey was to systematically review the studies conducted based on the problem of supplier

selection and order allocation since 2000. The total of 270 published articles about this field were systematically and carefully selected and summarized. In this paper, we determined firstly the main tools that have been employed in the domain of supplier selection and order allocation about the recent 17 years. Secondly, we provided the most international journals published articles related to these problems. Thirdly, we demonstrated the different years when authors published articles related to these fields.

The supplier selection with order allocation problem has attracted the interest of many researchers, and the number of research studies on this topic has increased in the last years. Several multi-criteria decision-making methods (MCDM) have been proposed in the literature to select suppliers which include both qualitative and quantitative criteria. According to the results obtained in this systematic review, we found that the number of pre-selection methods is limited despite this step is very important in the supplier selection process. This screening process makes identifying a suitable subset of suppliers and reduces the large set of initial suppliers to a smaller manageable set of acceptable suppliers by ranking them under a pre-defined set of criteria. Among the benefits of this pre-qualification step is that the possibility of rejecting good suppliers at an early stage is reduced.

On the contrary, authors paid attention to MCDM methods and integrated methods because the supplier selection problem is multi-criteria decision-making problem which includes qualitative and quantitative criteria. These methods are very quick and easy to use, but they depend on human judgment because the different weights given to the



various attributes depend on the decision makers' subjective judgment.

Also, we showed that the AHP method is the most popular MCDM method used in this field area by 46 articles and the second approach is the TOPSIS. The AHP method has more several criticisms such as the rank reversal of the alternatives. Then, we found that the applied MCDM methods in this field suffer from two major shortcomings: (1) the non-meaningfulness of the resulting rankings in mixed data contexts (i.e., the rankings of alternatives may change under admissible transformations of the initial attribute values, in the measurement-theoretic sense of the term) and (2) rank reversals that the rankings of alternatives may change if a new alternative is added or an old one is deleted from it or replaced in it).

In this board literature, several recent studies have pointed out to the importance of the order allocation problem in the supplier selection issue which is considered most important functions to be performed by the purchasing decision makers. For finding the best solution for the flowing decision “what to buy?”, “in which period?”, many mathematical programming models have been developed in the recent years in this context. It may also be argued that the mathematical programming models are more objective than MCDM methods because the decision maker can define explicitly the objective function.

In this review, we classified the order allocation problem in two strategies: single-sourcing problem (47 articles considered the single-item models and 41 articles the multiple-item models) and multiple- or dual-sourcing problems (66 articles studied the case of the single-period model and 21 papers the case of multi-period models). Moreover, we classified the mathematical models according to the objective function as either a single-objective function or multiple-objective functions. Besides, we discussed the different methods used in the literature to solve these models. Yet we found that the most popular of these models are a real practical case in the industrial sector by 137 articles. Nowadays, quantitative methods received more attention in recent researches in this domain. The authors are based in their researches on the exact method or intelligence artificial approaches to solve these mathematical programming according the complexity of the problem.

There is an overall suggestion for future research that may be pursued. Firstly, we propose to make the MCDM methods able to handle properly mixed attribute values because the attribute values have different levels of measurement. Secondly, we should take into consideration the rank reversal problem in MCDM method because the final rank of alternatives in the global ranking can be reversed when a new alternative is removed or added from the initial set of alternatives.

Thirdly, we will suggest applying the exact method such as branch and bound to solve the NP-hard problems in the supplier selection and order allocation problem for finding the optimal solution. Finally, during that time the researchers did not give attention to apply these methods in service industries and sectors as well.

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