Decision support models for supplier development: systematic literature review and research agenda

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Abstract: The continuing trend towards sourcing components and semi-finished goods for less vertically integrated manufacturing systems globally leads to a dramatic increase in supply options for companies. To ensure that companies benefit from the potentials global sourcing offers, supplier-buyer relationships need to be managed efficiently. Due to the decreasing share of value-adding activities provided in-house, suppliers are more and more considered as an essential contributor to the buying company's competitive position. Consequently, to realize and sustain competitive advantages, companies try to establish institutionalized long-term relationships to their most important suppliers and to actively improve the productivity and performance of their supplier base. To support supplier development in practice, researchers have developed decision support models that provide assistance in selecting and implementing suitable supplier development activities.

The aim of this paper is to provide a comprehensive and systematic overview of decision support models for supplier development and to develop a research agenda that helps to identify promising areas for future research in this area. First, typical applications for supplier development as well as potential development measures that can be adopted to improve the performance of suppliers are identified. Secondly, a systematic literature review with a focus on decision support models for supplier development is conducted. Based on the analysis of the literature, we define a research agenda that synthesizes key trends and promising research opportunities and thus highlight areas where more decision support models are needed to foster supplier development initiatives in practice.

Keywords: supplier development; supplier improvement; decision support models; systematic literature review; literature analysis

Introduction

An increasing fragmentation and global dispersion of manufacturing has convinced many companies that suppliers are essential contributors to their competitive position (Krause et al. 1998, Mol 2003). Especially in situations where it is difficult to substitute suppliers, or where suppliers contribute components or services that are critical for the buying decision of the end customers, the performance of the suppliers directly influences the competitiveness of company.

Consequently, whenever a buying company is not satisfied with the performance of its suppliers (e.g., due to low quality, low service levels, insufficient capacity, low innovative strength, or low environmental awareness) or the range of products or services provided, it may decide to develop the suppliers' capabilities (Krause 1997, Wagner 2006). Supplier development may broadly be defined as any effort undertaken to increase the performance of the existing suppliers (Hahn et al. 1990, Watts and Hahn 1993, Hartley and Choi 1996, Krause and Ellram 1997, Krause 1999), and it might be the preferred option in many cases as compared to vertical integration or supplier switching (Wagner 2010). Supplier development measures can be short-term oriented (e.g., with the aim of improving supplier delivery times) or have a long-term focus (e.g., with the aim of strategically enhancing the buyer's supply base), and they can have a direct or an indirect character (Wagner and Krause 2009, Wagner 2010). In the case of direct measures, the buying firm directly invests resources into a supplier, e.g. for on-site consultation, training programs, temporary personnel transfer, or providing equipment (Sucky and Durst 2013, Prahinski and Benton 2004, Wagner 2006, Bai and Sarkis 2011, Kumar et al. 2012). In the case of indirect supplier development, the buying firm adopts a passive role, for example by setting performance goals or improvement targets or by offering incentives to the supplier(s) (Wagner 2006, Wagner and Krause 2009, Sucky and Durst 2013). The success of supplier development activities depends on various internal and external factors, such as the capabilities of the supplier, the duration of the customer-supplier relationship, the distribution of power, technological uncertainties, or the organizations' corporate strategies (Bai and Sarkis 2011, Sucky and Durst 2013). In addition, successful initiatives also provide long-term benefits for the involved suppliers that continue beyond the project scope (Nagati and Rebolledo 2013).

Supplier development has attracted increased attention in recent years, with the majority of publications being empirical or conceptual in nature. Examples include case studies on green and environmentally sustainable supplier development (Agan et al. 2016, Blome et al. 2014), on the impact of supplier development on buyer-supplier performance improvement (Humphreys et al. 2004), or on successful supplier development activities implemented in certain industry cases (Modi and Mabert 2007). Apart from empirical and conceptual research, researchers have also started to propose mathematical models for supporting managers in selecting, implementing and monitoring supplier development activities. We refer to such mathematical models as 'decision support models' in the following. Decision support models for supplier development can give valuable support in practice, for example by identifying suppliers suitable for development or by deriving optimal investment volumes for supplier development activities. As will be shown in this paper, decision support models for supplier development have attracted an increased attention in recent years.

Supplier development is not the only area related to the management of suppliers that has received an increased attention in recent years. Other research areas that belong to the broad domain of 'supplier management', such as supplier selection, supplier evaluation, or the management of supplier-buyer relationship, also witnessed increasing publication numbers recently, which led to a couple of literature reviews that appeared in these areas in recent years. A closer analysis of these literature reviews, however, unveils that they either focus on empirical and conceptual works, or that their object of analysis are decision support models, albeit not for supplier development. The Appendix gives a structured overview of related literature reviews in the area of supplier management and differentiates the work at hand from existing surveys.

As research on decision support models for supplier development has experienced a strong increase in the number of publications in recent years (see Figure 4), there is a need for a review that analyses and synthesises existing works in this area and that highlights potentials for future research. Since no review of decision support models for supplier development exists so far, the paper at hand conducts a systematic literature review on this topic. The contribution can be summarized as follows:

- The paper presents a comprehensive and structured overview of research on decision support models for supplier development summarizing development measures considered, modeling approaches and application areas;
- The paper synthesizes and categorizes the existing approaches, which helps researchers in positioning their own work in the literature and practitioners in finding suitable decision support for specific supplier development topics;

- The paper identifies promising research gaps and develops an agenda on future research opportunities.

The remainder of the paper is structured as follows: The next section discusses a typical supplier development process and develops a framework with content categories that are used to classify the literature. Section 3 describes the methodology used for searching the literature. Works that propose decision support models for supplier development are reviewed and discussed in Section 4. Suggestions for future research are discussed in Section 5 based on the results of the literature review. The paper concludes in Section 6.

Conceptual framework

To ensure a methodologically rigorous evaluation of the literature retrieved in our systematic review (see also Melnyk et al. 2009; Cooper 2010), this section introduces a conceptual framework that will later be used for classifying and discussing the literature sample. The conceptual framework considers two dimensions of decision support models for supplier development. The first dimension systematizes the attributes of the supplier development approach (such as the objective of supplier development or the supplier development measure that is implemented, for example), while the second dimension focuses on technical properties of the proposed decision support model (such as model type and solution approach, for example). The framework was first developed deductively based on conceptual works on supplier development (e.g., Hahn et al. 1990, Krause et al. 1998, Sucky and Durst 2013) and quantitative modelling frameworks in operations management (e.g., Sasikumar and Kannan 2009; Brandenburg et al. 2014; Zimmer et al. 2016), and then inductively refined during the coding process after evaluating the results of the systematic literature search (see also Hochrein et al. (2015) for a more detailed description of deductive and inductive content category building). Both dimensions of the framework are discussed in the following.

Content categories

Supplier relationship management (SRM) is concerned with strategically planning and managing all interactions between a buying company and its suppliers. SRM encompasses various activities, such as the identification of suitable suppliers and their selection, the evaluation and development of suppliers, as well as a continuous monitoring of the suppliers' performance. These and other activities need to be addressed comprehensively in the buying company's purchasing strategy, with the result being a cyclic integrated SRM process that is illustrated in Figure 1. Even though SRM has started to attract attention in the literature many years ago, researchers have just recently started to investigate the different dimensions of SRM from an integrated perspective (cf. Park et al. 2010). According to the integrated SRM process illustrated in Figure 1, SRM starts with the identification of potential suppliers, followed by a systematic selection and evaluation process. Suppliers that do not meet the required performance targets either need to be developed or replaced. All investments into the supplier base should be monitored to keep track of their costs and performance impact. After the suppliers have been evaluated, the process starts anew.

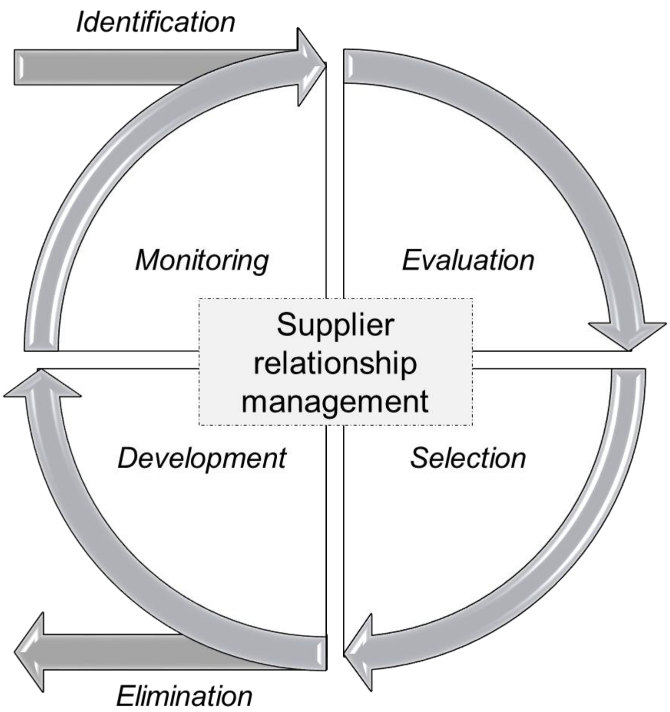

Figure 1. Supplier relationship management process

The direct or indirect development of suppliers, which is an integral part of the strategic SRM process, has attracted the attention of researchers already in the 1960s (Leenders 1966). Today, there is a growing consensus that supplier development consists of three main steps:

1. *Prepare supplier development*: In the first step, the buying company needs to evaluate whether supplier development measures are necessary or not. Subsequently, the buying company has to identify suppliers it intends to develop (cf. Bai and Sarkis 2011).
2. *Develop the supplier(s)*: Once the buying company has decided to develop one or more suppliers, it needs to select supplier attributes it wishes to improve. Subsequently, the buying company needs to select appropriate (direct and/or indirect) supplier development measures. At the end of phase 2, the supplier development measures are implemented (cf. Humphreys and Chan 2004).
3. *Monitor and control supplier development*: After supplier development measures have been initiated, the measures need to be monitored continuously. In case supplier development measures do not result in the expected outcomes, it may be necessary to modify or cancel the measures or to select another supplier for development (cf. Meisel 2012).

Building on the three phases of supplier development (SD), Figure 2 illustrates a set of content categories that will later be used to classify and discuss the selected articles in Section 4.

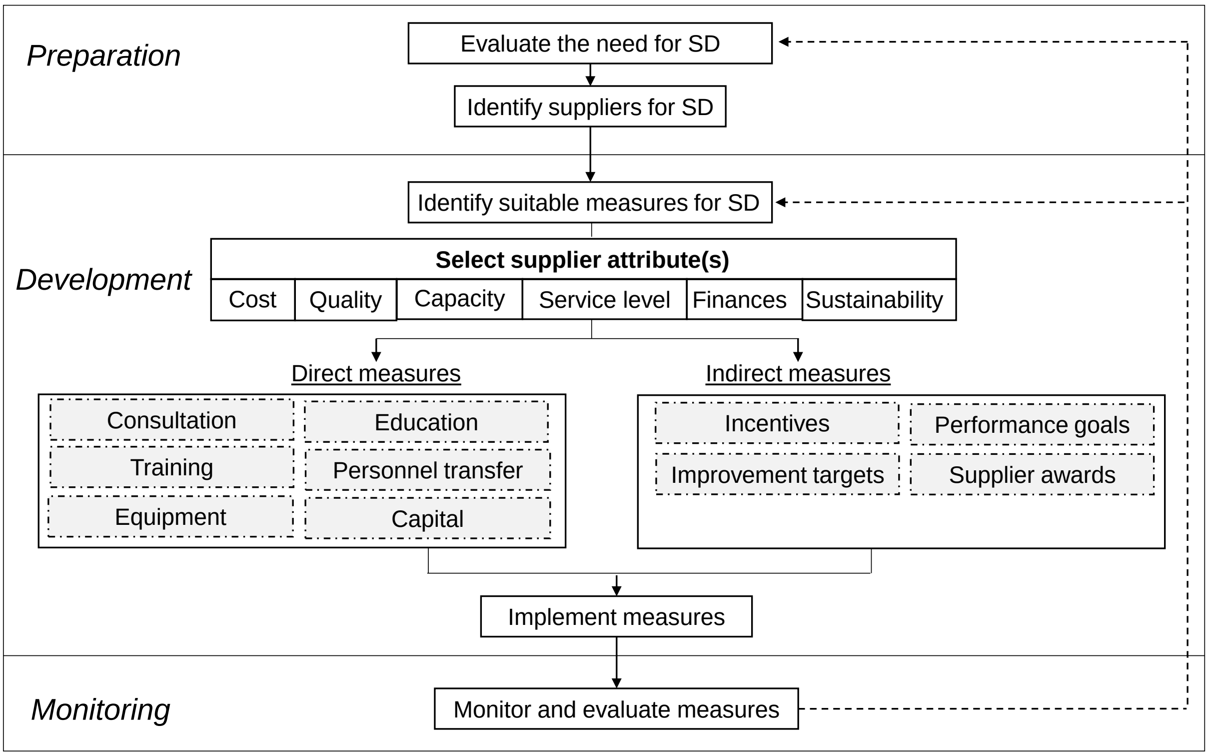

Figure 2. Conceptual framework for content categories

Modelling categories

Quantitative (mathematical) modelling has enjoyed a strong popularity in operations management over the last decades. Models in this area are often differentiated according to the modelling purpose, which can either be descriptive or normative. Whereas descriptive approaches aim at understanding and explaining the characteristics of the model and the associated functional relationships, normative approaches seek to identify and to develop strategies and actions to find an optimal solution for a specific problem taking account of the manager's preferences (Bertrand and Fransoo 2002; Shapiro 2007). The different model types employed in normative modelling can broadly be categorized into optimization models, heuristic and simulation models and multi-criteria decision making (MCDM) models (see Sasikumar and Kannan (2009) and Brandenburg et al. (2014) for a similar classification of model types and solution techniques for supply chain modelling). Figure 3 gives an overview of popular approaches used in operations management research for each of the three categories. For optimization models, for example, linear, non-linear and dynamic programming models have frequently been proposed in the past. In the area of heuristics, fuzzy and rough sets approaches as well as meta-heuristics have frequently been used. Examples for MCDM models that usually evaluate multiple conflicting criteria include are best-worst methods (BWM), the analytic hierarchy process (AHP), the analytic network process (ANP), or the data envelopment analysis (DEA).

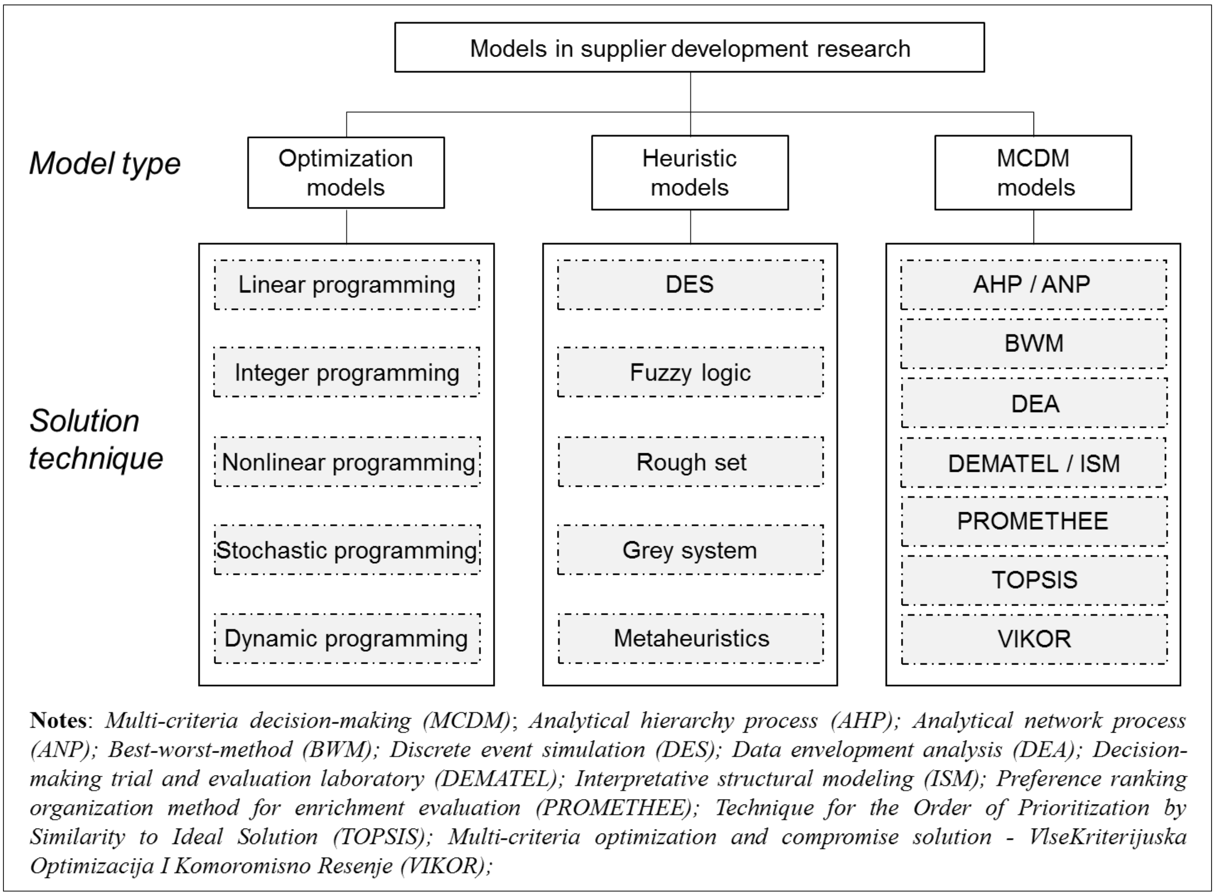

Figure 3. Conceptual framework for modelling categories

Systematic literature review methodology

The aim of literature reviews, in general, is to point out popular streams of research, to synthesize research results, to assess the knowledge base in a certain research field, and to identify future research opportunities (Seuring and Gold 2012). Prior research has frequently differentiated between systematic and narrative literature reviews (e.g., Tranfield et al. 2003, Denyer and Tranfield 2009, Cooper 2010; Rhoades 2011). The difference between both types of reviews is that narrative reviews rely mainly on the experience and assessment of the researcher(s) when generating and evaluation the sample, whereas systematic literature reviews are conducted using a clearly-defined and systematic literature search and selection methodology (Tranfield et al. 2003, Denyer and Tranfield 2009, Cooper 2010). While both types of literature reviews can make an important contribution to their respective field, the advantage of systematic literature reviews is that they enable the reader to reproduce sample generation and evaluation, which makes it easier to verify, to interpret and to follow up on the findings of the literature review. For this reason, the authors decided to employ a systematic literature review approach in the paper at hand.

One challenge the authors encountered when conducting this review was to define suitable boundaries for the inclusion of papers into the review. While too restrictive inclusion criteria could lead to an exclusion of relevant works from this review, a very broad definition of supplier development may lead to an excessively large literature sample that would be difficult to evaluate in a single paper. Some of the supplier development measures mentioned in Figure 2 point towards comprehensive research streams (see, e.g., Tsay et al. (1999) for a review of contracts and incentive systems in supply chains or Glock (2012) for works that cooperatively try to reduce costs in buyer-supplier relationships) whose simultaneous review would be out of the scope of a single paper. To keep this literature review focused, the authors decided to include only decision support models in this survey that explicitly refer to supplier development in developing or applying decision support models, or that study decision support models for supplier development (without explicitly referring to this term), but that have been cited in works that meet the first selection criterion. We acknowledge that our literature search methodology may have missed works that may be related to supplier development, and therefore make no claim for completeness.

The purpose and content of this literature review can be classified according to the following taxonomy, which is based on Cooper (2010) and Hochrein and Glock (2012):

- **Goal**: The aim of this paper is to provide a comprehensive and systematic overview of decision support models for supplier development and to develop a research agenda that helps to identify promising areas for future research in this field.
- **Coverage**: The paper aims to provide an overview of the literature by using an established literature search methodology. The paper intends to include existing works that meet the selection criteria defined in this study without limitations on the year of publication.
- **Organization**: The paper adopts a conceptual organization and groups sampled works into a set of content categories based on a conceptual framework that reflects both important characteristics of the supplier development process as well as important properties of the proposed decision support models (see Figures 2 and 3).
- **Audience**: The audience of this study are general and specialized scholars as well as practitioners interested in the field of supplier management.
- **Literature search**: Building on the methodology of a systematic literature review described in Denyer and Tranfield (2009) and applied, for example, in Glock et al. (2014) or Glock and Grosse (2015), we systematically searched the literature to identify articles that develop or apply decision support models for supplier development. Two databases that cover the relevant research field of production, operations, supply chain and logistics management, namely Scopus and Business Source Premier (BSP), were searched using keywords outlined in the following. The two selected databases have frequently been used for systematic literature reviews in the area of operations and supply chain management (Glock and Hochrein 2011, Hochrein and Glock 2012; Wetzstein et al. 2016; Hochrein et al. 2015; Zimmer et al. 2016), and combining both databases prevents possible shortcomings of one of the databases (see also Menachof et al. 2009). Keywords were selected based on our conceptual framework (see Figure 2). Two groups of keywords (A and B) were generated as follows:

  - Group A keywords: "*supplier*" OR "*vendor*";
  - Group B keywords: "development" OR "improvement" OR "training" OR "*investment*" OR "*consultation*" OR "*education*" OR "*personnel transfer*" OR "*equipment*" OR "*incentives*" OR "*performance goals*" OR "*improvement*" OR "*award*".

  The search was directed towards papers that contain at least one keyword combination from group A and B either in their title, abstract or list of keywords. The language of the papers was limited to English, and the year of publication was not restricted, thus making use of the entire coverage of the databases. Only works that appeared in peer-reviewed academic journals were considered relevant. A pre-selection of peer-reviewed journals was not applied. The database search was complemented by a backward snowball search in which the reference lists of papers that were found in the database searches were checked manually for relevance.
- **Selection criteria**: Since an initial search revealed that many papers do not specify their methodology in their title, abstract or list of keywords, keywords related to the methodological focus of this paper (decision support models) were not used in the

database search. Thus, we used only the content-related keywords in the database search and manually checked all identified papers for methodological relevance according to Figure 3 (see, for a similar approach, Cankurtaran et al. 2013). Articles that develop or apply quantitative models (as defined in Figure 3) to support decisions on supplier development (as defined in Figure 2) were included in the sample.[1] Papers with a different content focus (e.g., an exclusive focus on supplier selection, supplier evaluation, or supplier monitoring; see Section 2) or works that did not propose decision support models (e.g., empirical studies) were excluded from the analysis.

- **Article selection**: Each paper identified during the literature search was first evaluated for possible relevance based on its title and abstract. Subsequently, all works that remained in the initial working sample were completely read to assess their relevance for this study based on the defined selection criteria and grouped according to the proposed categories.

Review of decision support models for supplier development

Descriptive results of the literature search process

The results of the literature search are summarized in the review protocol in Table 1 (all numbers effective April 2017).

Filter type	*Descriptions and guidelines*	*Results*	
Inclusion criteria	Articles that: 1. were identified during the database search or 2. appeared in the reference lists of one of the selected papers *Topic*: Articles that develop or apply quantitative models to support decisions on supplier development *Language*: Limited to English *Time span*: Any year of publication *Paper type*: Academic (peer-reviewed) journal articles		
Keywords	Group A keywords: “supplier" OR "vendor”; Group B keywords: “development" OR “improvement" OR "training" OR "investment" OR "consultation" OR "education" OR "personnel transfer" OR "equipment" OR "incentives" OR "performance goals" OR "improvement" OR "award"		
Keyword search	Selected online databases were searched with the keywords defined above. Relevance was ensured by requiring that all articles contain at least one keyword combination from group A and B in their title, abstract or list of keywords.	<u>*BSP*</u> 284	<u>*Scopus*</u> 624
Consolidation	*First evaluation of the articles and consolidation* Results from selected databases were checked for relevance by subjecting all papers to an analysis of their title and abstract. Duplicate articles that were found in both databases were eliminated.	74	
Snowball approach	Additional articles identified using a snowball approach applied to all previously selected articles.	25	
Working sample		**99**	
Content evaluation	*Second evaluation of the articles by defined criteria* Relevance of content was ensured by requiring that the selected articles meet the criteria for inclusion. All articles in the working sample were completely read to examine their content.	↓	

[1] We use the terms ‘selected papers’ and ‘sampled paper’ interchangeable in this paper to refer to works included in (selected for) the sample.

Final sample	**46**

Table 1. Review protocol

As can be seen, the database search led to 624 initial hits in Scopus and 284 hits in Business Source Premier. After a first screening for relevance in light of the defined selection criteria and after eliminating duplicate papers that were found in both databases, 74 papers remained in the initial sample. The initial sample was complemented by 25 additional works from the snowball search, resulting in a working sample of 99 papers. Papers contained in the working sample were completely read to examine their content, which led to a further exclusion of 53 papers and a final sample of 46 works.

Figure 4 shows the number of sampled papers published per year. As can be seen, the first decision support models for supplier development were published in 2000 (the works of Liu et al. 2000 and Kim 2000). The trend line highlights the increasing and recent research output on this topic, with 28 papers (~60%) published between 2014 and 2017. Figure 5 provides an overview of the academic peer-reviewed journals that published papers contained in the final sample. As can be seen, the *International Journal of Production Economics* (9) published the largest number of relevant papers. The *European Journal of Operational Research* (7), *Computers & Industrial Engineering* (3), the *Journal of Cleaner Production* (3), *Production & Operations Management* (3), and the *International Journal of Production Research* (3) are other popular outlets for research in this area that published three or more papers *Other* (12) summarizes journals that published only one sampled paper each.

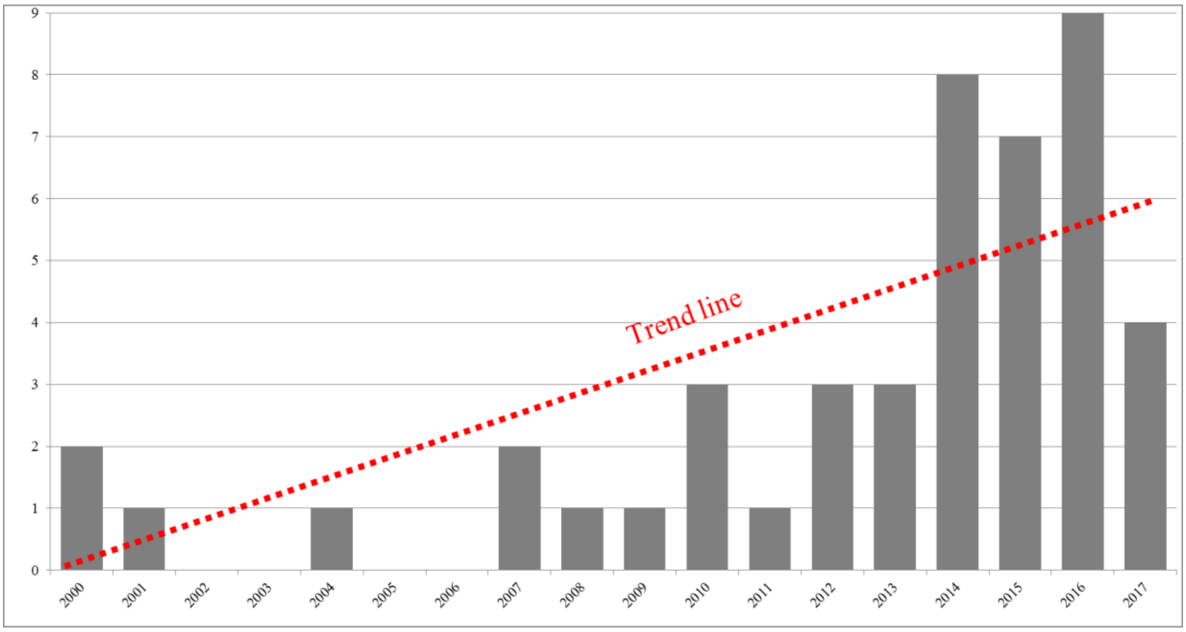

Figure 4. Number of papers published per year

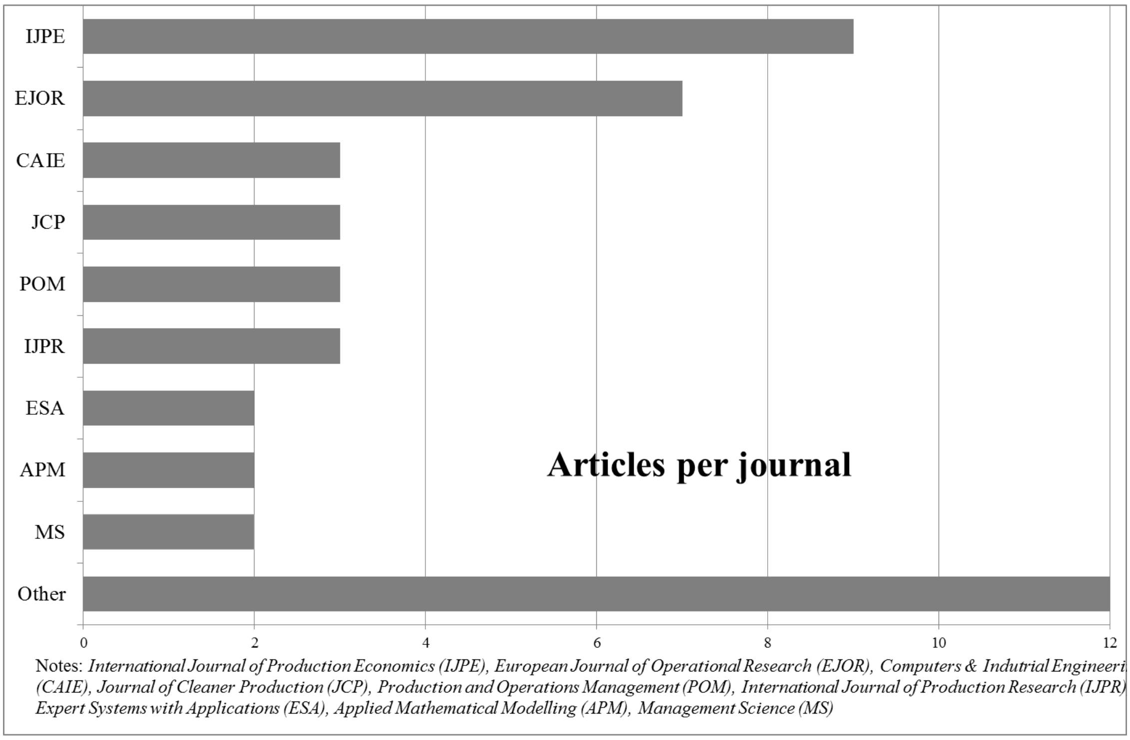

Figure 5. Number of papers published per journals

Decision support models for supplier development

Decision support models for supplier development that were found in the systematic literature search are discussed according to the three phases of supplier development (cf. Section 2) in the following section. In case models support more than one process step, they were assigned to the content category that best reflects their core content.

Prepare supplier development

According to the content-oriented framework in Figure 2, supplier development starts with a preparation step. First, the buying company needs to evaluate whether supplier development is altogether necessary, and in case the need for supplier development is confirmed, it needs to identify suppliers that should be developed in the next step. Our review of the literature showed that the two preparation steps – i.e. evaluating the need for supplier development and identifying suppliers to be developed – have been addressed in an integrated way by most researchers. The most popular approach was to screen the supplier base for low-performing suppliers, and in case such suppliers were identified, to select these suppliers for supplier development. In all papers that support the first phase of the supplier development process, MCDM models were used.

Forker and Mendez (2001), for example, developed a benchmarking model based on a Data Envelopment Analysis (DEA) for identifying suppliers who could benefit most from supplier development efforts. The DEA enables the decision maker to evaluate the relation of quality output (e.g., defects) and input (e.g., time, money) for each supplier, and it indicates whether a supplier is efficient relative to its peer suppliers. The efficiency score calculated by the method helps to identify best-performing suppliers, and it also highlights the performance difference between best-performing and low-performing suppliers. Low-performing suppliers could be candidates for supplier development efforts. An alternative DEA approach was proposed by **Liu et al. (2000)**, who used the results of the DEA also to derive improvement targets for low-performing suppliers. Another DEA approach for preparing supplier development can be found in **Talluri and Narasimhan (2004)**.

Sharma and Yu (2013) used the AHP for ranking a company's suppliers and for identifying underperforming suppliers in a Pareto analysis. The ranking process consists of three steps: I) define evaluation criteria; II) establish a pairwise comparison matrix by interviewing the decision maker; III) calculate weights and rank the suppliers. An important advantage of the method proposed by the authors is that it is not limited to a particular performance criterion, but that it can flexibly consider different evaluation criteria for supplier development. Another ranking method was proposed by **Araz and Ozkarahan (2007)**, who employed a multi-criteria analysis (PROMETEE) for selecting suppliers for development. After implementing supplier development measures, the method supports a continuous monitoring of the suppliers to see if the suppliers improve their performance as intended, or if the supplier development programs have to be continued or changed.

Omurca (2013) developed a two-step approach for selecting suppliers for supplier development. First, a fuzzy c-means clustering algorithm was used to categorize the suppliers of a company based on their performance ratings. Secondly, an attribute reduction method based on rough set theory was implemented to identify promising suppliers for supplier development. The fuzzy c-means approach was also used by **Akman (2015)** for evaluating the performance of suppliers. The proposed method first assigns suppliers to three groups according to their economic performance (poor, medium and good performance). Suppliers with poor and medium performance could directly be considered as candidates for development with a focus on economic performance. Suppliers with a good performance were evaluated in a second step with respect to their environmental performance. Suppliers with a good economic, but a poor environmental performance, could again be considered as candidates for supplier development.

Osiro et al. (2014) proposed a decision support model based on fuzzy inference combined with a fuzzy grid that helps a buying firm to evaluate which suppliers should be subjected to supplier development. The model considers different criteria for the classification of suppliers and purchased items. Items are classified into noncritical, leverage, bottleneck, and strategic items, and suppliers are categorized according to their delivery performance and their potential for long-term partnerships. Based on the derived categorization of suppliers and items, several directives for supplier development actions plans (namely: replace supplier, sustain relationship, begin new development program, develop follow-up program, or allocate strategic items) can be deduced.

Chen et al. (2015a) proposed a mathematical programming approach to evaluate the suppliers' process improvement capabilities and possible cost of supplier development investments. Solving the model leads to a process capability index that helps buyers to identify suppliers with the greatest potential to improve product quality during supplier development programs.

Rezaei et al. (2015) proposed a multi-criteria decision-making model based on the best-worst method for segmenting and subsequently selecting suppliers for supplier development. The authors used a supplier potential matrix that considers two key dimension of supplier development, namely supplier capabilities (measured in terms of technical, quality, delivery, intangible, service, financial, sustainable and organizational dimensions) and supplier willingness to collaborate (measured by the willingness to improve performance, to share information, to rely on each other and to involve in a long-term relationship), which can both be either low or high. Several strategies to improve in either one or both dimensions, such as improved commitment and collaboration, raising competitive pressure, improved feedback, or knowledge transfer, were discussed.

Routroy and Pradhan (2014) developed a benchmarking model to identify and categorize critical success factors for supplier development. They first identified thirteen critical success factors of supplier development (such as direct involvement, incentives, top management commitment, or information sharing) and then adapted an Interpretative Structural Modelling (ISM) approach to develop a relationship among the success factors. The model supports the decision maker in identifying main drivers (e.g., incentives) for a successful supplier development initiative. **Dalvi and Kant (2017)** adopted a different perspective and proposed a fuzzy AHP approach to identify and prioritize barriers to supplier development. Companies then have the opportunity to resolve these barriers before implementing supplier development measures, which contributes to increasing the success potential of supplier development initiatives.

Lima-Junior and Carpinetti (2016) proposed an approach for evaluating performance improvement potentials of suppliers by combining the metrics of the SCOR® model with fuzzy TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) approaches. Based on an evaluation in the dimensions cost and delivery performance, suppliers are categorized into four groups that allow deriving directions for action plans to support their continuous improvement. **Trapp and Sarkis (2016)** developed a combined supplier selection and supplier development model with the objective to maximize the supplier's sustainability performance rating while simultaneously satisfying supply chain-related constraints. The authors assumed that each selected supplier is required to participate in a sustainability training, and that for the total expenses associated with supplier training, a budget is available.

Kumar et al. (2012) finally proposed a Fuzzy Quality Function Deployment (QFD) model for ranking supplier performance attributes. Their approach consists of three basic steps: I) identify performance attributes of the supplier and the buyer; II) weight the buyer's performance attributes and establish a relationship between the supplier's and the buyer's performance attributes; III) use a fuzzy approach to rank the supplier's performance attributes according to the preferences of the buyer. Attributes of the supplier with a low performance value could then be improved in a supplier development initiative.

Develop the supplier(s)

After the need for supplier development has been identified, and after one or more suppliers have been selected for supplier development, the actual supplier development initiatives need to be implemented. This step usually starts with the identification of suitable supplier development measures. As was pointed out in Section 2.1, the literature differentiates between direct and indirect supplier development. Direct supplier development initiatives lead to an active involvement of the buying company in performance improvement efforts at the supplier, whereas in the case of indirect supplier development, the buying company tries to influence the environment the supplier operates in to give the supplier an incentive to improve its performance on its own (Wagner 2010, 2011).

Direct supplier development

When evaluating works that study direct supplier development initiatives, we noticed that works in this area can further be assigned to one of four sub-categories. One set of papers, for example, assumed that one or more supplier development measures have been defined at the outset, and calculated optimal investment volumes into the respective measures. The second set of papers assumes that the buying company competes with a single or multiple companies, and investigates how developing suppliers may lead to spillover effects. The third set of works compares supplier development to alternative measures, such as supplier switching. The last set of papers assumes that the buying company faces more than a single supplier development measure and compares the available measures to support selecting the most promising one(s). The four sub-categories and the papers we assigned to them will be discussed in the following.

<u>*Calculating investment volumes*</u>

Works that studied direct supplier development initiatives often concentrated on calculating optimal investment volumes for supplier development programs. One example in this area is the work of **Talluri et al. (2010)**, who considered both the case where a single buyer and the case where two buyers face multiple suppliers. The authors assumed that a limited budget is available for supplier development, and that manufacturing firms can cooperate in developing joint suppliers. Supplier development, in turn, was assumed a long-term process, such that regular (uncertain) returns occur over the investment period. For this scenario, the model determines the investment into each supplier such that a target return is achieved at minimum risk. **Kim (2000)** studied a supply chain consisting of a single supplier and a single buyer, where the buyer has the option to support the supplier in lowering its production cost via a subsidy. The influence of the subsidy on the supplier's production cost was modelled using a learning curve. Lower production cost at the supplier, in turn, enables the buyer to sell the product at a lower price to the end customers, increasing end customer demand. The analysis revealed that supplier development is especially beneficial in scenarios with highly price-sensitive demand that appreciates the performance improvement at the supplier. **Proch et al. (2017)** investigated a closely related scenario. In contrast to Kim (2000), the authors also proposed a negotiation algorithm that distributes the cooperation gain among the parties involved. **Bhattacharyya and Guiffrida (2015)** developed an optimization model for a buyer who intends to invest into a supplier to improve the supplier's delivery performance. The model determines the optimal investment volume from the buyer's point of view considering a budget constraint. The proposed model can be used as a managerial decision tool to increase the service levels of suppliers by means of reducing their untimely deliveries. **Glock (2016)** studied another two-stage supply chain where the buyer has the option to develop the supplier by training its workers. In case the buyer decides to develop the supplier, the buyer delegates employees from its own workforce to the supplier who then train the supplier's workers at the supplier's premises. The model developed by Glock (2016) supports the decision of whether or not to develop the supplier, and it calculates both an optimal number of workers that should be delegated to the supplier as well as optimal points in time when the workers should be delegated and withdrawn again. A similar setting was addressed by **Lolli et al. (2016)**, who investigated a situation where a buyer sources products from multiple suppliers. The suppliers produce items that may be non-conforming, with the rate of non-conformance reducing subject to learning. The authors considered two sources of learning, namely learning-by-doing, which depends on the units processed by the supplier, and induced learning, which results from training hours the buyer allocates to the suppliers. The model proposed in this paper supports the buyer in specifying an appropriate amount of training depending on initial defect rates, learning rates etc. **Marchi et al. (2016)** studied a single-vendor single-buyer supply chain with centralized coordination in the presence of an uncertain investment opportunity. In this setting, the vendor has the option to increase its production rate and to lower its unit production cost at an investment. The outcome of this investment was assumed uncertain, however. As the buyer is in a better financial position in terms of liquidity and solvency than the supplier, the buyer could initiate a supplier development program to support the supplier in its investment. The authors showed that financial collaboration in terms of supplier development may help to overcome scepticism that may arise in the case of uncertain investments, and that it may improve the performance of the entire supply chain. **Cui et al. (2017)** investigated a situation where a single buyer sources a product from two suppliers. Customer demand was assumed stochastic, and the inventory records of the suppliers were assumed inaccurate. To improve inventory accuracies, which enables the suppliers to offer higher service levels, the suppliers may invest into RFID technology that facilitates tracking products. To support the supplier, the buyer may take over a share of the RFID investment cost. The model proposed in this paper supports the buyer and suppliers in determining optimal investment volumes. **Mizgier et al. (In 2017)** considered a single manufacturer sourcing products from multiple suppliers and assumed that the manufacturer has the option to allocate capital to the suppliers to develop them. In allocating capital to the suppliers, the manufacturer can use different capital allocation principles that, for example, take account of its degree of risk aversion. If the manufacturer is highly risk averse, for instance, it would invest lower amounts of capital into risky supplier development projects. The paper introduced and compared different capital allocation principles and thus supports buyers in selecting the right principle for financing supplier development initiatives. **Zhu et al. (2017)** finally studied a two-stage supply chain where a supplier delivers a product to a single buyer. The production process at the supplier was assumed imperfect producing defective items. Both the buyer and the supplier were assumed to have the option to invest in the supplier's production process to improve the quality of the products produced there, and a logarithmic investment function was used to model the impact of the buyer's and the supplier's investments on the expected number of nonconforming items. The results of the paper imply that in case the buyer is interested in a high quality level, s/he should participate in the quality improvement at the supplier. The authors also proposed a concept that ensures that buyer and supplier improve the supplier's quality in a way that is optimal from a system's point of view.

Considering competition

If a company decides to develop a supplier that delivers products also to the company's competitors, then the competitors could benefit from the company's supplier development initiative as well. Several researchers investigated such so-called spillovers and analyzed how companies should develop suppliers in a scenario where a competitor could benefit from the investment. **Qi et al. (2015)**, for example, studied the case where two competing firms invest into a shared supplier to increase the supplier's capacity, and where the investment may spill over to the respective competitor. The authors developed a multi-player game and studied the consequences of supplier development investments under competition from the perspectives of the different players. The model supports determining optimal investments into suppliers and highlights their possible consequences and potential spillover effects in case the supplier is shared with a competitor. Similarly, **Agrawal et al. (2015)** analyzed investment strategies for supplier development when the actual improvement is unknown a priori and when the benefits resulting from supplier development investments can spill over to competing companies sourcing from the same suppliers. The studied investment game with Markov perfect equilibria characterized by the investment thresholds revealed that competition determines a firm's timing of investment in a shared supplier. **Wang et al. (2014)** investigated a scenario where two competing manufacturers share a single supplier, and where the production process at the supplier is imperfect producing defective items. Both manufacturers may invest into the supplier to improve the supplier's production yield. The authors formulated a two-stage game, where in the first stage, both manufacturers specify their supplier development investment, and where the supplier realizes an improved yield rate in the second stage. The manufacturers also place orders in the second stage of the game and compete for service level in the end customer market. The authors specified conditions that guarantee an equilibrium for the manufacturers and showed that spillovers reduce the supplier development investment. This effect is, however, moderated by several other factors, such as market competition or the relative benefit manufacturers can gain from supplier development. **Chen et al. (2015b)** considered a situation where two OEMs (buyers) source a product from a single supplier. The buyers compete both on price and product quality. To induce the supplier to improve its product quality, the buyers have the option to participate in the supplier's quality investment. The authors formulated the problem as a dynamic game and solved it via backward induction. The paper investigated two scenarios: in the case of a powerful supplier, the supplier determines the product quality level in response to the incentive set by the OEMs, while the OEMs decide about how they should participate in the quality investment; in the case of powerful OEMs, the OEMs define the quality level and their share in the investment, while the supplier decides about the wholesale price. **Friedl and Wagner (2016)** studied a similar scenario and considered two risk-neutral buyers sourcing a single component from an incumbent supplier. The authors studied the case where both buyers independently have the option to develop the supplier to reduce purchasing costs. Their results revealed that cooperation between the two buying firms always leads to a lower total development investment than non-cooperation, even in the case when the costs for the development investments differ for both buyers.

Comparing supplier development and supplier switching

If the relative benefit of supplier development is not yet fully clear, a buying company may want to compare a possible supplier development initiative to the case where a new and better performing supplier is selected, possible as a backup alternative. In this line of thought, **Friedl and Wagner (2012)** studied a firm's decision of whether to develop an incumbent supplier at an investment or to switch to an alternative supplier. The model assumed that the buyer's investment reduces the unit cost of the supplier's component, such that the buyer can directly benefit from its investment. The proposed model compares both options – supplier development and supplier switching – and determines an optimal investment volume for the supplier development alternative. The results of the paper indicate that supplier development is especially beneficial in situations where the variance of the incumbent supplier's cost and/or the purchase price of an item on the market are high. **Hu et al. (2013)** studied a scenario where a buyer sources a product from a supplier whose production process is subject to disruptions. If a disruption occurs, the entire production capacity is lost. In the event of a disruption, the supplier may invest into its production process to restore its production capacity, with the outcome of the process restauration investment being, however, uncertain. The paper assumes that the buyer has two options to protect itself against disruptions: first, s/he can contract another reliable supplier to hedge against possible interruptions, or it can implement incentive mechanisms to induce its supplier to invest into process reliability. As an incentive, the buyer could order more than required or pay a higher than usual wholesale price. For the incentive case, the paper proposes both ex-ante and ex-post incentive mechanisms. The model proposed in the paper supports determining an optimal order quantity, an optimal wholesale price and an optimal process restauration investment. **Clemons and Slotnick (2016)** considered a similar situation where a buyer sources a product from a supplier, and where deliveries are subject to random disruptions. As in Hu et al. (2013), a disruption induces the loss of the entire delivery. The buyer has the option to source the product from a new second supplier in addition, who delivers the product at a lower initial quality, but without a disruption risk. If the buyer decides to contract the second supplier, the buyer needs to develop the new supplier by transferring knowledge at an investment cost. The model proposed in this paper supports the decision of whether or not to contract the second supplier, and it also supports calculating an optimal supplier development investment. **Pun (2014)** considered a scenario where a buyer may outsource a product either to a component manufacturer or to a company that also acts as a competitor in the same market than the buyer. To improve the quality of the buyer's product, the buyer or the suppliers can invest into process improvements that increase the reservation price of the end customers, leading to higher turnover. The paper supports the decisions of which supplier to select and how to improve the quality of the product, and it also illustrates how the process improvement affects competition.

Evaluating alternative supplier development measures

In situations where several supplier development programs are available, the buyer may want to concentrate its investment on a single or on a few very promising measures. In this case, mathematical models can support the relative evaluation and eventual ranking of the existing supplier development alternatives. As in the case of selecting suppliers for supplier development, our review of the literature indicated that decision analysis techniques were very popular in this particular field of research. **Govindan et al. (2010)**, for example, suggested a decision analysis procedure to identify suitable supplier development measures by investigating main criteria that affect the success of supplier development. First, the authors suggested using a survey to identify supplier development success criteria, such as competitive pressure, top management support, or supplier commitment. Secondly, they proposed an ISM approach to rank the criteria according to their improvement potential. The results of the method help selecting the right supplier development program for a particular application by making sure that those supplier attributes are addressed that would benefit most from development. **Dou et al. (2014a)** developed a grey analytical network process-based model to identify green supplier development programs (such as transferring employees with environmental expertise to suppliers or providing advice on green technologies to suppliers) that help improve the supplier's environmental performance. **Dou et al. (2014b)** applied the fuzzy scoring and DEMATEL (decision-making trial and evaluation laboratory) portfolio methods to develop an evaluation model for environmental supplier development programs taking into account different supplier performance factors, namely operational factors, environmental factors and especially low carbon management factors. The proposed model facilitates analysing the effectiveness of different supplier development programs. Similarly, **Routroy and Kumar (2014)** developed a fuzzy DEMATEL methodology to identify and assess supplier development enablers. Their method suggests that in a first step, supplier development enablers should be identified in a literature search, during brain storming sessions and during in-reviews. Subsequently, their DEMATEL method can be used to evaluate the impact of the supplier development enablers on the performance of a particular supplier development program. The results of their method support the selection and an efficient implementation of supplier development programs. **Bai and Sarkis (2014)** studied supplier development from a game-theoretical point of view. The authors considered different cooperative and non-cooperative scenarios and analyzed the profitability of different supplier development initiatives. The paper thus provides insights into how to determine two types of investments, knowledge investments and capital resources investments, required for developing a supplier. **Bai et al. (2016)** proposed a methodology that helps to evaluate and analyze investments in green supplier development programs using rough set theory and a fuzzy clustering approach. The developed model supports decisions on whether a buyer should invest in a supplier and which green supplier development program should be chosen to increase both the environmental and the overall business performance of the suppliers. **Awasthi and Kanan (2016)** finally developed a fuzzy Nominal Group Technique to identify criteria for evaluating green supplier development programs including rankings for different programs. Their model helps to select the most efficient green supplier development programs for implementation.

Indirect supplier development

Indirect supplier development programs have received less attention in the literature so far as compared to direct supplier development measures. One work in this area is the one of **Narasimhan et al. (2008)**, who studied how suppliers should respond to requests for quotes. The authors proposed that the buyer should share its knowledge about former winning quotes and procurement decisions with its suppliers to increases competition among them. The developed model uses a DEA and helps the supplier in preparing suitable quotes based on the knowledge about former winning quotes provided by the buyer. **Chao et al. (2009)** investigated a scenario in which both the supplier's and the buyer's process capabilities influence end product quality, and where both parties are asymmetrically informed about the process capability of the supplier. To induce the supplier to improve its process capabilities at an investment, the buyer may implement a contract that forwards a share of the product recall cost to the supplier. The contracts proposed in the paper use information obtained in a root cause analysis that reveals which supply chain member is responsible for the quality problems of the end product. The paper investigates how the proposed contracts influence the profit of the buyer and the quality of the end product. In addition, it studies how a menu of contracts can be used to screen the supplier's initial process capability.

Monitor and evaluate supplier development

After supplier development measures have been initiated, they need to be monitored and evaluated. Monitoring, in this context, refers to a continuous supervision of the supplier development activities while the activities are being implemented. The primary intention of monitoring is to make sure that the supplier development activities are implemented as intended, and that they contribute towards the goals of the buyer. In case it turns out during monitoring that the supplier development activities have a different effect than expected or that they have been implemented incorrectly, the buying company has to adjust or cancel the measures. Evaluation, in contrast, refers to an assessment of the supplier development activities after the activities have been completed. An evaluation of supplier development activities could include a cost-benefit-analysis, for example. The results of the evaluation step could be used to draw insights regarding the future implementation of supplier development activities.

Bai and Sarkis (2010) developed a model for evaluating the performance of alternative green supplier development programs. The objective of this approach is to aid organizations in prioritizing their investments in green supplier development programs. The authors applied rough set theory to identify supplier attributes and to link them to performance outcomes at the buyer. In doing so, this approach can assist the decision maker in evaluating which green supplier development programs should be improved and which programs are no longer required to increase environmental performance. **Bai and Sarkis (2011)** proposed a two-stage multi-method approach that helps organizations to identify which organizational practices and programs relate to supplier performance. This methodology integrates grey system with rough set theory, where the first method is used to support decision making and the second method for data mining. The proposed integrated method can then be used to continuously evaluate supplier development programs, which supports finding both problematic programs (that should be eliminated) and successful programs (that should be developed further). **Fu et al. (2012)** developed a grey-based DEMATEL methodology for managing, evaluating, and maintaining green supplier development programs. First, managers are asked to rate their existing green supplier development programs by linguistic terms (ranging from no influence to very high influence). Secondly, the DEMATEL method was applied to evaluate the success factors of green supplier development programs. The method was applied in a case study to illustrate its applicability.

Discussion

Table 2a provides an overview of all identified articles and their content classification as described in the conceptual framework in Section 2 (see Figure 2). Table 2b summarizes the literature sample with regard to the technical analysis of the modelling framework (see Figure 3). In Tables 2a and 2b, works are marked with an X if they support decisions in a specific phase of the supplier development process. Works marked with (X) partially support the respective phase of the SD process, but the focus of the model is on a different phase. Empty fields indicate that the respective model does not support the respective phase or attribute in question, or that no information on the respective phase or attribute could be derived from the paper.

Regarding the support of the three major steps of supplier development defined above, it can be seen that the implementation of supplier development measures received the most attention in prior research (~65.2% of the sampled papers), followed by the preparation of supplier development measures (~34.8% of the sampled papers). The monitoring and evaluation of supplier development measures (~10.9% of the sampled papers) received the least attention. With respect to the third supplier development phase, we found that especially works that propose methods for monitoring supplier development activities are rare.

Author(s)	Content analysis									
	SD phase			Supplier attributes						Measures
	Pre	Dev	Mon	Co	Qu	Ca	SL	Fi	Su	
Agrawal et al. (2015)		X			X					*$ Capital*
Akman (2015)	X			(X)	(X)		(X)		X	
Araz und Ozkarahan (2007)	X		(X)	(X)	(X)					*Knowledge, Training*
Awasthi and Kannan (2016)		X							X	
Bai and Sarkis (2010)			X					X	X	
Bai and Sarkis (2011)			X					X	X	
Bai and Sarkis (2014)		X				X				*$ Capital, Knowledge*
Bai et al. (2016)		X	(X)					X	X	
Bhattacharyya and Guiffrida (2015)		X					X			*$ Capital*
Chao et al. (2009)		X			X					*Incentive contract*
Chen et al. (2015a)	X				X					
Chen et al. (2015b)		X			X					*$ Capital*
Clemons and Slotnick (2016)		X			X					*Knowledge transfer/investment*
Cui et al. (2017)		X					X			*$ Capital*
Dalvi and Kant (2017)	X									
Dou et al. (2014a)		X							X	
Dou et al. (2014b)		X							X	
Forker and Mendez (2001)	X				X					
Friedl and Wagner (2012)		X		X						*$ Capital*
Friedl and Wagner (2016)		X		X						*$ Capital*
Fu et al. (2012)			X						X	
Glock (2016)	(X)	X		X						*Training*
Govindan et al. (2010)		X								
Hu et al. (2013)		X			X					*Incentive contract*
Kim (2000)		X		X						*$ Capital*
Kumar et al. (2012)	X			X			X			
Lima-Junior Carpinetti (2016)	X			X			X			
Liu et al. (2000)	X			X	X		X			*Improvement targets*
Lolli et al. (2016)		X			X					*Supplier training*
Marchi et al. (2016)		X			X					*Capital*
Mizgier et al. (2017)		X								*$ Capital*
Narasimhan et al. (2008)		X		X	X		X			*Information*
Omurca (2013)	X			X						
Osiro et al. (2014)	X			(X)	(X)		(X)			
Proch et al. (2017)		X		X						*$ Capital*
Pun (2014)		X			X					*$ Capital*
Qi et al. (2015)		X				X				*$ Capital*
Rezaei et al. (2015)	X	(X)		X						
Routroy and Kumar (2014)		X		X	(X)		(X)			
Routroy and Pradhan (2014)	X			(X)	(X)	(X)	(X)	(X)	(X)	
Sharma and Yu (2013)	X			(X)	(X)	(X)	(X)	(X)	(X)	
Talluri and Narasimhan (2004)	X									
Talluri et al. (2010)		X						(X)		*$ Capital*
Trapp and Sarkis (2016)	X	(X)							X	*Training*
Wang et al. (2014)		X			X		X			*General*
Zhu et al. (2007)		X			X					*$ Capital*

Table 2a: Content-classification of the sampled papers in light of the conceptual framework developed in this paper

With respect to the buying companies' goals in engaging in supplier development, Table 2a shows that the improvement of the buying company's cost position (37.0%), product quality (43.5%), service levels (26.1%), and sustainability (23.9%) have most frequently been studied in the sampled papers. Improving the capacity of the supplier (8.7%) or the supplier's financial position (13.0%) have attracted less attention. Most popular supplier development measures are direct investments ($ capital) and training.

Technical analysis					
Author(s)	Model type			Solution technique	Uncertainty
	Optimization	Heuristics	MCDM		
Agrawal et al. (2015)	X			*Dynamic programming*	*Quality improvement capability*
Akman (2015)			X	*VIKOR*	/
Araz und Ozkarahan (2007)			X	*PROMETHEE*	/
Awasthi and Kannan (2016)		(X)	X	*(Fuzzy) VIKOR*	/
Bai and Sarkis (2010)		X		*Rough set*	/
Bai and Sarkis (2011)		X		*Rough set*	/
Bai and Sarkis (2014)	X			*Dynamic programming*	/
Bai et al. (2016)		X		*Rough set*	/
Bhattacharyya and Guiffrida (2015)		X		*Metaheuristics*	/
Chao et al. (2009)	X			*Dynamic programming*	*Supplier´s process capability*
Chen et al. (2015a)	X			*Non-linear programming*	*Quality improvement capability*
Chen et al. (2015b)	X			*Dynamic programming*	/
Clemons and Slotnick (2016)		X		*Simulation*	*Market demand; supply disruption*
Cui et al. (2017)	X			*Non-linear programming*	*Market demand; inventory inaccuracies*
Dalvi and Kant (2017)		(X)	X	*(Fuzzy) AHP*	/
Dou et al. (2014a)		(X)	X	*(Grey) ANP*	/
Dou et al. (2014b)		(X)	X	*(Fuzzy) DEMATEL*	/
Forker and Mendez (2001)			X	*DEA*	/
Friedl and Wagner (2012)	X			*Stochastic P.*	*Market price; supplier's unit cost*
Friedl and Wagner (2016)	X			*Stochastic P.*	*Market price; supplier's unit cost*
Fu et al. (2012)		(X)	X	*(Grey) DEMATEL*	/
Glock (2016)	X			*Non-linear programming*	/
Govindan et al. (2010)			X	*ISM*	/
Hu et al. (2013)	X			*Dynamic programming*	*Process restauration*
Kim (2000)	X			*Non-linear programming*	
Kumar et al. (2012)		X		*Fuzzy logic*	/
Lima-Junior Carpinetti (2016)		(X)	X	*(Fuzzy) TOPSIS*	/
Liu et al. (2000)			X	*DEA*	/
Lolli et al. (2016)	X			*Integer programming*	/
Marchi et al. (2016)	X			*Non-linear programming*	*Capacity improvement potential*
Mizgier et al. (In Press)	X			*Non-linear programming*	*Investment*
Narasimhan et al. (2008)			X	*DEA*	/
Omurca (2013)		X		*Rough set*	/
Osiro et al. (2014)		X		*Fuzzy logic*	/
Proch et al. (2017)	X			*Non-linear programming*	/
Pun (2014)	X			*Dynamic programming*	/
Qi et al. (2015)	X			*Dynamic programming*	*Capacity improvement potential*
Rezaei et al. (2015)			X	*BWM*	/
Routroy and Kumar (2014)		(X)	X	*(Fuzzy) DEMATEL*	/
Routroy and Pradhan (2014)			X	*ISM*	/
Sharma and Yu (2013)			X	*AHP*	/
Talluri and Narasimhan (2004)			X	*DEA*	
Talluri et al. (2010)	X			*Non-linear programming*	*Investment*
Trapp and Sarkis (2016)	X			*Integer programming*	/
Wang et al. (2014)	X			*Dynamic programming*	*Market demand; process yield*
Zhu et al. (2017)	X			*Dynamic programming*	

Table 2b: Model-classification of the sampled papers in light of the conceptual framework developed in this paper

Concerning model types, Table 2b shows that optimization methods have been employed in 21 of the sampled papers, with dynamic programming (9 papers) and non-linear programming (8 papers) being the most frequently used methods. In addition, MCDM approaches have been popular in the sampled papers (17 papers). In this category, the DEA method (4 papers) has most frequently been employed. 15 papers developed heuristic models. Within this modelling category, Rough Set Theory (4 papers) has most often been used. Surprisingly, only one of the sampled papers employed a simulation approach.

In addition, we could observe that 18 of the sampled papers implemented the developed decision support model using real data. Table 2c gives an overview of method implementation based on real data regarding also the context of implementation.

Author(s)	Method implementation based on data availability		Context of implementation	
	hypothetical	actual	Industrial sector	OEM / supplier location
Agrawal et al. (2015)	-	-	-	-
Akman (2015)		x	automobile	Turkey
Araz und Ozkarahan (2007)	x	-	-	-
Awasthi and Kannan (2016)		x	automobile	India
Bai and Sarkis (2010)	x	-	-	-
Bai and Sarkis (2011)	x	-	-	-
Bai and Sarkis (2014)	x			
Bai et al. (2016)	x	-	-	-
Bhattacharyya and Guiffrida (2015)	x	-	-	-
Chao et al. (2009)	x	-	-	-
Chen et al. (2015a)	-	-	-	-
Chen et al. (2015b)	x	-	-	-
Clemons and Slotnick (2016)	x	-	-	-
Cui et al. (2017)	-	x	tobacco	China
Dalvi and Kant (2017)	-	-	-	-
Dou et al. (2014a)	-	x	agricultural equipment	China
Dou et al. (2014b)			automobile	China
Forker and Mendez (2001)	-	x	electronic	North America
Friedl and Wagner (2012)	-	-	-	-
Friedl and Wagner (2016)	x	-	-	-
Fu et al. (2012)	-	x	telecommunications equipment	China
Glock (2016)	x	-	-	-
Govindan et al. (2010)	-	x	automobile	India
Hu et al. (2013)	-	-	-	-
Kim (2000)	x	-	-	-
Kumar et al. (2012)		x	manufacturing	India
Lima-Junior Carpinetti (2016)	-	x	automobile	-
Liu et al. (2000)	-	x	agricultural equipment	-
Lolli et al. (2016)	-	x	-	-
Marchi et al. (2016)	x	-	-	-
Mizgier et al. (2017)	-	x	automobile	global
Narasimhan et al. (2008)	x	-	-	-
Omurca (2013)		x	telecommunications	global
Osiro et al. (2014)	-	x	automobile	global
Proch et al. (2017)	x	-	-	-
Pun (2014)	-	-	-	-
Qi et al. (2015)	x	-	-	-
Rezaei et al. (2015)	-	x	high-tech	China
Routroy and Kumar (2014)	-	x	manufacturing	India
Routroy and Pradhan (2014)	-	x	gear manufacturing	India
Sharma and Yu (2013)	-	-	-	-
Talluri and Narasimhan (2004)	-	x	telecommunications	global
Talluri et al. (2010)	x	-	-	-
Trapp and Sarkis (2016)	x	-	-	-
Wang et al. (2014)	-	-	-	-
Zhu et al. (2007)	-	-	-	-

Table 2c: Method implementation based on real data

Conclusion

This paper presented a systematic review of the literature on decision support models for supplier development. First, the paper proposed a framework for supplier development based on the strategic supplier relationship management process and then categorized the supplier development process into three major steps, namely 1) a preparation phase, 2) a development phase, and 3) a monitoring phase. Subsequently, papers that were found during the literature search were assigned to the categories of the proposed framework and discussed. In total, 46 papers that proposed decision support models for supplier development were identified in this literature review.

Our analysis showed that decision support models for supplier development have attracted an increased attention in recent years, with publication numbers increasing strongly since 2010 (over 60% of the sampled articles were published since 2014). Our review also indicated that the proposed decision support approaches frequently combine different issues of supplier relationship management and mix supplier development with supplier evaluation and selection. A majority of the sampled papers develops decision support models for supplier selection for development, including grouping or ranking techniques to identify relevant suppliers and capabilities for development as well as for comparing and finding suitable supplier development measures. Our review also shows that environmental sustainability was often addressed, in particular in recent years, and that several contributions discussed the development of green supplier capabilities. In addition, uncertainty regarding performance measures and ambiguous and imprecise appraisals, which is a typical characteristic of supplier development, is often captured by introducing fuzzy or grey approaches.

This review extends the existing literature on supplier development by giving an exhaustive overview of works that develop decision support models for supplier development, and it may support researchers in identifying promising areas for future research. The results of our literature review indicate the following research recommendations (*RR*):

- *RR 1:* Comparing the number of works that develop decision support models with the high number of empirical and conceptual works on supplier development and the importance of this topic in practice, we conclude that more quantitative models are needed to support managerial decision making in this area.
- *RR 2:* Many existing models support only selected steps of the supplier development process. We hypothesize, however, that more models are needed that adopt an integrated view of the supplier development process (i.e., that support several or ideally even all steps of the supplier development process) to maximize the benefits supplier development offers, and to improve the performance of the supplier as good as possible.
- *RR 3:* We could observe an increase in publication numbers of decision support models for environmentally sustainable supplier development initiatives and programs in recent years. However, social sustainability issues, such as worker welfare and ethical issues (Lu et al. 2012) or integrative approaches following the triple bottom line (cf. Elkington 1997) are missing to a large extent in such works.
- *RR 4:* Optimization models that calculate optimal investment volumes for supplier development programs, and in particular investment risks related to supplier development programs, are rather scarce. More research of this kind is needed for managerial decision support. In addition, only one work employed a simulation approach for managerial decision support, which could point towards research potential in this area.
- *RR 5:* Works that develop decision support models for monitoring the performance and success of implemented supplier development measures are still rare. Apart from the development of appropriate measurement approaches, optimal stopping models that indicate when to interrupt supplier development programs could provide valuable insights. Due to uncertainties arising in supplier development projects, the completion time of such projects can only be imperfectly estimated ex ante, and the estimation is

likely to be revised later as new information is gathered in the development process, which may include project termination (cf. Chi et al. 1997).

- *RR 6:* In light of an increasing number of works on financial supply chain management, the topic of improving the financial position of suppliers seems to be under-researched in supplier development models. Given a reduction in the availability of loans in recent years, which is often referred to as ‘credit crunch’, strong financial asymmetries among the supply chain parties threaten the competitiveness of the whole supply chain and may create an incentive to intensify investments into suppliers (cf. Marchi et al. 2016).
- *RR 7*: Only About 39% of the sampled papers show an actual implementation of the developed decision support model based on actual cases and real data. More applications using real world scenarios are needed for illustrating the benefits and practicability of the developed models.

Although the paper at hand used an established and scientifically rigorous research methodology, the paper has some limitations. First, the sample of the literature review was limited to articles published in peer-reviewed journals. Including other works, such as book chapters or conference proceedings, could have resulted in additional relevant works and further insights. Similarly, the keywords used in the database search and the selection filters applied in searching the literature may have led to the exclusion of potentially relevant works. Secondly, assigning the selected papers to the categories of the developed conceptual framework and the phases of supplier development (content categories) involved some amount of judgment, as some papers did not clearly state their specific focus within the supplier development process as well as a specific supplier development measure. Given the still limited number of decision support models and the importance of supplier development initiatives for long-term business success, this review could be seen as starting point for future works that address the identified research gaps.

Appendix

Review	**Focus**		**Review type**
	Content	**Methods**	
Wetzstein et al. (2016)	Supplier selection	Empirical / normative analytical	Systematic
Zimmer et al. (2016)	Sustainable supplier management	Normative analytical	Systematic
Karsak and Dursun (2016)	Supplier selection	Normative analytical (stochastic/fuzzy)	Systematic
Yawar and Seuring (2015)	Social issues in supply chains	Empirical / Normative analytical	Systematic
Sillanpää et al. (2015)	Supplier development	Empirical (case studies)	Narrative
Govindan et al. (2015)	Green supplier evaluation/selection	Normative analytical (MCDA)	Narrative
Noshad and Awasthi (2015)	Supplier quality development	Empirical (industry practices) / Normative analytical	Narrative
Sucky and Durst (2013)	Supplier development	Empirical	Systematic
Igarashi et al. (2013)	Green supplier selection	Empirical / Normative analytical	Systematic
Chai et al. (2013)	Supplier selection	Normative analytical (MCDA)	Systematic
Gimenez and Tachizawa (2012)	Green supplier evaluation	Empirical	Systematic
Wu and Barnes (2011)	Supplier selection	Normative analytical	Narrative

		(MCDA)	
Ho et al. (2010)	Supplier evaluation and selection	Normative analytical (MCDA)	Narrative
Jain et al. (2009)	Supplier selection	Normative analytical (MCDA)	Narrative
Aissaoui et al. (2007)	Supplier selection	Normative analytical (MCDA)	Narrative
De Boer et al. (2001)	Supplier selection	Normative analytical (MCDA)	Narrative
Weber et al. (1991)	Supplier selection	Normative analytical	Narrative

Table A1: Related literature reviews

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