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A review of methods supporting supplier selection

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Abstract

In this paper we present a review of decision methods reported in the literature for supporting the supplier selection process. The review is based on an extensive search in the academic literature. We position the contributions in a framework that takes the diversity of procurement situations in terms of complexity and importance into account and covers all phases in the supplier selection process from initial problem definition, over the formulation of criteria, the qualification of potential suppliers, to the final choice among the qualified suppliers. Moreover, we propose decision methods and techniques that previously have not been suggested in a purchasing context. The proposed methods specifically accommodate for buying situations for which few or no decision models were published so far. This paper extends previous reviews by Weber et al. (Eur. J. Oper. Res. 50 (1991) 2), Holt (Int. J. Project Mange. 16 (1998) 153) and Degraeve et al. (Eur. J. Oper. Res. 125 (1) (2000a) 34) in that it classifies the models in a framework developed by De Boer (Ph. D. Thesis, University of Twente, Enschede, The Netherlands, 1998) which recognises more steps in the buying process than only the final among qualified suppliers and accommodates for the diversity of procurement situations. © 2001 Published by Elsevier Science Ltd.

Keywords: Supplier selection; Decision models

1. Motivation for the review

With the increasing significance of the purchasing function, purchasing decisions become more important. As organisations become more dependent on suppliers the direct and indirect consequences of poor decision-making become more severe. For example, in industrial companies, purchasing's share in the total turnover typically ranges between 50–90% (Telgen, 1994), making decisions about purchasing strategies and operations primary determinants of profitability. In addition, several developments further complicate purchasing decision-making. Globalisation of trade and the Internet enlarge a purchaser's choice set. Changing customer preferences require a broader and faster supplier selection. Public Procurement regulations demand more transparency in decision-making. New organisational forms lead to the involvement of more decision-makers. Fig. 1 shows how these developments impact on the complexity and importance of purchasing decisions.

These developments strongly urge for a more systematic and transparent approach to purchasing decision-making, especially regarding the area of supplier selection (see e.g. Carter et al., 1998). Contemporary operations research (OR) offers a range of methods and techniques that may support the purchasing decision-maker in dealing with the increased complexity and importance of his/her decisions. Examples of such techniques are multi-criteria decision aid, problem structuring approaches, mathematical programming and data mining techniques. OR-models may enhance the *effectiveness* of purchasing decisions by:

- aiding the purchaser in solving the 'right problem', e.g. refraining from dropping a supplier when the delivery problems are actually caused by feeding the supplier with outdated information;
- aiding the purchaser in taking more and relevant alternatives criteria into account when making purchasing (management) decisions, e.g. more long-term considerations when deciding on make-or-buy;

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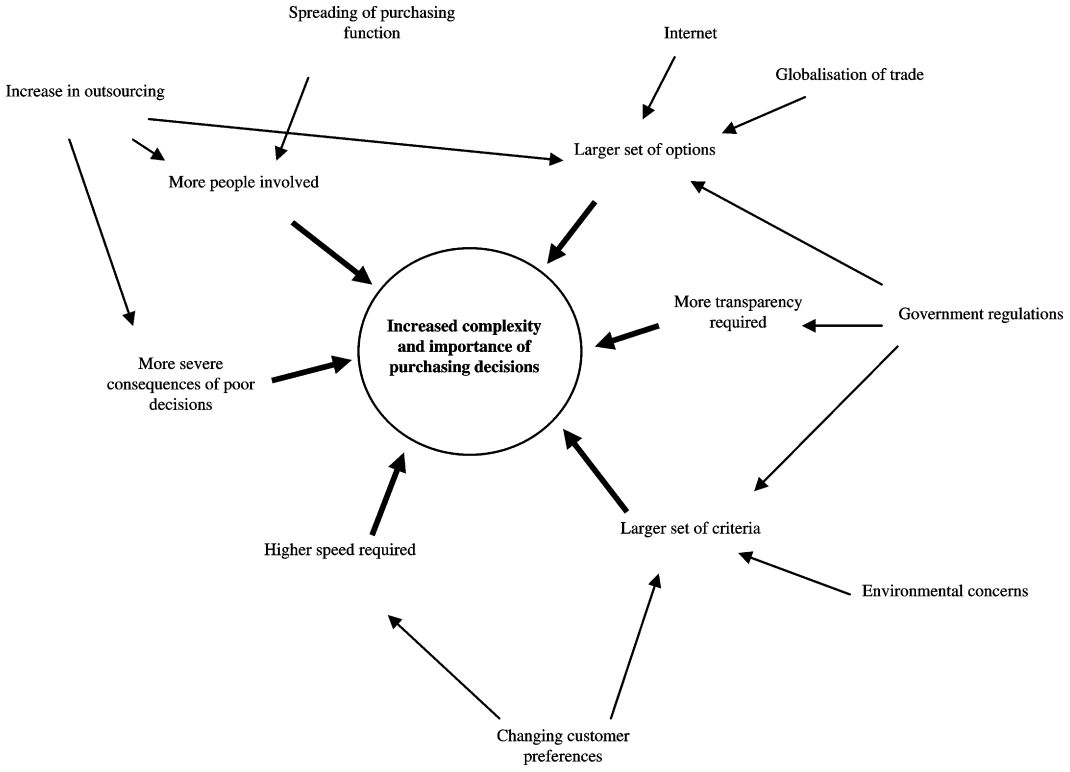

Fig. 1. Impact of developments on the complexity of initial purchasing decisions (De Boer, 1998).

- aiding the purchaser to more precisely model the decision situation, e.g. dealing specifically with intangible factors and group decision making.

In addition, OR-models may improve the *efficiency* of purchasing (management) decision making by:

- enabling automated and faster computation and analysis of decision making information, e.g. data on suppliers found on the Internet;
- enabling more efficient storage of purchasing decision making processes and access to this information in future cases, e.g. saving files that contain criteria-structures for supplier evaluation;
- eliminating redundant criteria and alternatives from the decision or evaluation process, e.g. in extensive and expensive supplier audit programmes;
- facilitating more efficient communication about and justification of the outcome of decision-making processes, e.g. when reporting to management or suppliers.

Moreover, we dissociate ourselves from the traditional scepticism towards the use of decision models in purchasing implying that the mathematical nature of the models is incompatible with the highly emotion and intuition driven practice of purchasing decision-making. Various researchers have reported on the benefits of a systematic approach to supplier selection decision-making (see e.g. Vonderembse and Tracey, 1999; Weber, 1991; De Looff, 1997). The key-point is to consider decision models as instruments for eliciting, communicating and scrutinising one's personal and subjective preference structures and uncertainties rather than a rigid format replacing this all.

Apart from covering the state-of-the-art decision models available at present, this paper extends previous reviews by Weber et al. (1991), Holt (1998) and Degraeve et al. (2000) in three ways.

First, we not only consider the final choice phase in the supplier selection process as Weber et al. (1991), Holt (1998) and Degraeve et al. (2000) do, but recognise several decision-making steps prior to the ultimate choice phase such as the formulation of criteria and the pre-qualification of (potential) suppliers.

Secondly, in the prescriptive framework we accommodate for the diversity of purchasing situations in recognising differences between first time buys, modified rebuys and straight rebuys of routine or strategic items. Degraeve et al. (2000) only evaluate the existing decision models for rebuy purchases. Weber et al. (1991) categorise the literature on supplier selection with regard to (1) the particular criteria mentioned in the article, (2) the purchasing environment and (3) the decision technique used. This approach may not be the most effective one for helping a purchaser to find an adequate decision method in a particular situation as a specific set of criteria may be accommodated by more than one method. Furthermore, the criteria mentioned by Weber et al. (1991) are highly situation specific. Also, Weber et al.

define the different purchasing environments quite broadly and vaguely as "JIT", "MRP", "general industrial purchasing" or a specific sector. Again, it does not follow why one decision method would be appropriate for a JIT environment and not for a MRP environment.

We argue that situational factors such as the *number of suppliers* available, the *importance of the purchase and/or the supplier relationship* and the amount and nature of *uncertainty* present, are far more determinative for the suitability of a certain decision method in a particular purchasing situation. Although several authors on this subject suggest a variety of factors to be taken into account (see for example Oxenfeldt, 1979; Pinsoneault and Kraemer, 1989), importance and complexity appear to be the main underlying determinants. In our discussion and overview we take these situational factors as the starting point for categorising and evaluating the decision models in the purchasing literature.

Thirdly, we also explore decision models and techniques in Operations Research that previously have not been considered for supporting the supplier selection process. In purchasing, methods and techniques from OR have so far almost exclusively been applied to operational and logistical decisions. Other levels and areas of decision-making such as make-or-buy, supplier selection and decisions about supply strategies have gained far less attention. In particular, we focus on buying situations for which few or no decision models were published so far.

The remainder of the paper is organised as follows. In Section 2 we present a prescriptive framework for classifying the available models for supplier selection decision support. In the third and fourth section respectively, we review the existing literature and propose decision methods and techniques that have not been previously suggested in a purchasing context. Finally, we will draw conclusions and give suggestions for future research.

2. Framework for the review

The framework we present for reviewing the supplier selection methods accommodates the diversity of situations in terms of complexity and importance found in the present-day purchasing practice on one axis. On the other axis it covers the different phases in the supplier selection process, ranging from (1) finding out exactly what we want to achieve by selecting a supplier (2) defining the criteria (3) pre-qualifying suitable suppliers to (4) making a final choice. The framework is shown in Table 1.

The different positions in the framework have different characteristics that are determinative for the suitability of the various methods. Below we explain the structure of the framework.

In order to incorporate complexity and importance into the framework we have combined the industrial

Table 1
The supplier selection framework (De Boer, 1998)

	New task	Modified rebuy (leverage items)	Straight rebuy (routine items)	Straight rebuy (strategic/bottleneck)
Problem definition	Use a supplier or not?	Use more, fewer or other suppliers?	Replacing the current supplier?	How to deal with the supplier?
	Varying importance	Moderate/high importance	Low/moderate importance	High importance
	One-off decision	Repeating decision	Repeating decision	Repeating evaluation
Formulation of criteria	No historical data on suppliers available	Historical data on suppliers available	Historical data on suppliers available	Historical data on suppliers available, yet very few actual selections
	No previously used criteria available	Previously used criteria available	Previously used criteria available	Previously used criteria available
	Varying importance			
Qualification	Small initial set of suppliers	Large set of initial suppliers	Large set of initial suppliers	Very small set of suppliers
	Sorting rather than ranking	Sorting as well as ranking	Sorting rather than ranking	Sorting rather than ranking
	No historical records available	Historical data available	Historical data available	Historical data available
Choice	Small initial set of suppliers	Small to moderate set of initial suppliers	Small to moderate set of initial suppliers	Very small set of suppliers (often only one)
	Ranking rather than sorting	Ranking rather than sorting	Ranking rather than sorting	Historical data available
	Many criteria	Also: how to allocate volume?	Fewer criteria	Evaluation rather selection
	Much interaction	Fewer criteria	Less interaction	Sole sourcing
	No historical records available	Less interaction	Historical data available	
	Varying importance	Historical data available	Model used again	
	Model used once	Model used again	Single sourcing rather than multiple sourcing	

Table 2
Classification of purchasing situations (Faris et al., 1967)

New task situation	Entirely new product/service; no previous experience No (known) suppliers High level of uncertainty with respect to the specification Extensive problem solving; group decision-making
Modified rebuy	New product/service to be purchased from known suppliers Existing (modified) products to be purchased from new suppliers Moderate level of uncertainty with respect to specification Less extensive problem solving
Straight rebuy	Perfect information concerning specification and supplier Involves placing an order within existing contracts and agreements

Table 3
Purchasing portfolio matrix (Kraljic, 1983)

	Low-supply risk	High-supply risk
Low-profit impact	*Routine items*	*Bottleneck items*
	Many suppliers	Monopolistic supply market
	Rationalise purchasing procedures	Long-term contracts
	Systems contracting	Develop alternatives (internally)
	Automate/delegate	Contingency planning
High-profit impact	*Leverage items*	*Strategic items*
	Many suppliers available	Few (difficult to switch) suppliers
	Competitive bidding	Medium/long-term contracts
	Short-term contracts	Supplier development/ partnership (develop alternatives 'externally')
	Active sourcing	Continous review

marketing literature with Kraljic's (1983) purchasing portfolio approach. Several authors, mostly from the field of industrial marketing, have studied complexity in purchasing and supplier selection (Fisher, 1970; Faris et al., 1967; and Bunn, 1993). Faris et al. (1967) distinguish three typical situations of varying complexity. Peculiar characteristics of these situations are presented in Table 2 below.

Obviously, new task situations are the most complex, at least in the sense that their level of uncertainty is the highest. Although the work by Faris et al. (1967) dates back more than 30 years, what remains useful is the classification as such despite the recent suggestions (see for example Thompson et al., 1998) that the way people (inter)act in the different situations has changed over the years due to the professionalisation of purchasing. The distinction between new task, modified rebuy and straight rebuy facilitates a recognisable 'entrance' for the purchaser and at the same time the classification comprises different levels of uncertainty about the purchase and the accompanying supplier selection.

A useful framework for covering additional dimensions of complexity as well as importance is Kraljic's (1983) portfolio approach. In this portfolio, the perceived importance and complexity of a purchasing situation is identified in terms of two factors: profit impact and supply risk. Profit impact includes such elements as the (expected) monetary volume involved with the goods and/or services to be purchased and the impact on (future) product quality. Indicators of supply risk may include the availability of the goods/services under consideration and the number of potential suppliers. Depending on the values of these factors, purchases (and therefore the related supplier selection decisions) can be grouped according to Kraljic's classification into strategic, bottleneck, leverage and routine purchases. This is illustrated in Table 3.

We have used the models by Faris et al. (1967) and Kraljic (1983) to develop a prescriptive framework of supplier selection situations that not necessarily coincides with supplier selection processes found in practice. Its prime purpose is to offer a purchaser a manageable number of typical, different supplier selection situations with associated ways of carrying out and organising the supplier selection process. To each of these situations, suitable methods (if available) will be assigned.

A first distinction made in our framework shown in Table 1, is that between one-off and/or first-time supplier selections versus repeated supplier selections. This distinction obviously follows the distinction between new task and rebuy very closely.

Within new task situations we may distinguish between situations of relative high importance and situations of relative low importance. However, irrespective of the importance, the basic sequencing, preparation and execution of the steps in the supplier selection process will be the same. For example, due to the unique character of the situation, the process can hardly be prepared in advance.

Within Rebuy situations we may expect more variety in terms of the organisation and execution of the steps in the supplier selection process.

In what follows, we show how these variations closely relate to the different situations in Kraljic's model.

In case of a routine item, there are many suppliers that could supply the item. However, because of the low value of the item, it will not pay off to frequently search for and select suppliers. Moreover, usually a whole set of related routine items (e.g. stationary items) is assigned to one (or two) suppliers in order to achieve a highly efficient ordering and administration procedure. The choice of the supplier is fixed for a reasonable period of time. Intermediate changes in the desired or required items are dealt with by the current supplier. Irrespective of such specific changes in the items requested and/or actually purchased, the appropriateness of the supplier is typically reconsidered periodically and if necessary a new (adaptive) selection will take place.

In case of bottleneck and strategic items, the choice of the supplier is also more or less fixed. Small changes in the specification of the items are automatically dealt with by the existing supplier. However, the reason for this is very different from that in the routine case. In these cases with a high supply risk, there are virtually no suppliers to choose from immediately, either because of a highly unique specification (i.e. a very strong resource tie between the buying company and the supplier) or because of the scarcity of the material. As a result, the choice set is often much smaller. Decision models are primarily used as means for periodic evaluation (monitoring) of the existing supplier.

Leverage items typically involve modified rebuy situations. There are many suppliers to choose from while the high value (and saving potential) of the items justifies proactive search and frequent selection of suppliers. However, the execution of the first steps in the process (problem definition, formulation of criteria and prequalification) is often decoupled from the final choice. The first three steps result in the so-called approved vendor lists. Final (frequent) choices are made from these approved vendor lists.

We note that the framework implicitly also addresses the impact of (inter-firm) relationships between the buyer and the seller on the selection process and the use of decision models. Depending on the substance and the strength of the relationship, the nature of the decision alternatives may differ. For example, in new task situations, where it is unlikely that the buying company has ever been in contact with the suppliers, the decision alternatives are primarily shaped by the offerings of these suppliers, i.e. the products or services they produce. In modified rebuys and especially in straight rebuys for strategic and bottleneck items however, the interaction between buyer and supplier is likely to be more intense and relationships may have been going on for a long time. Consequently, the selection concerns a choice between different sets of supplier characteristics, e.g. its processes, employees, culture, etc., rather than merely the specific products or services they provide.

3. Review of the existing literature

In this section, we present the results of an extensive literature search on decision support for supplier selection. Each type of method is explained in a general way. For the more interested reader, specific references to the papers in each category are added to pinpoint to the features of the proposed model or to the particular problem it tries to handle.

3.1. Search methodology

The sources used for our study consisted of scientific refereed journals, textbooks, doctoral dissertations and refereed conference proceedings. Publications in languages other than English and non-refereed professional publications were not included.

The search keys used were supplier selection, vendor selection, purchasing decision-making. Fig. 2 shows a possible array of methods that we might expect to find in the literature.

Qualitative methods may include tools for visualising and analysing the decision-maker's perception of a problem situation and tools for brainstorming about possible (alternative) solutions. The collection of quantitative methods comprises a wide variety of approaches. Data-mining techniques can be used to analyse similar decisions made in the past in order to derive general patterns and decision rules that may subsequently be used to improve the efficiency and effectiveness of future decisions. Optimisation techniques, such as linear programming, may aid a decision-maker in finding optimal solutions of problems that can be described as minimising some cost function. Multi-criteria decision analysis techniques support the decision-maker in systematically evaluating a set of alternatives on several criteria which may be all of a different nature.

Furthermore, we only included articles that report on a method or technique that specifically aims at

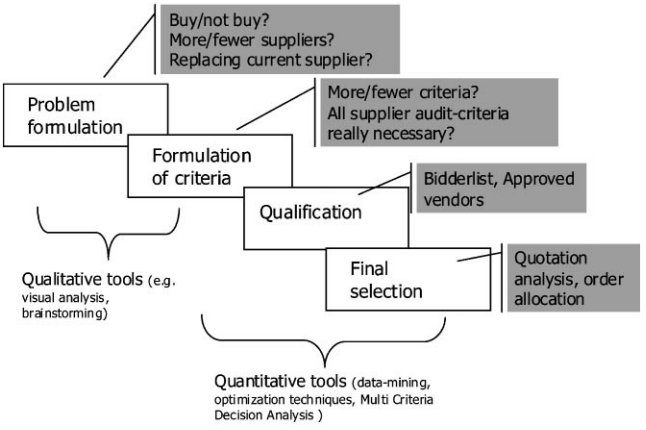

Fig. 2. Rough positioning of decision methods in supplier selection.

supporting a decision-maker in one or more of the four steps of the supplier selection process as defined in Section 2. This implies that articles merely describing the supplier selection process or the relevant criteria have not been included. Also, articles reporting on methods for monitoring an existing supplier relationship were excluded.

3.2. Decision methods for problem definition and formulation of criteria.

Decision methods for problem definition are methods that support the decision-maker in carefully questioning the need for a decision and the alternatives that seem to be available. In the case of supplier selection it thus involves determining what the ultimate problem is and why selecting one or more suppliers seems the best way to handle it. Our search did not identify any publication that treats the phase of problem definition in supplier selection. As to the phase of formulation of criteria, only two reports on techniques were found in the purchasing and supply literature. Mandal and Deshmukh (1994) propose interpretive structural modelling (ISM) as a technique based on group judgement to identify and summarise relationships between supplier choice criteria through a graphical model. They suggest it aids the purchaser by separating dependent criteria from independent criteria. The dependent criteria are important to consider in the final choice-phase while the independent criteria are important to consider for screening acceptable suppliers (prior to the final choice).

Vokurka, Choobineh and Vadi (1996) develop an expert system that covers multiple phases in the supplier selection process, among which the formulation of supplier selection criteria. The knowledge base of this expert system is developed using the existing literature and a senior purchasing manager. Subsequently, other (non-experts) users may consult the system to obtain suggestions as to which criteria to use in a particular situation.

3.3. Decision methods for pre-qualification of suitable suppliers

In this paper we define pre-qualification as the process of reducing the set of 'all' suppliers to a smaller set of acceptable suppliers. This process may be carried out in more than one step. However, the first step always consists of defining and determining the set of acceptable suppliers while possible subsequent steps serve to reduce the number of suppliers to consider. Basically therefore, pre-qualification is *sorting* process rather than a *ranking* process. However, the subtle yet important difference between sorting and ranking is often not explicitly made in the (purchasing) literature. Therefore, the articles we discuss here under the heading of pre-qualification have originally appeared as 'supplier selection' articles. We acknowledge that they could be used in the final choice phase but that their sorting nature makes them more suitable for pre-qualification. Our discussion of the literature proceeds as follows. First we explain the methods in basic terms. Next, we more specifically go into the references and show what has been done.

3.3.1. Categorical methods

Basically, categorical methods are qualitative models. Based on historical data and the buyer's experience current or familiar suppliers are evaluated on a set of criteria. The evaluations actually consist of categorising the supplier's performance on a criterion as either 'positive', 'neutral' or 'negative'. After a supplier has been rated on all criteria, the buyer gives an overall rating, again through ticking one of the three options. In this way, suppliers are sorted into three categories. The categorical method is discussed widely in (primarily) Purchasing textbooks, e.g. Zenz (1981) and Timmerman (1986).

3.3.2. Data envelopment analysis (DEA)

DEA is built around the concept of the 'efficiency' of a decision alternative. The alternatives are evaluated on benefit criteria (output) and cost criteria (input). The efficiency of an alternative (e.g. a supplier) is defined as the ratio of the weighted sum of its outputs (i.e. the performance of the supplier) to the weighted sum of its inputs (i.e. the costs of using the supplier). For each supplier, the DEA method finds the most favourable set of weights, i.e. the set of weights that maximises the supplier's efficiency rating without making its own or any other supplier's rating greater than one. In this way the DEA method aids the buyer in classifying the suppliers (or their initial bids) into two categories: the efficient suppliers and the inefficient suppliers. Weber has primarily discussed the application of DEA in supplier selection in several publications, see Weber and Ellram (1992), Weber and Desai (1996) and Weber et al. (1998). Apart from just categorising suppliers, Weber shows how DEA can be used as a tool for negotiating with inefficient suppliers. Other publications featuring DEA in supplier selection are Papagapiou et al. (1996) and Liu et al. (2000).

3.3.3. Cluster analysis (CA)

CA is a basic method from statistics which uses a classification algorithm to group a number of items which are described by a set of numerical attribute scores into a number of clusters such that the differences between items within a cluster are minimal and the differences between items from different clusters are maximal. Obviously, CA can also be applied to a group of suppliers that are described by scores on some criteria. The result is a classification of suppliers in clusters of comparable

Table 4
Classification of supplier choice models (adapted from Degraeve, et al., 2000a)

Single deal				Multiple deal			
	No inventory management over time		Inventory management over time	No inventory management over time		Inventory management over time	
Rating/linear weighting	Total cost approaches	Mathematical programming	Mathematical programming	Rating/linear weighting	Mathematical programming	Mathematical programming	Statistical
Timmerman (1986) (categorical method, linear averaging)	Timmerman (1986) (cost ratio method)	Chaudhry et al. (1993)	Buffa and Jackson (1983)	Grando and Sianesi (1996)	Rosenthal et al. (1995)	Bender et al. (1985)	Ronen and Trietsch (1988)
Barbarosoglu and Yazgac (1997)	Monczka and Trecha (1988)	Weber and Current (1993)			Current and Weber (1994)	Degraeve and Roodhooft (2000)	
Nydick and Hill (1992)	Smytka and Clemens (1993)	Pan (1989)			Akinc (1993)		
Gregory (1986)		Das and Tyagi (1994)			Sadrian and Yoon (1994)		
Willis et al. (1993)					Turner (1988)		
Li et al. (1997)					Benton (1991)		
Soukoup (1987)					Karpak et al. (1999)		
Thompson (1990)							
Thompson (1991)							
De Boer et al. (1998)							

suppliers. Hinkle et al. (1969) were the first to report this, followed some 20 years later by Holt (1998).

3.3.4. Case-based-reasoning (CBR) systems

CBR systems fall in the category of the so-called artificial intelligence (AI) approach. Basically, a CBR-system is a software-driven database which provides a decision-maker with useful information and experiences from similar, previous decision situations. CBR is still very new and only few systems have been developed for purchasing decision-making. Ng et al. (1995) developed a CBR-system for the pre-qualification of suppliers.

3.4. Decision models for the final choice-phase

The vast majority of the decision models found apply to the supplier choice phase of the buying process. Supplier choice models can be distinguished in three ways, as reported in Table 4.

Almost two-thirds of the existing supplier choice models can be characterised as 'single-deal' or 'package' models. These models consider the selection of a supplier for one product or a group of items at once. However, 'multiple-deal' models take into account interdependencies that could exist among different products in or across the productgroups. For example, a supplier may offer a larger discount based on total sales volume, irrespective of the product mix. Order costs could be minimised by combining orders for several products into one single order form. Quality audits for different products might be executed simultaneously. Multiple-deal models also take into account that a supplier may perform on different levels within a productgroup. For example, a supplier can produce high-quality single-sided printed circuit boards, but deliver low-quality four-layered PCBs.

Most of the existing literature on decision methods for supplier choice does not consider inventory management of the items purchased. Only a few models incorporate the decision to schedule orders over time with the vendor selection decision, although it can be argued that ordering policy and supplier choice influence one another. If, for example, due to inventory management reasons (e.g. perishable inventory) frequent ordering is necessary, a supplier with a low unit price but a high-ordering cost (e.g. no EDI-system) can generate a higher total cost than a supplier with a higher unit price and an EDI-system. Another example is the trade-off between receiving a quantity discount and the inventory holding costs when buying larger lotsizes.

A third distinction concerns the specific technique used in modelling the choice phase. As in the section on methods for supplier qualification, we first explain each technique in basic terms and then go into the references to show what has been done.

3.4.1. Linear weighting models

In linear weighting models weights are given to the criteria, the biggest weight indicating the highest importance. Ratings on the criteria are multiplied by their weights and summed in order to obtain a single figure for each supplier. The supplier with the highest overall rating can then be selected. This basic linear weighting model is described mostly in Purchasing textbooks, see e.g. Zenz (1981) and in Timmerman (1986). Over the past 10 to 15 years a wide variety of slightly different linear weighting models have been suggested for supplier choice.

A first adaptation concerns the compensatory nature of the basic linear weighting model. In a compensatory model a high rating on one criterion can compensate a low rating on another criterion, whereas in non-compensatory models different minimum levels for each criterion are required. The Outranking approach suggested by De Boer et al. (1998) can be described as quasi-compensatory. This approach among other things allows the buyer to in advance specify limits to the compensation for bad scores on one or more criteria. Grando and Sianesi (1996) suggest their rating model to be non-compensatory since they do not combine ratings on different criteria into one overall rating, but only provide separate information to the decision maker. However, this seems not to give enough guidance in the practical case implementation of their model, where they still suggest applying weights to the different criteria.

Gregory (1986), who introduces two methods for splitting orders among suppliers that receive the same maximum rating constitutes a second adaptation.

Thirdly, a large number of adaptations have been suggested in order to make linear weighting models better capable of dealing with the uncertainty and imprecision that inevitably surrounds supplier choice in practice.

Soukoup (1987) proposes a simulation-based approach to account for uncertainty with respect to the demand for the item or service purchased.

Some adapted models specifically account for the imprecision of the rating mechanism itself. With imprecision we refer to the difficulty of determining the score of a supplier on a criterion or the importance of some criterion with a high degree of precision. Nydick and Hill (1992), Barbarosoglu and Yazgaç (1997), Narasimhan (1983) and Masella and Rangone (2000) propose the use of the analytic hierarchy process (AHP) to deal with imprecision in supplier choice. In short, AHP circumvents the difficulty of having to provide point estimates for criteria weights as well as performance scores in the basic linear weighting model. Instead, using AHP the buyer is only required to give verbal, qualitative statements regarding the relative importance of one criterion versus another criterion and similarly regarding the relative preference for one supplier versus another on a criterion. Sarkis and Talluri (2000) propose the use of the analytical network process (ANP), a more sophisticated version of AHP, for supplier selection. Willis et al. (1993) also use such pairwise comparisons among suppliers, measuring each criterion in terms of its specific unit of analysis. Another group of authors has suggested various statistical techniques to deal with imprecision when using linear weighting models. Williams (1984) proposes the use of conjoint-analysis in deriving criteria weights. Min (1994) and Petroni and Braglia (2000), respectively, apply the so-called 'indifference trade-off' method and principal component analysis for essentially the same purpose. Although the techniques differ, they have in common that the buyer does not directly have to provide precise numerical criteria weights. Thompson (1990, 1991) proposed Monte Carlo simulation and the Thurston Case V scaling technique, respectively. Again, the buyer does not directly have to set criteria weights and assign performance scores on the criteria. Instead, it suffices to give ranges of scores or simply qualitative rank-order information. However, the use of these statistical methods will clearly not be straightforward for most users and make the process quite cumbersome.

Finally, a number of authors suggests to use fuzzy sets theory (FST) to model uncertainty and imprecision in supplier choice situations. In short, FST offers a mathematically precise way of modelling vague preferences for example when it comes to setting weights of performance scores on criteria. Simply stated, FST makes it possible to mathematically describe a statement like: "criterion X should have a weight of *around* 0.8". FST can be combined with other techniques to improve the quality of the final tools. An example is presented by Morlacchi (Morlacchi, 1997; Morlacchi et al., 1997), who develops a model that combines the use of fuzzy set with AHP and implement it to evaluate small suppliers in the engineering and machine sectors. In a subsequent development of the work, Morlacchi (1999) focuses on the design process of such supplier evaluation model, pointing to the advantages and the disadvantages of using hybrid approaches of techniques. In addition, Li et al. (1997) and Holt (1998) discuss the application of FST in supplier choice.

3.4.2. Total cost of ownership (TCO) models

TCO-based models attempt to include all quantifiable costs in the supplier choice that are incurred throughout the purchased item's life cycle. Following Ellram (1994) a distinction can be made between (a) pre-transaction (b) transaction and (c) post-transaction costs. TCO-based models for supplier choice basically consists of summarisation and quantification of all or several costs associated with the choice of vendors and subsequently adjusting or penalising the unit price quoted by the supplier with this figure in some way. For large organisations with computerised cost accounting systems Timmerman (1986) proposes the so-called cost-ratio method. This method collects all costs related to quality, delivery

and service and expresses them as a benefit or penalty percentage on unit price. Monczka and Trecha (1988) and Smytka and Clemens (1993) combine a total cost approach with rating systems for criteria such as service and delivery performance for which it is more difficult to obtain the cost figures. All these total cost approaches are single-deal models and applied to relatively simple cases where cost data can be gathered using a spreadsheet.

3.4.3. Mathematical programming models

Given an appropriate decision setting, MP allows the decision-maker to formulate the decision problem in terms of a mathematical objective function that subsequently needs to be maximised (e.g. maximise profit) or minimised (e.g. minimise costs) by varying the values of the variables in the objective function (e.g. the amount ordered with supplier X). On the one hand, it may be argued that MP-models are more objective than rating models because they 'force' the decision-maker to explicitly state the objective function. At the other hand, MP-models often only consider the more quantitative criteria.

Apart from Chaudhry et al. (1993), Weber and Current (1993), Pan (1989), Das and Tyagi (1994) and Buffa and Jackson (1983) all mathematical programming models consider several products simultaneously. Many of the mathematical programming models (Pan, 1989; Chaudhry et al., 1993; Rosenthal et al., 1995; Sadrian and Yoon, 1994) assume predetermined levels on quality, service and delivery constraints. Weber and Current (1993) overcome this problem by using more complex weighting and constraint methods and presenting trade-off curves among the multiple objectives as decision support to purchasing managers. Weber and Desai (1996) propose data envelopment analysis (DEA) for evaluation of vendors that were already selected. Weber, Current and Desai (1998) combine MP and the DEA method to provide buyers with a tool for negotiations with vendors that were not selected right away as well as to evaluate different numbers of suppliers to use (Weber et al., 2000). Karpak et al. (1999) use goal programming to minimise costs and maximise quality and delivery reliability when selecting suppliers and allocating orders between them. Some of the mathematical programming models (Chaudhry et al., 1993; Rosenthal et al., 1995; Sadrian and Yoon, 1994; Ganeshan et al., 1999) focus on the modelling of specific discounting environments. Akinc (1993) concentrates on decision support regarding the number of suppliers. Benton (1991) presents a heuristic procedure to solve the multiple item problem with a non-linear objective function. Current and Weber (1994) use facility location modelling constructs for the vendor choice problem. Das and Tyagi (1994) develop a decision support system for a wholesaler where the choice of the manufacturer is only one of several factors that has to be optimised in order to minimise the total cost of the wholesaling service. Other issues include selecting warehouses, assigning transportation modes and determining the service level to retailers. Only Bender et al. (1985), Buffa and Jackson (1983) and Degraeve and Roodhooft (2000) simultaneously consider the inventory management and supplier choice decisions. However, in Bender et al. (1985) the mathematical programming model formulation is not included while Buffa and Jackson (1983) only solve a single-item problem. Degraeve and Roodhooft (1998–2000) develop a mathematical programming model that minimises the total cost of ownership of the supplier choice and inventory management policy using activity-based costing information. Degraeve et al. (2000) extend this methodology to the service sector in developing an airline selection model for the procurement of business travel. Finally, Ghoudsypour and O'Brien (1998) combine AHP and MP in order to take into account tangible as well as intangible criteria and to optimise order allocation among suppliers.

3.4.4. Statistical models

Statistical models deal with the stochastic uncertainty related to the vendor choice. Although stochastic uncertainty is present in most types of purchasing situations, e.g. by not knowing exactly how the internal demand for the items or services purchased will develop, only very few supplier choice models really handle this problem. To our knowledge, the published statistical models only accommodate for uncertainty with regard to one criterion at a time. Ronen and Trietsch (1988) develop a decision support system for supplier choice and ordering policy in the context of a large one/off project where the order lead time is uncertain. Soukoup (1987) introduces a simulation solution for unstable demand in his rating model.

3.4.5. Artificial intelligence (AI)-based models

AI-based models are based on computer-aided systems that in one way or another can be 'trained' by a purchasing expert or historic data. Subsequently, non-experts who face similar but new decision situations can consult the system. Examples of methods based on artificial intelligence (AI) technology that have been applied to supplier choice include neural networks and expert systems. Although only few examples of AI methods applied to the supplier evaluation problem can be found in the literature to date it is important to investigate these methods for their potentialities. Because of newness of some methods, such as Internet-based technology, only few examples with a demonstrative character are already available.

One of the strengths of methods such as Neural Networks is that they do not require formalisation of the decision-making process. In that respect, Neural Networks can cope better with complexity and uncertainty

than 'traditional methods', because AI-based approach are designed to be more like to human judgement functioning.

The user of the system only has to provide the Neural Network with the characteristics of the current situation, e.g. the performance of the supplier on the criteria. The Neural Network subsequently makes the actual trade-off for the user, based on what it has 'learned' from the expert or cases in the past. At the same time, this strength can be seen as a weakness because it also implies that the user of the Neural Network will not be able to explain the trade-off to others, for example to suppliers that will not receive business. This makes Neural Networks primarily suitable for situations where external justification is less important or as a 'shadow' method in combination with a traditional method. Albino and Garavelli (1998) present a decision support system based on Neural Networks. The model is an adaptive backpropagation network for subcontractor rating for construction firms. This type of network learns to rate subcontractors directly on the basis of some examples and does not require formalisation of the decision-maker expertise in terms of decision-rules.

Khoo et al. (1998) discuss the potential use of an Internet-based technology called intelligent software agents (ISAs). ISA's are generally used for automating the procurement of goods. The authors suggest different types of agents — learning agents and shopping agents — that can be applied to the supplier selection problem. The focus is on the development of a simple model to demonstrate the effectiveness of using intelligent software agents for electronic sourcing.

Another AI technology, case-based reasoning (CBR) systems is proposed by Cook (1997). This technology is very new and only a few CBR systems have been developed for the use in purchasing decision-making, but some characteristics of CBR systems such as the capability to use information from previous negotiations and the easy training of the system, make them interesting in connection with supplier choice.

An example of CBR Systems, developed by Ng et al. (1995) for contractor pre-qualification was already discussed in the previous section.

Another AI-technology used in supplier evaluation is expert systems. Vokurka et al. (1996) developed an expert system able to support also the supplier choice phase.

3.5. Assignment of the supplier selection literature to the framework

The assignment of the literature described above to the framework proceeds along three criteria. These criteria are operationalisations of the situational complexity and importance. At the outset of our paper we defined these two factors to be highly determinative for the suitability of a decision method in a certain situation.

The first criterion relates to complexity of the situation and considers the nature of the activity that is to be supported by the method described in the article: defining the supplier selection problem, formulating criteria, qualifying or selecting suppliers. For example, technically speaking supplier qualification comes down to *sorting* suppliers into different clusters (e.g. acceptable and not acceptable) while the final choice phase consists of *ranking* a number of acceptable suppliers. Sorting and ranking are two different activities. In addition, for each position in the framework we investigate to what extent the specific, technical characteristics of that position (e.g. the number of suppliers to evaluate) 'rule out' one or more methods. For example, the number of available suppliers for routine items is higher than for bottleneck items.

A second complexity-related criterion concerns the amount of information assumed to be available in each framework position. The lack of historical performance records of suppliers may exclude the use of methods that require such information. In new-task situations for example, there is hardly historic information available.

The third criterion relates to the importance of the situation. The expected effort required to use a certain decision model can be evaluated (albeit only roughly) in the light of the (relative) importance of the activity in each framework position. In Table 5, we have summarised the results of the literature search in the framework:

4. Overview of possible future applications

The previous section has made clear that support in the phase of problem definition is an underdeveloped area in supplier selection since we did not come across any model in the purchasing literature that pays attention to this important phase (see Table 5). Some approaches in the operations research literature deal explicitly with problem definition but have thus far not been used in the purchasing literature. Some examples of these methods are shown in Table 6. We emphasise that this list is not exhaustive. Nevertheless, we believe Table 6 gives a fair picture of the variety of approaches available to support the phase of problem definition.

From Table 5, we also conclude that the process of generating criteria as well as evaluating the relevance of existing decision criteria in supplier selection have not gained much attention in the purchasing literature. To our knowledge, only Mandal and Deskmukh (1994) provide decision support for formulating criteria. Table 7 shows some OR-methods that currently are not used in supplier selection.

We also identified three additional methods that seem particularly suitable for supplier qualification phase. These three models are elucidated in Table 8.

Table 5
Positioning of literature in supplier selection framework

	New task	Modified rebuy	Straight rebuy (routine items)	Straight rebuy (strategic/bottleneck)
Problem definition	None found			
Formulation of criteria			Mandal and Deskmukh (1994)	Mandal and Deskmukh (1994) Vokurka et al. (1996)
Qualification	De Boer et al. (1998)	Barbarosoglu and Yazgaç (1997)	De Boer et al. (1998)	Timmerman (categorical) (1986)
	Timmerman (categorical) (1986)	De Boer et al. (1998)	Hinkle et al. (1969)	
		Grando and Sianesi (1996)	Holt (1998)	
		Gregory (1986)	Papagapiou et al. (1996)	
		Hinkle et al. (1969)	Timmerman (categorical) (1986)	
		Holt (1998)		
		Li et al. (1997)		
		Liu et al. (2000)		
		Min (1994)		
		Narasimhan (1983)		
		Ng and Skitmore (1995)		
		Nydick and Hill (1992)		
		Papagapiou et al. (1996)		
		Soukoup (1987)		
		Thompson (1990)		
		Timmerman (categorical) (1986)		
		Vokurka et al. (1996)		
		Williams (1984)		
		Willis et al. (1993)		
Choice	Barbarosoglu and Yazgaç (1997)	Akinc (1993)	Albino and Garavelli (1998)	Barbarosoglu and Yazgaç (1997)
	De Boer et al. (1998)	Albino and Garavelli (1998)	Barbarosoglu and Yazgaç (1997)	De Boer et al. (1998)
	Grando and Sianesi (1996)	Barbarosoglu and Yazgaç (1997)	De Boer et al. (1998)	Grando and Sianesi (1996)
	Gregory (1986)	Bender et al. (1985)	Grando and Sianesi (1996)	Gregory (1986)
	Holt (1998)	Benton (1991)	Gregory (1986)	Holt (1998)
	Li et al. (1997)	Buffa and Jackson (1983)	Holt (1998)	Li et al. (1997)
	Masella and Rangone (2000)	Chaudry et al. (1993)	Khoo et al. (1998)	Masella and Rangone (2000)
	Min (1994)	Current and Weber (1994)	Li et al. (1997)	Min (1994)
	Narasimhan (1983)	Das and Tyagi (1994)	Masella and Rangone (2000)	Morlacchi (1997, 1999)
	Nydick and Hill (1992)	De Boer et al. (1998)	Min (1994)	Narasimhan (1983)
	Sarkis and Talluri (2000)	Degraeve and Roodhooft (1998, 1999, 2000)	Narasimhan (1983)	Nydick and Hill (1992)
	Thompson (1990, 1991)	Degraeve et al. (2000b)	Nydick and Hill (1992)	Sarkis and Talluri (2000)
	Vokurka et al. (1996)	Weber and Ellram (1992)	Soukoup (1987)	Thompson (1990, 1991)
	Morlacchi (1997, 1999)	Gareshan et al. (1999)	Thompson (1990, 1991)	Williams (1984)
	Williams (1984)	Ghoudsypour and O'Brien (1998)	Williams (1984)	Willis et al. (1993)
	Willis et al. (1993)	Grando and Sianesi (1996)	Willis et al. (1993)	Yoon and Naadimuthu (1993)
	Yoon and Naadimuthu (1993)	Gregory (1986)	Yoon and Naadimuthu (1993)	
		Holt (1998), Morlacchi (1997, 1999)		
		Karpak et al. (1999), Khoo et al. (1998)		
		Li et al. (1997)		
		Masella and Rangone (2000), Min (1994)		
		Monczka and Trecha (1988)		
		Narasimhan (1983)		

Table 5 (continued)

	New task	Modified rebuy	Straight rebuy (routine items)	Straight rebuy (strategic/bottleneck)
Problem definition	None found			
		Nydick and Hill (1992) Pan (1989) Petroni and Braglia (2000) Ronen and Trietsch (1988) Rosenthal et al. (1995) Sadrian and Yoon (1994), Turner (1988) Smytka and Clemens (1993) Soukoup (1987) Thompson (1990, 1991) Timmerman (cost-ratio) (1986) Vokurka et al. (1996) Weber and Current (1993) Weber and Desai (1996) Weber (1991) Weber et al. (1991, 1999, 2000) Williams (1984) Willis et al. (1993) Yoon and Naadimuthu (1993)		

Table 6
Methods and techniques for supporting problem definition

Method	Purpose in supplier selection
WWS-analyse (Basadur et al., 1994)	Critically investigating if changing the supplier base is only one out of several solutions for a perceived problem. Perhaps changing the supplier base is not even necessary
Cognitive Mapping (Warren, 1995)	Improving insight in factors that trigger the need for supplier base changes
AIDA (Rosenhead, 1989)	Investigating whether a change of the supplier base is feasible, compatible and/or consistent with other decision areas, e.g. marketing, RD, etc
Strategy Generation Table (Howard, 1988)	Single out feasible and reasonable possibilities of changing the supplier base given various other developments and constraints
Influence Diagrams (Howard, 1988)	Improving insight in factors that trigger the need for supplier base changes.
Framework for Formulation of Alternatives (Arbel and Tong, 1982)	Systematically generating alternatives for changing the supplier base.

We also identified several OR-methods that handle the supplier choice phase from quite a different angle than the models published in the purchasing literature (Table 9).

Again, we assign the methods discussed in this section in our framework using the same criteria as in the previous section (Table 10).

5. Conclusion and suggestions for future research

From our analysis of the methods currently being reported for supplier selection and the potential still left unused we draw the following conclusions.

First, most attention has so far been paid to the choice phase in the supplier selection process. The phases prior to the choice phase (problem definition, criteria formulation and qualification) have received far less attention from researchers in operations research or purchasing and supply. The choice phase often being the most visible phase in the process, this is not very surprising. However, the quality of the choice phase is largely dependent on the quality of the steps prior to that phase. If purchasers strive for sound decision making they should also pay attention to these early steps. Our analysis did show that several suitable OR-methods are available for problem definition, formulation of criteria and qualification. Further

Table 7
Methods for formulation of criteria

Methods	Purpose in supplier selection
Rough sets (Slowinski, 1992)	Evaluating the usefulness of existing criteria for supplier selection and evaluation. For example, tracing redundant criteria in an extensive supplier audit program
Value focused thinking (Keeney, 1994)	Producing a manageable, essential set of criteria for the qualification, choice and evaluation phases in supplier selection

Table 8
Methods for supporting pre-qualification of suppliers

Method	Typical feature
Conjunctive screening (Hwang and Yoon, 1981)	A supplier is acceptable if the supplier equals or exceeds a minimum score on each criterion
Disjunctive screening (Hwang and Yoon, 1981)	A supplier is acceptable if the supplier at least equals or exceeds a minimum score on one criterion
Lexicographical screening (Hwang and Yoon, 1981)	Criteria are ranked in order of importance. Suppliers are first evaluated on the most important criterion. Suppliers that pass this criterion are then evaluated on the second criterion and so on.

research on the application of these methods therefore seems useful.

Secondly, the vast majority of the publications found seem to have been written in the context of selecting a supplier for the purchase of a product to be used in a manufacturing environment. As most of the literature on the purchasing of services boils down to the summing up of relevant criteria and the 'do's and don'ts', the attentive reader has noticed that only one of the decision models (Degraeve et al., 2000) discussed here were developed in a service purchasing context. From a point of view of reflecting Purchasing's significance in sectors other than manufacturing, e.g. service industry, it would be worthwhile to investigate and illustrate the specifics of using decision methods in supplier selection in those areas as well. More specifically, further research on the suitability of decision methods for supplier selection in Government Procurement seems at place given the relatively higher need for justifying public procurement decisions and the European Union regulations on tendering. Apart from that however, the framework for classifying decision methods for supplier selection developed in this paper, and therefore the suitability of the various decision methods, does not depend on the specific industry or product or service under consideration. The differences between various sectors and products and services with regard to supplier selection ultimately boil down to different intrinsic meanings of selection criteria and different relevant importances of weights but these differences in itself do not determine the suitability of a certain decision method.

Thirdly, the assignment of methods in our framework of supplier selection situations shows that not all methods are equally useful in every possible purchasing situation. However, the existing articles on methods for supplier selection do not sufficiently address this contextual issue. Often they assume, explicitly or implicitly, that their method is applicable in all purchasing contexts. At most, a reference is made to a particular industry in which a method has been empirically tested or the need to change the criteria considered when applying the method to another type of product. However, neither the specific industry nor the particular criteria at hand determine the usefulness of certain method. Our framework shows that more generic, situational characteristics like the number of suppliers available, the availability of historic information, the importance of the buy as well as the phasing and organisation of the whole supplier selection process are more determinative for the suitability of a certain method. In future research therefore, more attention should be paid to positioning new contributions in such a framework.

Table 9
Methods for supporting supplier choice

Method	Typical feature
Topsis (Hwang and Yoon, 1981)	Suppliers are compared to best-in-class and worst-in-class performance
Distance from Target (Hwang and Yoon, 1981)	Suppliers are compared to a virtual 'ideal' supplier
Maximin (Chen and Hwang, 1991)	Based on the idea that a 'chain' is as strong as its weakest 'link'.
Linear assignment (Chen and Hwang, 1991)	Requires the purchaser to rank order suppliers only on each criterion separately
STEM (Vincke, 1986)	Interactive procedure which does not require fixed criteria weights
Even swaps (Hammond et al., 1998)	Systematic procedure which aims at converting a comparison of suppliers on several criteria to a comparison on fewer and ultimately one criterion

Table 10
Positioning of currently unused methods in supplier selection framework

	New Task	Modified rebuy	Straight rebuy (routine items)	Straight rebuy (strategic/bn)
Problem definition	Basadur et al. (1994), Warren (1995), Rosenhead (1989), Howard (1988), Arbel and Tong (1982)			
Formulation of criteria	Keeney (1994)	Keeney (1994), Slowinski (1992)		Keeney (1994)
Qualification	Hwang and Yoon (1981)			Hwang and Yoon (conjunctive)
Choice	Hwang and Yoon (Topsis, Distance from Target), Chen and Hwang (1991), Vincke (1986), Hammond et al. (1998)			Hwang and Yoon (Distance from Target)

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