

Procedural rationality in supplier selection: Outlining three heuristics for choosing selection criteria

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Introduction and overview of the paper

Background of the research

A lot has been written about supplier selection, in a descriptive way (see e.g. Grønhaug, 1975; Dempsey, 1978; Monczka et al., 1998; Bharadwaj, 2004; Nair et al., 2015) as well as from a more normative perspective (see e.g. Weber et al., 1991; Tam and Tummala, 2001; Wu and Barnes, 2011). The existing body of literature provides insight in the various criteria and information sources that purchasers use and how certain stages in the process could be supported by decision models. Regarding the existing literature on supplier selection Verma and Pullman (1998) state that: “..while the supplier selection literature is rich in terms of (a) conceptual and empirical work and (b) decision support methods for purchasing managers, none of the articles cited above has studied how managers actually choose suppliers” (pp. 740). The existing supplier selection literature does not explain *how* and *why* the purchaser executes the supplier selection process in the way that he or she does. In particular, the literature treats a number of characteristics of the supplier selection process as given, such as (a) the initial set of suppliers that is being considered (b) the number of successive stages in which this set is narrowed down and (c) the criteria, information sources and evaluation technologies that are used in each stage. The bulk of the supplier selection literature still focuses on developing models for supporting purchasers in choosing between bids at the very end of the process, implicitly accepting the mentioned characteristics as a point of departure and outside the scope of the research (Wu and Barnes, 2011).

Objective of and rationale for the research

Studies of human search and evaluation processes (e.g. Johnson & Payne, 1985), however, clearly suggest that these characteristics are far from given. Just as any other decision-maker, purchasers must *choose* where to begin their search for suppliers, which criteria to include in the search and how many suppliers to evaluate with regard to each criterion. Given the specific situation, a subset of supplier selection criteria must be identified and chosen, depending on their relative importance (Pedraza-Acosta et al., 2016). Search for and evaluation of suppliers can be costly however, and time and resources are by definition limited. One way or another, a purchaser must decide on a procedure – a heuristic – that yields a satisfactory supplier without incurring excessive search and deliberation costs. Heuristics are “rules of thumb” that provide decision-makers with an appropriate, adaptive response to complex decision situations where neither the exact problem, possible alternative solutions to it nor criteria for evaluation of the solutions are given (Payne et al., 1993). Heuristics have been widely discussed in the

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5 organization and management literature ever since the seminal work by Simon (1955) and his
6 notion of bounded rationality. Given the limits to cognitive and economic resources, human
7 decision-making is inherently heuristic, yet the specific heuristic used may vary from situation to
8 situation (Gigerenzer and Goldstein, 1996), and, as discussed in Abatecola (2014), the
9 consequences of using a particular heuristic may be considered from different perspectives. In
10 many ways, heuristics typically ignore much of the information available and are prone to bias.
11 On the other hand, as shown by Gigerenzer and Goldstein (1996), under certain circumstances,
12 such ignorance and simplicity may outperform more elaborate and sophisticated models.
13 A heuristic enables the purchaser to somehow weigh the benefits of deeper and/or broader search
14 against the cost of doing so. In other words, the heuristic guides the purchaser in designing and
15 shaping the supplier selection process. Please note that the heuristic does not decide *which*
16 specific supplier should be chosen, but it decides *how* the choice should take place.
17 There are still only a few models describing such a heuristic for the case of industrial supplier
18 selection, and the main objective of the paper is to contribute to filling this gap by developing a
19 formal description of such a heuristic. This may deepen our understanding of the purchaser's
20 behavior. In particular, it would enable the formulation of specific hypotheses about supplier
21 selection heuristics and the experimental and empirical verification of these hypotheses. Once we
22 better understand the nature of the supplier selection heuristics used by purchasers, more
23 effective support tools can be developed. The lack of models of the heuristics used in supplier
24 selection and the potential of such models for theory development and supporting practitioners
25 provide the rationale for this research. Clearly, purchasers do not necessarily need decision
26 models or tools to make decisions. The question as always is, however, to what extent a more
27 explicit and systematic approach to decision-making can improve the quality of the outcome of
28 the decision. In a recent article, Kaufmann et al. (2012) find, based on extensive empirical
29 research, that a more conscious and analytical approach to supplier selection leads to improved
30 quality of the decisions, measured in both financial and non-financial supplier performance. The
31 objective of this research is to provide some formal models – of varying degree of complexity –
32 that may assist purchasers in more explicitly and consciously analyzing their intuitive decision
33 processes and improving them.
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41 *Research question and theoretical basis*

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44 Given the objective of the research, the basic question we aim to answer in this paper is: “How
45 can we formally describe some simple heuristics that reflect basic properties of supplier selection
46 processes and explicitly take into account cognitive and economical limits to search and
47 evaluation activities?”.

48 The research is primarily theoretical, yet draws on various empirical accounts and studies of
49 supplier selection. The main theoretical basis lies in the literature on bounded rationality (Simon
50 1955, 1997; Conlisk, 1996) and more specifically Simon's notion of procedural rationality
51 (Simon, 1976). We attempt to make bounded rationality and the notion of procedural rationality
52 more concrete for the case of supplier selection by formally describing three heuristics for
53 choosing selection criteria. The heuristics are all based on the same logic but differ slightly in
54 terms of the precision of the input information required from the purchaser. The most
55 sophisticated of the three heuristics is built around a so-called Goal Programming model (Masud
56 and Hwang, 1981; Taylor and Anderson, 1979). The heuristics are first and foremost aimed at
57 handling both simple and more complex modified rebuy situations in which the purchaser has
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4 some previous experience with purchasing the type of product or service at hand. Furthermore, as
5 part of explaining the intended application of the heuristics, we shall discuss how they relate to
6 well-known purchasing tools such as Kraljic's (1983) portfolio approach and the categorical
7 methods for supplier selection (Stevens, 1987; Zenz, 1981).
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10 11 12 13 14 *Organization of the paper*

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16 The paper is organized as follows. The next section discusses the relevant literature on supplier
17 selection and consists of two parts. The first part draws on descriptive literature and provides a
18 first set of assumptions about how purchasers seem to come to reasonable supplier selections.
19 The second part contains a discussion of the few existing formal heuristics for supplier selection
20 in the literature. Based on the discussion of the literature, we then propose and develop three new,
21 formal heuristics for designing supplier selection processes, all inspired by the concept of
22 bounded rationality. The final section of the paper contains implications of the research for
23 practitioners and researchers.
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29 **Presentation and discussion of relevant literature**

30 31 32 *Characteristics of the supplier selection process*

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35 Supplier selection heuristics used by purchasers have received very little attention in the
36 literature. By far, most attention is paid to the perceived importance of different supplier selection
37 criteria, sources of information for evaluating potential suppliers on these criteria and decision
38 models for ranking bids. Still, from the available literature some typical characteristics of supplier
39 selection processes can be distilled that seem useful for the purpose of this paper. Below we
40 discuss these features.
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43 First of all, obvious as it may seem, purchasers consider a limited number of suppliers with
44 regard to a limited number of criteria. The number of suppliers considered may vary from over
45 thirty to just one. The number of criteria applied may vary from just 'price' to a range of other
46 quantitative and/or qualitative criteria. Sometimes, hierarchies of criteria are constructed,
47 especially when supportive decision models such as the Analytical Hierarchy Process (AHP) are
48 used (see e.g. Narasimhan, 1983; Tam and Tummala, 2001; Schoenherr et al., 2008).
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51 Usually, the supplier selection process follows a number of successive stages in which an initial
52 set of suppliers is compiled and subsequently narrowed down by evaluating them on different
53 criteria. Different evaluation mechanisms may be used in different stages. Table 1 shows the
54 possible stages in a supplier selection process. The stages follow from comprehensive empirical
55 research carried out by Sink and Langley (1997) on the topic of purchasing logistical services
56 from third-party logistics (3PL) service providers. For each stage, typical criteria, evaluation
57 methods and sources of information are shown. The classic study by Mintzberg et al. (1976) also
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4 contains several cases of supplier selection and most of these clearly show a similar, “multi
5 stage” structure. In a more recent publication, Van Weele (2010) also presents a typical multi
6 stage structure of the supplier selection process, in which the number of the suppliers considered
7 is narrowed down at each stage.
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14 In general, the supplier selection process may take any of the three shapes as shown in figure 1.
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21 In shape A the purchaser gradually compiles a list of potential bidders until a sufficient number
22 has been reached. A number of potential bidders may be discarded upon evaluation on certain
23 ‘knock-out’ criteria before requests for proposals (RFP’s) are sent out. Hence, RFP’s are only
24 sent to a subset of the initial list of potential bidders. Based on evaluation of the bids, a small
25 number – usually two or three – is conditionally selected. The final selection follows after
26 negotiations with these two or three candidates.
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29 A theoretical explanation of shape A can be found in the classic literature on bounded rationality
30 and in particular the notion of satisficing (Simon, 1955; Cyert et al., 1956; Simon, 1976; Simon,
31 1997). A typical example of satisficing in organizational decision-making was already observed
32 almost sixty years ago by Cyert et al. (1956) in their detailed analysis of a business decision
33 which also included selecting an external consultant: “...the search for alternatives terminates
34 when a satisfactory solution has been discovered even though the field of possibilities has not
35 been exhausted” (p. 247).
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39 So, following this logic, compiling a long list of potential suppliers stops when the purchaser
40 believes that the set of suppliers collected is sufficient in the sense that at least one of them will
41 fulfill the essential conditions for that particular purchase. Limiting the first search to the long list
42 is a result of both the decision-maker’s limited cognitive capacities and the fact that the available
43 time and economic resources will be limited. This explains the left hand side of shape A,
44 designated as “(I)” in figure 1.
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47 Once the long list has been compiled, the process of identifying the “best” among these is also
48 likely to depend on the cost of evaluating the candidate suppliers in more detail as well as the
49 existence of certain implicit or explicit “aspiration levels” regarding the score on relevant criteria.
50 Cyert et al. (1956) suggest that there is an “...inverse relation between the cost or difficulty of
51 this investigational task and the number of alternative courses of action that are examined
52 carefully” (p. 247). The extensive experiments by Payne et al. (1993) confirm this relationship.
53 Accepting this relationship, it makes sense that not all suppliers on the long list are evaluated on
54 the same set of criteria. Criteria that imply more “expensive” or demanding forms of evaluation,
55 for example visiting the supplier’s factory to assess their production and engineering capability,
56 or asking them to produce a prototype of the product to be delivered, are likely to be “saved” for
57 a few remaining candidates at the end of the selection process. Criteria that require less effort and
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resources, for example checking if a supplier has a ISO 9001 certificate as a way of assessing its quality management capability, may be used to first narrow down the long list to a short list. All in all, the choice of a final supplier from the long list will therefore follow a series of evaluations, with the number of suppliers gradually decreasing and different criteria being used in different evaluations. This explains the right hand side of shape A, designated as “(II)” in figure 1.

Regarding the so-called “knock out” criteria, there may be subtle differences in interpreting their function. On the one hand, their purpose may be to “simply” narrow down the list of options. On the other hand, their purpose may be to secure a minimum level of supplier performance in certain areas because of their absolute, intrinsic importance, irrespective of the length of the list of options. For example, a criterion assessing the supplier’s CSR performance may both be used to narrow down the list of options while at the same time, the buying company may have some absolute minimum requirements that all suppliers must fulfill in this respect, e.g. refraining from using subcontractors in areas known for using child labour. Following Cyert et al. (1956) we can distinguish between *comparing suppliers relative to each other* and *comparing a single supplier relative to some sort of absolute aspiration level*. We shall return to this distinction later in the paper.

Shapes B and C appear typically – but not exclusively – in public sector procurement. In a public sector setting shape B represents a process where the RFP is published in a public database which is accessible to all suppliers. Any supplier within a designated area (e.g. the European Union) may in principle submit a proposal. Hence, the number of proposals received cannot directly be set by the purchaser. Before a given deadline, the purchaser must evaluate all proposals that have been received. The proposals must all be evaluated on the same criterion or criteria. Shape B therefore awards the contract to the winner ‘at once’ out of the total set of proposals received. Shape C consists of two steps. First, a call for Notifications of Interest (NOI) is published. The NOI’s are evaluated on a similar set of criteria and reduced to a set of 5-7 bidders. Next, the received bids are evaluated on another set of criteria and a final winner is produced. Clearly, the shapes shown in figure 1 represent basic types. In practice, variants may be used.

A theoretical explanation for shapes B and C may follow the same logic as used in the case of shape A. The interesting difference from a bounded rationality perspective between shape A on the one hand and shapes B and C on the other hand, is that, in the latter cases, the decision-maker (the purchaser) cannot directly control the amount of evaluation effort to be used in the selection process. Contrary to the situation in shape A, the purchaser does not have the freedom to gradually build up a list of suppliers with a length that he or she thinks is sufficient. Instead, the purchaser has to “wait and see” how many suppliers respond. However, the purchaser does have the freedom to choose between the procedures leading to either shape B or shape C and which criteria to use in either process. Heijboer and Telgen (2002) point out that the cost of evaluating bids is an important factor in this choice. Shape B seems appropriate when the expected number of bidders is low and/or the cost of evaluating is very low, e.g. when simply picking the bid with the lowest price is enough. Shape C seems more appropriate when the evaluation requires more complex and expensive evaluations.

A number of different sources of information and methods for data gathering and analysis may be used in different stages, e.g. searching in databases, sending out RFI’s, plant visits, tender evaluations, trial deliveries and so on, see again table 1. These sources of information as such are

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4 well addressed in the literature, see e.g. Dempsey (1978) and Deeter-Schmelz and Kennedy
5 (2002). The rise of E-procurement, and in particular E-sourcing (De Boer et al., 2002) has added
6 the internet as an important new source of information for purchasers. In one way or another, the
7 purchaser must determine which sources are to be used and to what extent.
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10 Certain ‘technological’ precedence relations may exist between subsequent stages in the search
11 and evaluation process. For example, a supplier visit can only take place after the supplier first
12 has been identified and located. In other words: some criteria cannot be evaluated without prior
13 evaluation of some other criterion. Certain economies of scale may play a role as well. For
14 example, a plant visit offers the opportunity to almost simultaneously evaluate many aspects of
15 the supplier’s processes and capabilities. Also, a third party specializing in providing information
16 about suppliers – e.g. about their financial situation and ownership structure – may be hired by
17 the purchaser. In both examples, the information obtained may not be exactly to the purchaser’s
18 specification but the cost of obtaining ‘imperfect’ information about many aspects through these
19 channels may be relatively low compared to the cost of separately obtaining ‘ideal’ information
20 about each individual aspect of the suppliers. We shall return to this issue later in the paper.
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24 As already mentioned the search and evaluation of suppliers is subject to time and cost
25 constraints. The impact of time pressure on the search and evaluation of suppliers has long been
26 acknowledged (see e.g. Grønhaug, 1975). Still, how to precisely spend the limited amount of
27 time available must somehow be specified by a heuristic. Examples of search and evaluation
28 costs include the cost of communicating, travelling, purchasing information from third parties,
29 paying for trial deliveries and so forth. While the presence of these costs is generally
30 acknowledged in the industrial purchasing and marketing literature – and more in general in the
31 area of transaction cost economics – there are only a few models that explicitly capture these
32 costs in a supplier selection setting (see e.g. Barua et al., 1997). Depending on the situation and
33 the available knowledge in the organization, purchasers may be more or less able to estimate the
34 costs of using the different information sources and data gathering methods as well as the
35 expected variance in the ‘performance’ of suppliers on these criteria. On the one hand, a
36 sufficiently large ‘pool’ of satisfactory suppliers must be created in any given stage in order to
37 provide a sufficient number of suppliers that will be satisfactory with regard to the criteria
38 applied in the next stage. On the other hand, the pool should not be too wide in order to avoid
39 excessive costs of search and deliberation in any given stage and reserve sufficient resources for
40 the next stages. In one way or another, the supplier selection heuristic must balance time pressure
41 and the cost of search and evaluation with the expected benefits of the search and evaluation.
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47 The characteristics described above seem to fit very well with the general logic and assumptions
48 of Simon’s concept of bounded rationality (Simon, 1955), and more specifically satisficing and
49 procedural rationality (Simon, 1978). Procedural rationality refers to the effectiveness, or one
50 could say the appropriateness or reasonableness, of the chosen procedure for making a decision in
51 the light of human cognitive powers and limitations (Simon, 1978, p.9). Later in this paper we
52 shall use this concept to develop three formal descriptions of a heuristic for choosing selection
53 criteria. First, we discuss the existing supplier selection heuristics in the literature.
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58 *Existing supplier selection heuristics*
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5 Despite the wealth of papers on models for supporting purchasers in choosing between bids at the
6 very end of the supplier selection process (i.e. “*which* supplier to choose”), only a few formal
7 heuristics for designing and shaping the process (i.e. “*how to* decide which one to choose”) have
8 been described so far¹. These contributions primarily focus on the question *how many* bidders
9 should be used in the final stage of the supplier selection process. We shall now discuss these
10 contributions in more detail and in particular comment on their requirements in terms of the
11 information that must be provided by a purchaser and the assumptions about the nature of the
12 supplier selection process underlying them. At the end of this subsection we shall specifically
13 address how this paper makes a distinct contribution to these existing heuristics.
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16 Barua et al. (1997) study the supplier selection process in the context of the emergence of the
17 Internet. In particular, they are interested in the effects of the drastically reduced search costs on
18 supplier selection strategies. They consider two strategies (procedures): (1) sequential evaluation
19 with stopping rules and (2) bidding procedures. Sequential evaluation as defined by Barua et al.
20 is to some extent comparable to a process of shape A in figure 1 yet there there are some distinct
21 differences. Firstly, in Barua et al. (1997) the starting point is that after a websearch the purchaser
22 has identified a set of n suppliers. However, the authors do not specify how this search has taken
23 place. In figure 1 it is assumed that this set n is build up in one or more steps by evaluating
24 suppliers on one or more criteria such as location, size and so on. Secondly, given the n identified
25 suppliers, Barua et al. assume that the purchaser evaluates the suppliers one by one on all relevant
26 criteria simultaneously. The purchaser terminates the process when the expected benefits of a next
27 evaluation exceed the expected costs of doing so. This approach is fundamentally different from
28 the approach assumed in figure 1 (shape A) in which the purchaser gradually narrows n down by
29 successive evaluation of n on different sets of criteria. Each evaluation sees a number of suppliers
30 being eliminated from the process. The process ends when one supplier is left. The different
31 approaches are illustrated in figure 2. Route X represents the approach by Barua et al. (1997).
32 Supplier 1 (S_1) is evaluated on all criteria ($C_1 - C_6$), followed by S_2 and so on. Route Y represents
33 the approach in shape A from figure 1: all suppliers are first evaluated on criterion C_1 , after
34 elimination of one or more suppliers (in this case S_6) the remaining suppliers are evaluated on C_2 .
35 This will again reduce the set (this time S_2 is eliminated) and the process continues until the set of
36 suppliers has been reduced to one.
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47 Based on previous case studies – see again table 1 – and practitioner oriented publications about
48 tendering (e.g. Wilkinson and Thorson, 1995) we suspect that route Y is actually much more
49 common in practice than route X. The former is also much closer to the procedures for public
50 tendering in the European Union than the latter.
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56 ¹ We acknowledge the paper by Masi et al. (2013) and the paper by Bergman and Lundberg (2013) as providing
57 support to a purchaser when choosing a particular Multi-Criteria Decision Making (MCDM) technique for different
58 purchasing situations. However, these papers do not provide support for the designing and shaping of the entire
59 supplier selection process as covered by the heuristics developed in the current paper.
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5 Barua et al. provide a mathematical analysis that maximises the pay-off from the selection in
6 terms of the expected total costs. These include the costs of search, communication, evaluation,
7 the price paid and a financial equivalent of the scores of a supplier on other attributes such as
8 delivery and quality. The analysis assists in deciding between procedure (1) and procedure (2).
9 The analysis relies on the specification of a number of parameters and probability distribution
10 functions. For example, the purchaser must specify the total cost of using the current supplier,
11 including a monetary valuation of supplier performance on criteria other than price such as
12 delivery, quality, reliability and so on.
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15 De Boer et al. (2000), Heijboer and Telgen (2002) and Heijboer (2003) studied the problem of
16 formally modeling the trade-off between the expected benefit of adding another supplier to the
17 bidderslist and the additional cost of doing so. Their model, the so-called Economic Tender
18 Quantity (ETQ), specifies the optimal number of bidders given that some assumptions are
19 adhered to. One critical assumption concerns the purchaser's ability to estimate the actual cost of
20 tender evaluation and the expected differences between the bids from the suppliers. While the
21 ETQ approach yields a number of useful insights – both theoretically and empirically – there are
22 some clear limitations. Firstly, the ETQ approach considers only quantifiable costs and price.
23 Other criteria that often play an important role in supplier selection – especially criteria of a more
24 qualitative nature – are not accommodated. Secondly, the ETQ model does not capture the
25 screening stages in supplier selection prior to the final bidding. It should be noted that the authors
26 recognize and discuss these limitations in their paper (De Boer et al.; 2000) and suggest that
27 future research should explore the potential of techniques such as Goal Programming in
28 addressing them. The current paper is clearly inspired by this suggestion.
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33 Berger et al. (2004) present a decision-analysis approach for determining the optimal size of a
34 firm's supplier base from a risk-management point of view. However, their model addresses the
35 question of how many suppliers should be used rather than how many should be included in
36 phases of search and evaluation prior to using them.
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39 In this article we propose an alternative approach which differs in a number of ways from the
40 existing formal analyses by Barua et al. (1997), De Boer et al. (2000) and Berger et al. (2004). In
41 fact, our approach includes three heuristics, all based on the same principles but varying slightly
42 in terms of the precision of input information required from the purchaser. Firstly, rather than
43 focusing on price or cost alone, we suggest an approach that accommodates the evaluation of
44 multiple criteria and the use of a variety of methods for gathering the necessary information and
45 for performing the evaluation. Secondly, our approach allows for a sequential selection process of
46 the type of route Y in figure 2, which we suspect to be a more common approach than type X.
47 Thirdly, our approach does not require the exact specification of probability distributions of the
48 scores of suppliers on the different criteria. Given these differences, the approach presented in
49 this article is intended as a simpler and a more extensive model of the supplier selection process
50 than the few existing heuristics in the literature.
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5 The differences between the three heuristics in our approach and the existing models in the
6 literature are summarized in table 2. In the next section, we shall explain the three heuristics in
7 more detail. Table 2 clearly shows how the heuristics developed in this paper add to the existing
8 literature.
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10 11 12 **Three heuristics for choosing supplier selection criteria based on the satisficing principle** 13

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15 The basic assumptions on which we base the three proposed heuristics are the following:
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- 17 - The purchaser is able to identify a set of possibly relevant criteria² for the supplier selection
18 problem at hand. Furthermore, there may exist a certain necessary order in which some of
19 these criteria must be evaluated;
- 20 - The purchaser is able to make comparative – qualitative – statements about the relevance or
21 importance of evaluating a supplier on one criterion versus another criterion. Differences in
22 perceived importance may express (a) different degrees to which the suppliers' performance
23 on a criterion are expected to vary and (b) differences in terms of the intrinsic importance of
24 that criterion;
- 25 - The purchaser is able to make qualitative, comparative statements about the relative cost or
26 effort of evaluating a supplier on one criterion versus another criterion;
- 27 - The purchaser selects a subset of all criteria perceived possible and allocates the available
28 time and resources in such a way that a reasonable balance is struck between performing a
29 sufficient number of evaluations on the one hand and limiting the cost of all evaluations on
30 the other hand. In other words, the purchaser strives for procedural rationality (Simon, 1986).
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35 The assumptions above will typically fit with supplier selection in both simple and complex
36 modified rebuy situations (see Bunn, 1993). In such cases, the purchaser has previous experience
37 with the type of purchase at hand and some knowledge of the supplier market, which enables him
38 or her to make the comparative statements and assessments described above. The assumptions
39 may hold to a lesser degree for new task purchasing situations which are characterized by a great
40 amount of uncertainty about what can or should be purchased and about the supplier market.
41 Still, as Bunn (1993) found, new task purchases do involve a high level of search activity and this
42 search activity must also follow some sort of heuristic procedure. The development of such
43 heuristics is an important topic for further research, which we shall get back to at the end of this
44 paper.
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48 In order to develop heuristic procedures for supplier selection we must first more specifically
49 define important dimensions of the "cost" and "value" of using a criterion.

50 Based on the literature review earlier in this paper and especially De Boer et al. (2000), typical
51 dimensions of the cost of using a certain criterion would be time spent on reading and discussing
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56 ² Strictly speaking we must distinguish between a criterion and the method and information source for evaluating the
57 score on that criterion. There may be more than one way to evaluate the same criterion. In the heuristic each criterion
58 is thought of as being a specific combination of a criterion and a method for evaluating it. However, for the sake of
59 notation we simply refer to a 'criterion'.
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4 documents, travelling cost, cost of buying information from third parties, cost of hiring experts
5 and so on.

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7 Regarding the value of using a criterion, and following the observations made by Cyert et al.
8 (1956) and Mintzberg et al. (1976) we distinguish between two dimensions of value, an
9 “intrinsic” value and a relative value. The *intrinsic or independent* value follows from obtaining
10 information about the supplier’s performance on a certain criterion, more or less irrespective of
11 how other suppliers perform. For example, in the offshore oil industry, having detailed
12 information about the supplier’s systems for health, security and environment (HSE) is of crucial
13 importance. The potential costs related to not having this information are extremely high and add
14 to the criterion’s value, i.e the value of evaluating a supplier on that criterion. Another dimension
15 of value is however related to the more *relative performance* of suppliers on a certain criterion. If
16 the expected difference between the performances of the suppliers on a certain criterion is large,
17 then there is much to gain by evaluating many suppliers on that criterion. However, if the
18 difference in performance between the suppliers on a certain criterion is perceived to be very
19 small, then in a sense, the evaluation on that criterion loses some of its relevance as choosing one
20 supplier instead of another will not change much in terms of the supplier’s performance.
21 In the heuristics developed below, the assessments of the cost and the value of using a criterion
22 are assumed to be based on the dimensions of cost and value described above. Although the three
23 heuristics use the same assumptions and are all based on the logic of procedural rationality they
24 differ in terms of their level of sophistication. Depending on the importance of the purchase for
25 example, or the relative amount of experience the purchaser has in a certain situation, the
26 heuristic that fits best may be considered first. The first heuristic (heuristic A) is the most
27 rudimentary of the three and requires very little effort on behalf of the purchaser. Heuristic B is
28 slightly more advanced in the sense that it employs a systematic method for eliciting the
29 assessments from the purchaser. Heuristic C is most advanced and requires building and solving
30 a basic goal-programming model. Each heuristic is now described in more detail below.
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37 *A simple heuristic based on ordinal scales for cost and value (heuristic A)*

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40 This heuristic only requires that the purchaser is able to identify a set of possibly relevant criteria
41 and can make some very rough (qualitative) assessments of the costs and benefits related to using
42 a certain criterion. Based on these assessments, the heuristic separates the initial set of possibly
43 relevant criteria into smaller sets of criteria. This allows the purchaser to more specifically
44 identify a set of criteria with a favorable cost-benefit balance. The spirit of the heuristic described
45 here is quite similar to the so-called Categorical methods for supplier selection (Stevens, 1978;
46 Zenz, 1981; Lee and Dobler, 1977). In such methods, the suppliers (rather than the criteria) are
47 assessed by the purchasers on an ordinal, qualitative scale. In our heuristic, the criteria
48 themselves are subject to such an assessment. The heuristic can be formulated as follows:
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50

51 Step 1

52 Identify the set of possibly relevant criteria, C_i , $i = 1 \dots N$.

53 Step 2

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55 Assess each criterion on two so-called ordinal scales, one for the expected cost of using the
56 criterion and one for the expected benefit of using the criterion. In its most basic form, the ordinal
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scale only has two “values”: “low” and “high”. The score of criterion C_i on the cost-scale is indicated as SC_{icost} , the score on the benefit scale is $SC_{ibenefit}$.

Step 3

Based on the assessment of the criteria in step 2, assign each criterion to one of the following four subsets:

Subset I, which contains the criteria with $SC_{icost} = \{low\}$ and $SC_{ibenefit} = \{high\}$

Subset II, which contains the criteria with $SC_{icost} = \{high\}$ and $SC_{ibenefit} = \{high\}$

Subset III, which contains the criteria with $SC_{icost} = \{low\}$ and $SC_{ibenefit} = \{low\}$

Subset IV, which contains the criteria with $SC_{icost} = \{high\}$ and $SC_{ibenefit} = \{low\}$

The criteria may be displayed in a matrix, as shown in figure 3 below. The criteria C1-C4 are merely examples.

- Insert figure 3 around here –

Before proceeding to step 4 and given the positions of the criteria in the matrix shown in figure 3, the purchaser may consider if criteria with high costs and/or low value could be adjusted in order to make them more attractive. Relevant questions are: what makes using this criterion expensive or laborious? Can we find another way of performing the evaluation that is less expensive but still gives us more or less the same value? For example, could we refrain from visiting a foreign supplier’s factory and instead hire a local consultant to perform a site inspection on behalf of us? Would the reduction in costs outweigh the loss of value in terms of less specific information obtained?

Step 4

Based on the allocation of the criteria to the four subsets, decide on a provisional design or structure of the supplier selection process. The logic of the heuristic suggests that most suppliers will be evaluated on the criteria in subset I. These criteria are valuable and their cost of use is low. However, a smaller subset of the suppliers that remain after evaluation on the criteria in subset I may be evaluated on one or more criteria from subset II. The latter also are valuable but more costly to use, and therefore their use is limited to a smaller number of suppliers.

Following the evaluation of suppliers on criteria from subsets I and II, criteria from subset III may be considered. The contribution of evaluating suppliers on the criteria from subset III is relatively low but so is the cost of using them. Perhaps the prime reason for using criteria from subset III is to reduce the number of suppliers (rather than to avoid making really poor decisions). Such a reduction may be desirable between the evaluations on criteria from subset I and subset II in case the number of suppliers that is left after evaluation on criteria from subset I is considered too high for an evaluation on criteria from subset II. Criteria from subset III may also be used after evaluation on criteria from subset II, simply because the buying firm wishes to use only one supplier. However, instead of using criteria from subset III, the purchaser may also decide to

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4 simply let fewer suppliers pass the evaluation on criteria from subset I (and/or subset II). This
5 will also depend on whether the value of a criterion is primarily intrinsic or relative. Criteria from
6 subset IV do not appear to be particularly attractive as they offer little value and are expensive in
7 their use. Still, occasionally, it may be necessary to include these criteria, for example due to
8 legal frameworks or pressure from customers or other stakeholders. Criteria from subset IV will
9 then be applied to as few suppliers as possible, and if possible, only to the final supplier at the
10 very end of the selection process, i.e. simply assessing if the chosen supplier fulfills the minimum
11 requirement for this criterion.

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13
14 All in all, the heuristic provides the general structure or design of the supplier selection process
15 by identifying the most useful and “cost-effective” criteria and suggesting in which sequence they
16 should be applied in the supplier selection process. In a particular case, factors such as time
17 pressure, will determine the precise set of criteria applied in each stage of the process.

20 21 *A slightly more advanced heuristic based on ratio scales for cost and value (heuristic B)*

22
23 The main idea behind this heuristic is similar to the idea behind heuristic A. This time however,
24 the assessment of the criteria C_i is done by so-called pair-wise comparisons on a ratio scale using
25 the Analytical Hierarchy Process (Saaty, 1980). This pair-wise comparison of all criteria leads to
26 quantitative scores or weights for each criterion, one expressing the cost of using a criterion
27 (again indicated by $SC_{i\text{cost}}$) and one expressing the benefit of using the same criterion ($SC_{i\text{benefit}}$).
28 The weights obtained are expressed on an interval scale running from 0 to 1.

29
30 As we focus on modified rebuy situations, the heuristic assumes that the purchaser is able to
31 roughly assess the cost and value of using one criterion in relation to another. Pair-wise
32 comparing supplier selection criteria in order to assign importance weights to them, and pairwise
33 evaluation of suppliers and bids is widely reported on in the literature, see for example
34 Narasimhan (1983), Nydick and Hill (1992), Barbarosoglu and Yazgac (1997) and more recently
35 Bruno et al. (2012) who report 53 articles in the supplier selection literature using AHP. In our
36 heuristic, however, AHP is used in the *design* of the supplier selection process, i.e. deciding on
37 which criteria to use, rather than which suppliers to use. Given the widespread use of AHP in
38 practice, and AHP being the main decision support methodology used for supplier selection, we
39 argue that it is reasonable to assume that AHP could be used effectively for the purposes of our
40 heuristic. AHP would only require statements of the type as shown in table 3. The statements to
41 choose from are based on the basic AHP ratio scale and would look as follows for our heuristic
42 (see table 3, based on and adapted from Saaty, 1980).

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48 - Insert table 3 around here –

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52 The verbal statements in the pairwise comparisons would correspond to numerical values on
53 Saaty’s ratio scale which enables computation of quantitative weights for $SC_{i\text{cost}}$ and $SC_{i\text{benefit}}$.
54 The computations can easily be automated and supported by for example Microsoft Excel or
55 commercial software for AHP.

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58 The steps of heuristic B are as follows:

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14 Step 1 (similar to step 1 in heuristic A)

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16 Step 2

17 Apply AHP to the set of criteria identified in step 1 in order to arrive at scores between 0 and 1
18 for SC_{icost} and $SC_{ibenefit}$. As an example, table 4 shows the type of values for C1-C4 after applying
19 AHP³.
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23 - Insert table 4 around here –
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27 Step 3

28 Plot the criteria in an XY-diagram showing their relative positions, see figure 4.
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31 - Insert figure 4 around here –
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35 The XY-diagram is similar to the matrix used in heuristic A. The difference is that more specific
36 information is available regarding the cost and value of each criterion, which allows for a more
37 precise consideration of the criteria in relation to each other rather than simply classifying them
38 in one of four categories as in heuristic A.
39

40
41 Step 4

42 Consider the XY-diagram and identify the criteria on the so-called efficient-frontier (McMullen,
43 2001). This is defined as the “..collection of points on a curve that possess a set of attributes
44 collectively dominating all other points not on the frontier” (McMullen, 2001, p. 338). In figure
45 4, the efficient frontier consists of criteria C1 and C2. None of the other criteria outperforms
46 these criteria with regard to cost and/or value. The criteria on the efficient frontier are the logical
47 candidates to consider first in the supplier selection process. In the example, C1 and C2 would be
48 considered first, possibly followed by C3 on a smaller set of suppliers. C4 is dominated by C3
49 and would be considered last. Again, similar to heuristic A, heuristic B does not necessarily
50 produce a complete rank-order of all criteria considered. They assist the purchaser in identifying
51 the most attractive criteria and in considering the design of the supplier process in a more
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57 ³ The values of SC_{icost} and $SC_{ibenefit}$ are purely illustrative and arbitrarily chosen by the author. The point of interest
58 for this paper is that AHP will generate exactly the same kind of values, i.e. numbers between 0 and 1 that sum to
59 unity.
60

deliberate manner. A more precise and complete result is achieved by applying heuristic C, described next.

A more advanced heuristic based on Goal Programming (heuristic C)

The third heuristic uses a Goal Programming (GP) approach (Taylor and Anderson, 1979). GP facilitates the formal modeling of simultaneously pursuing multiple goals, which in this case are related to keeping the cost of search down and at the same time getting as much “value” out the process. We believe it provides an intuitively appealing formulation of procedural rationality in supplier selection (Simon, 1986). There is no claim of finding the absolute “best” supplier in the end. Instead, the heuristic is concerned with designing a search *process* that strikes a reasonable balance between the cost of search and its value. From a technical point of view GP can be seen as an act of “optimizing”. Yet, as argued by Simon (1976) the whole point is that this “optimal” solution in the GP model is considered a “good” decision in the real world. In other words: GP becomes a tool for satisficing. As Simon (1997) stated: “If we could embed Linear Programming (LP) in a system for finding approximate LP formulations for real problems, we would have a powerful device for satisficing” (p. 326). The GP-based heuristic developed in this paper is intended in that vein. Compared to heuristics A and B, this heuristic is clearly most demanding in terms of the input information required from the purchaser and the effort required for building the model.

A basic GP formulation for heuristic C is shown below. First, we define the model’s variables and parameters. Next we explain their interrelationships and how parameter values are established.

x_i = fraction of supplier evaluations on criterion i

$i = 1, \dots, N$, number of perceived criteria

$\underline{x} = (x_1, x_2, \dots, x_N)$, vector of all fractions

d_i = contribution (weight) of evaluating a supplier on criterion i

c_i = cost (weight) of evaluating a supplier on criterion i

α_i = speed of diminishing marginal contributions from an evaluation on criterion i

β_i = speed of diminishing marginal cost of using criterion i

$f_d(\underline{x}) = \sum_{i=1}^N x_i^{\alpha_i} d_i$, total weighted contribution from \underline{x}

$$f_c(\underline{x}) = \sum_{i=1}^N x_i^{\beta_i} c_i, \text{ total weighted cost of } \underline{x}$$

$$d_a = \max_{\underline{x}} f_d(\underline{x}), \text{ aspiration level for contribution}$$

$$c_a = \min_{\underline{x}} f_c(\underline{x}), \text{ aspiration level for costs}$$

$$d^+ = \text{overachievement regarding contribution}$$

$$d^- = \text{underachievement regarding contribution}$$

$$c^+ = \text{overachievement regarding cost and effort}$$

$$c^- = \text{underachievement regarding cost and effort}$$

$$W_d = \text{weight of the contribution goal}$$

$$W_c = \text{weight of the cost and effort goal}$$

Using the above notation, the GP model is defined as:

$$\text{MIN } W_d d^- + W_c c^+ \quad (1)$$

Subject to:

$$f_d(\underline{x}) = d_a + d^+ - d^- \quad (2)$$

$$f_c(\underline{x}) = c_a + c^+ - c^- \quad (3)$$

$$x_1 \geq \dots \geq x_N \quad (4)$$

$$\sum_{i=1}^N x_i = 1 \quad (5)$$

$$x_i \geq 0, \forall i, d^+, d^-, c^+, c^- \geq 0, c_i, d_i > 0, \forall i, W_d, W_c > 0, 0 < \alpha_i \leq 1, 0 < \beta_i \leq 1, \forall i \quad (6)$$

The objective function (1) aims to simultaneously minimize the underachievement in terms of the total value or contribution of the evaluations and minimize the overachievement in terms of the costs of these evaluations. The value of x_i stipulates the fraction of all suppliers considered that should be evaluated on criterion i .

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6 The term “underachievement” refers to the fact that a certain aspiration level is set for the value
7 to be obtained. The objective function tries to minimize the gap between the actual value and the
8 aspiration level. The term “overachievement” has a similar meaning in relation to the costs of the
9 process. The aspiration levels for value and cost are denoted as d_a and c_a respectively.
10

11 In the GP model shown here, the weights W_d and W_c determine the overall balance between
12 contributed value and cost incurred. We shall get back to how these weights are chosen.
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14

15 Equation (2) denotes the level of under- or overachievement regarding contribution. Note that the
16 exponential nature of function $f_d(\underline{x})$ suggests diminishing marginal contributions depending on
17 the value of α_i . If $\alpha_i < 1$, the contribution of each additional amount of evaluation effort spent on
18 criterion i decreases, see also figure 5. Only if $\alpha_i = 1$, does each additional amount of effort
19 invested in the evaluation of criterion i result in a constant additional contribution. Assuming a
20 decreasing marginal contribution seems realistic as the probability of finding a supplier that
21 performs better on a certain criterion than the best performing supplier among the suppliers
22 evaluated so far becomes smaller for every additional supplier evaluated, see also De Boer et al.
23 (2000).
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28 - Insert figure 5 around here –
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32 The target level d_a can only be achieved if \underline{x} is such that $f_d(\underline{x})$ is maximised. This will lead to first
33 considering those criteria that contribute most. However, these criteria may not necessarily be the
34 cheapest criteria and therefore this \underline{x} is likely to result in a violation of the target level set for
35 costs. In addition, an evaluation on the most valuable criterion may require one or more prior
36 evaluations on other criteria. Therefore, usually, the target level d_a will not be met and some
37 degree of underachievement will occur.
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40 Equation (3) denotes the level of under- or overachievement regarding evaluation cost. Note that
41 the exponential nature of function $f_c(\underline{x})$ suggests diminishing marginal costs depending on the
42 value of β_i . If $\beta_i < 1$, the cost of each additional amount of evaluation on criterion i decreases.
43 Only if $\beta_i = 1$, does each additional amount of effort invested in the evaluation of criterion i incur
44 a constant additional cost. We argue that in many cases, it will be appropriate to use a value of β_i
45 < 1 . Based on the literature, see for example De Boer et al. (2000), we assume that part of the
46 cost of evaluating suppliers on a criterion will be fixed, for example, the time spent on defining
47 the criterion as part of a call for proposals must be done regardless of how many suppliers will be
48 evaluated, i.e. the fixed costs are incurred unless the purchaser decides to not use the criterion at
49 all. The other part of the costs however, will be variable, i.e. dependent on the number of
50 suppliers that is assessed. Regarding the variable costs, we assume that a certain learning effect
51 may occur when evaluating suppliers and their bids. Given such an effect, the time needed to
52 assess one more supplier will go down as more and more suppliers have been assessed. We
53 would therefore expect a shape of the cost function that starts with a rather steep ascend and then
54 gradually tapers off, basically as shown in figure 5. Although the function $f_c(\underline{x})$ approximates the
55 shape we would expect in case of a fixed cost component and a learning effect, we recognize that
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it is a rough approximation and that more sophisticated cost functions may be developed. We return to this issue in the last section of the paper.

The target level c_a can only be achieved if \underline{x} is such that $f_c(\underline{x})$ is minimized. This will lead to first considering those criteria that are least costly to evaluate. However, these criteria may not necessarily be the most valuable criteria and therefore evaluating all suppliers on these criteria will violate the target level set for contribution. In addition, an evaluation on the cheapest criterion may require one or more prior evaluations on other criteria. Therefore, usually, the target level c_a will not be met and some degree of overachievement will occur.

Constraint (4) models the possible precedence relations between the various criteria. For example, evaluation of a bid in terms of price and delivery conditions must follow the identification of the supplier in a (web) catalogue or some other source and requires evaluation of the supplier in terms of for example product coverage and location. In the model shown here we assume that the criteria $1, \dots, N$ are ordered such that criterion i must be evaluated before evaluation of criterion $i+1$ can take place. Obviously, this is an extreme assumption. However, this extreme case can easily be limited to only a subset of the criteria.

Constraint (5) makes sure that the fractions of suppliers evaluated on the various criteria sum up to 1. In other words, the heuristic determines which fraction of all suppliers considered is evaluated in each stage but not the absolute number of suppliers involved, see figure 6.

- Insert figure 6 around here -

Constraint (6) defines the maximum and minimum values of the various variables.

A numerical example of heuristic C

Similar to the example used in the descriptions of heuristic A and B, we consider a situation where a purchaser considers four criteria: Criterion1, Criterion2, Criterion3 and Criterion4. In addition, we assume (entirely illustrative) values for the different parameters as shown in table 5. The type of values for c_i and d_i could have been derived from a series of pair wise comparisons using the Analytical Hierarchy Process (AHP) developed by Saaty (1980) and explained earlier in the paper.

- Insert table 5 around here -

Given the values in table 5, it follows that:

$$f_d(\underline{x}) = (\sqrt{x_1} * 0.1) + (\sqrt{x_2} * 0.4) + (\sqrt{x_3} * 0.25) + (\sqrt{x_4} * 0.25)$$

$$f_c(\underline{x}) = (\sqrt{x_1} * 0.05) + (\sqrt{x_2} * 0.25) + (\sqrt{x_3} * 0.30) + (\sqrt{x_4} * 0.40)$$

The aspiration levels d_a and c_a for contribution and costs respectively, are found by determining extreme values of $f_d(\underline{x})$ and $f_c(\underline{x})$. $f_d(\underline{x})$ has a global maximum of 0.542 in $\underline{x} = (0.034, 0.542, 0.212, 0.212)$ and $f_c(\underline{x})$ has a local minimum of 0.05 in $\underline{x} = (1, 0, 0, 0)$. Furthermore, we assume that a precedence relation exists between Criterion1 and the other three criteria such that the use of Criterion2, Criterion3 or Criterion4 always requires prior evaluation on Criterion1. The GP model then becomes:

$$\text{MIN } W_d d^- + W_c c^+$$

Subject to:

$$(\sqrt{x_1} * 0.1) + (\sqrt{x_2} * 0.4) + (\sqrt{x_3} * 0.25) + (\sqrt{x_4} * 0.25) = 0.542 + d^+ - d^-$$

$$(\sqrt{x_1} * 0.05) + (\sqrt{x_2} * 0.25) + (\sqrt{x_3} * 0.30) + (\sqrt{x_4} * 0.40) = 0.05 + c^+ - c^-$$

$$x_1 \geq x_2, x_1 \geq x_3, x_1 \geq x_4$$

$$x_1 + x_2 + x_3 + x_4 = 1$$

$$x_i \geq 0, \forall i, d^+, d^-, c^+, c^- \geq 0$$

Note that the weights W_d and W_c have not yet been specified. Table 6 below shows the results of solving the GP model in a Microsoft Excel solver for different combinations of these weights.

- Insert table 6 around here -

In the first case ($W_d = 0.5, W_c = 1$), the supplier selection process would consist of one phase in which all considered suppliers are evaluated on Criterion1. Criterion2, Criterion3 and Criterion4 would not be included in the process. In the second case, ($W_d = W_c = 1$) the process would consist of two phases in which a single set of suppliers is evaluated on Criterion1 and Criterion2. This resembles a typical price-oriented bidding process as in shape B in figure 1. As the weight of contribution (W_d) exceeds the weight of cost (W_c) the amount of evaluation on the criteria that are relatively valuable (Criterion2, Criterion3 and Criterion4) increases and the supplier selection process stretches out over multiple phases, similar to shapes A and C in figure 1.

Heuristic C is clearly more laborious than heuristics A and B, but it also provides a more precise outcome by specifying (a) the number of stages in the supplier selection process, (b) the criteria

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4 to be considered at each stage and (c) the relative fraction of all initially considered suppliers to
5 be evaluated at each stage.
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8 9 **Discussion and conclusions**

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11 The research question stated in the beginning of the paper was: “How can we formally describe
12 some simple heuristics that reflect basic properties of supplier selection processes and explicitly
13 take into account cognitive and economical limits to search and evaluations activities?”
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16 The paper presents three such heuristics for designing the supplier selection process in modified
17 rebuy situations.
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20 The first, heuristic A, can be regarded as a very rudimentary model of procedural rationality
21 applied to supplier selection. It merely separates criteria with a favorable ratio between value and
22 cost from criteria that have a less favorable ratio. The main purpose is to facilitate a more
23 conscious choice of supplier selection criteria by “forcing” the purchaser to consider the value
24 and cost of each criterion. This heuristic may be seen as a tool similar to Kraljic’s original
25 purchasing portfolio (1983). An important function of the purchasing portfolio matrix is to
26 provide a framework for breaking down a large and complex problem, i.e. the question how to
27 deal with all purchased parts and their suppliers, into smaller subproblems and outlining basic
28 strategies for solving these. In its basic form, assigning purchased parts to the four quadrants in
29 the Kraljic matrix is based on rather rudimentary assessments of these parts in relation to two
30 dimensions, i.e. profit impact and supply risk. The assessments simply read “high” or “low” for
31 each dimension, similar to the assessments in heuristic A. Essentially, heuristics A, similar to the
32 Kraljic matrix, supports the purchaser by providing a tool for categorization. As proposed by
33 Bruner et al. (1956) in their seminal study of thinking, categorization serves several useful
34 purposes, including reducing environmental complexity, reducing the need for constant learning
35 and suggesting appropriate action.
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40 Heuristic B builds further on heuristic A by introducing a more systematic and precise way of
41 assessing the value and cost of using a certain supplier selection criterion and allowing a more
42 precise comparison of all criteria considered. The suggested method for performing the
43 assessments, AHP, is known as a robust method in the sense that the resulting scores are
44 relatively resistant to inconsistent input from the purchaser. Heuristic B can therefore be said to
45 be a more sophisticated version of heuristic A, similar to the extensions of the original Kraljic
46 approach that have been developed over the years, see for example the paper by Padhi et al.
47 (2012) that describes how a multi-criteria decision aid method using fuzzy sets was used to
48 facilitate the assessments of the purchased parts on the dimensions supply risk and profit impact.
49 In terms of its style and approach, heuristic B fits well with the large body of literature on the
50 Multi Criteria Decision Aid (MCDA) based approach to supporting supplier selection (De Boer
51 et al., 2001; Wu and Barnes, 2011).
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55 Heuristic C is a more advanced way of modeling procedural rationality, yet employing essentially
56 the same principles and assumptions as used in heuristics A and B, requiring primarily
57 comparative statements from the purchaser regarding the relative benefit of evaluating a supplier
58 on a certain criterion and the relative cost of using that criterion. The approach used in heuristic C
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5 is the most formal of the three, applying a classic Operations Research method for modelling
6 Simon's notion of satisficing.
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8 Despite the differences between heuristics A, B and C, it is interesting to see the consistency in
9 the outcomes of the examples shown in the previous section. All three heuristics identify criterion
10 C2 as the most attractive criterion. It is superior to C3 and C4. In heuristic A, C2 is also superior
11 to C1 as both are rated "low" on cost, while C1 is rated as "high" on value. In both heuristics B
12 and C, however, the assessments are more precise and C1 is considered lower in terms of cost
13 than C2. This makes C1 (together with C2) an efficient criterion, i.e. it is not dominated by any
14 other criterion. Heuristic B identifies these two efficient criteria and separates them from the
15 remaining inefficient criteria C3 and C4, which are both dominated by C2. This is a more
16 comprehensive result than the result of heuristic A, yet the purchaser still has to decide how C1
17 and C2 are to be used. Given that the time and resources for evaluation are limited, the question
18 is if relatively few suppliers should be evaluated on the high-value but slightly more expensive
19 criterion C2 or if a larger number of suppliers should be evaluated on the low-value but cheaper
20 criterion C1. Or should they both be used in combination? Heuristic C gives a more precise
21 answer to that question by modeling the decision as a goal programming problem. This allows for
22 a more precise balancing of value and cost, as well as including possible precedence relations
23 between criteria. Applying heuristic C to the example suggests that C2 and C1 are used
24 simultaneously at the start of the selection process, but, as more weight is given to value, C3 and
25 C4 are used as well, albeit on a smaller fraction of the suppliers.
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27 In the example only four criteria are used. The only reason for this is to keep the analysis simple
28 and to make it easier to show the differences between the heuristics. In practice, a far larger
29 number of criteria may be identified.
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34 Concluding, it appears that the general notion of procedural rationality can be specified for the
35 process of designing the supplier selection process by explicitly recognizing the cost and value of
36 criteria in the evaluation process. There is no one way of doing this, but at the most basic level, it
37 requires an ordinal ranking of criteria against cost and value. Already such a rudimentary,
38 qualitative, assessment can help identifying suitable criteria. The same logic, however, can be
39 developed further in more advanced procedures. It appears possible to develop heuristics for
40 choosing selection criteria that are compatible with the established approaches for the subsequent
41 selection of suppliers.
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45 In the following subsection we provide implications of the work presented in this paper for both
46 researchers and practitioners. In addition, we address the limitations of the research and suggest
47 issues for further research.
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51 *Implications for purchasers and suppliers*

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53 The heuristics may support purchasers in several ways. First, applying the heuristics draws
54 attention to the very design of the supplier selection process, rather than just focusing on the
55 "rightness" of the ultimate outcome. Why does the process followed in a concrete case look like
56 it does? Why use this particular number of stages in the selection? Why use these particular sets
57 of criteria in the specific stages? As also suggested in De Boer et al. (2000), supplier selection
58 processes can be seen as organizational routines and will have a natural tendency to stay rather
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5 fixed in order to provide stability in the organization. Typically, a limited number of simple
6 heuristics will be applied which prescribe how the supplier selection process should be carried
7 out, depending almost exclusively on the expected financial impact of the contract or purchase.
8 An example of such a simple heuristic is: “In case of a purchase above € 5000, at least three
9 suppliers should be invited to bid”. Clearly, this can be explained from a bounded rationality
10 perspective in the sense that this simple rule avoids (overly) costly deliberation for the smallest
11 purchases and aims at securing a minimum level of competition for the larger purchases. Still,
12 while extremely simple and easy to communicate and enforce, these heuristics are – as explained
13 earlier on in this paper – based on very crude simplifications of reality. The ETQ-model
14 developed in De Boer et al. (2000) already addressed this and showed that only using the
15 expected value of the contract as the basis for deciding how many suppliers should be invited to
16 bid, may lead to poor decisions if one considers each case of supplier selection separately. After
17 all, if the relative differences between suppliers’ bids are negligible, asking for more bids will
18 hardly help. The ETQ-model was suggested as a more advanced heuristic which considers both
19 the costs of tendering and the expected variance in the bids from the suppliers. The GP-model
20 proposed in this article (as part of heuristic C) should be seen in a similar vein; it is intended as a
21 more advanced heuristic compared to the very basic rules of thumb used in the current practice.
22 By more explicitly considering the relative value and cost of using a certain criterion a purchaser
23 may reflect critically on the heuristics currently used. Do the criteria currently used have a
24 favorable ratio between value and cost? Such reflections may lead to adapting or adjusting the
25 current criteria. Can an unfavorable ratio between cost and value for a criterion be improved by
26 reducing the cost of its use, for example by applying electronic processes rather than paper based
27 processes? The advent of E-procurement, and in particular solutions for identifying and analyzing
28 suppliers and products through webbased applications and intermediaries may offer efficient
29 alternatives for conventional approaches based on written questionnaires, on-site inspection,
30 travelling to supplier seminars and so on. On the other hand, however, the increasing pressure on
31 purchasers to take into account environmental and social issues when selecting suppliers, brings
32 with it additional costs as a result of assessing the environmental and social performance of
33 suppliers and the products or services offered by them (Igarashi et al., 2015). In this way, the
34 pressure to assess environmental and social performance – in addition to traditional, economic
35 performance – requires purchasers to reconsider the existing heuristics and to adapt these in such
36 a way that a reasonable balance is again struck between the value and cost of the assessment
37 efforts. Without carefully considering this balance, heuristics aimed at supporting
38 environmentally and socially sound supplier selections may become unnecessarily cumbersome
39 and ineffective. Analyzing differences between the supplier selection processes in the current
40 practice with the outcomes of applying the heuristics developed in this paper gives the purchaser
41 a tool for critically assessing the current practice and developing improvements. This again
42 underlines the importance of considering the possible positive and negative effects of applying a
43 specific heuristic in a specific situation and environment (Gigerenzer and Goldstein, 1996;
44 Abatecola, 2014) as discussed earlier in the introduction section of the paper.
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53 The supplier selection heuristics developed in this paper provide a simpler and more
54 comprehensive approach to modeling the supplier selection process than the few existing models
55 in the literature. This is important from the point of view of developing supportive tools for
56 practitioners. First of all, rather than requiring the purchaser to specify exact cost measurements,
57 the heuristics require comparative, verbal statements from a purchaser about the relative costs
58 and benefits of different supplier selection criteria. Established techniques such as the Analytical
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5 Hierarchy Process (Tam and Tummala, 2001) can be used to support this assessment.
6 Furthermore, the heuristics do not require defining and working with probability distributions. In
7 the case of heuristic C, the purchaser must specify a basic pattern which describes to what extent
8 the marginal contribution and cost of additional search seem to decrease. This specification could
9 be facilitated by offering a limited number of graphical patterns to choose from (each matching a
10 specific value of α_i and of β_i). The heuristics accommodate any type of criterion and cover all
11 phases from the first identification of suppliers up to the final bidding and approval stage. Adding
12 to the descriptive value of heuristic C is its way of searching which implies successive evaluation
13 of a diminishing set of suppliers on different (sets of) criteria rather than successive evaluation of
14 individual suppliers on all criteria at the same time. Finally, heuristic C explicitly takes into
15 account technical precedence relations between two or more criteria.
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19 The heuristics developed in this paper can also be developed into a useful tool for improving
20 communication between purchasers and suppliers. The heuristics may enable suppliers to more
21 accurately explain and predict the purchaser's search and evaluation strategies. Vendors and
22 suppliers may become more aware of which criteria – and related information sources –
23 purchasers are likely to use and to what extent. In addition, suppliers may be in a better position
24 to consider to what extent they effectively communicate their specific competitive strengths to
25 prospective customers. What are the current costs for a customer to receive and process this
26 information? How can these costs be reduced? In this way, suppliers may be able to develop
27 more effective communication strategies.
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30 *Suggestions for further research*

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33 Bounded rationality as a general concept has by now been widely recognized and Simon's work
34 is cited in numerous studies, books and papers. Still, there exist surprisingly few detailed and
35 operational models of its application in organizational decision-making (Foss, 2001; Munier et
36 al., 1999). It is hoped that the approach used in this paper – in particular the use of Goal
37 Programming – may stimulate this type of research. In addition to the very basic goal
38 programming model developed in this paper, more advanced goal programming techniques and
39 other multi-criteria techniques may be considered as well (Munier et al., 1999). Heuristic C also
40 provides a subtle but distinct variant of Simon's familiar interpretation of satisficing as a process
41 of successive evaluation of *single* alternatives, i.e. alternatives are evaluated one by one until a
42 satisfactory one has been found. The supplier selection practice clearly shows examples – see
43 again table 1 – of a different approach in which *a set of alternatives* is evaluated simultaneously
44 yet the set is gradually reduced through successive evaluations on different criteria. More detailed
45 case based research is called for in order to document and analyze more examples of this type.
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50 The supplier selection heuristics developed in this paper lend themselves very well for simulation
51 based research. In such studies, see for example De Boer et al. (2003), intelligent software agents
52 could be equipped with different variants of the heuristics and its performance could be studied
53 under different circumstances. For example, such simulation studies could evolve around the
54 suggested self-reinforcing mechanism in firms as proposed in Abatecola (2014). In this
55 mechanism, heuristics provide a crucial function by processing feedback from past decisions into
56 new managerial decisions and outcomes. Environmental characteristics and decision-maker
57 features further influence the decision-making. This generic model proposed by Abatecola could
58 be simulated for a supplier selection setting. Environmental characteristics could for example
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4 reflect the number and behaviour of suppliers, the ease of collecting information about them, the
5 relative difference between their performance and so on and so forth. Decision-maker features
6 could reflect the purchaser's objectives, perception and resources. The effects of applying the
7 three heuristics developed in this paper could be monitored under varying circumstances and
8 compared to other heuristics.
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11 The heuristics also provide a clear framework for designing field studies and experiments for
12 testing its assumptions and for further refinement. For example, experiments featuring
13 information display boards and other process tracing methods (Todd and Benbasat, 1987) could
14 be used to test the heuristics' predictive and supportive qualities. Such experiments would also
15 allow a systematic comparison of the heuristics for supplier selection with the highly generic
16 heuristics proposed by Gigerenzer and Goldstein (1996).
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20 It is also hoped that the research in this paper may contribute to a much needed shift in supplier
21 selection research, moving the attention away from developing additional models for the final bid
22 selection to the early, largely ignored, stages of designing and shaping the entire selection
23 process.
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26 Finally, there are clearly many unresolved problems to address. As explained earlier in the paper,
27 the assumptions underlying the heuristics developed in this paper fit well with modified rebuy
28 situations but less well with new task purchases. In depth field research is needed to develop
29 appropriate heuristics for such purchases. In addition, heuristic C needs further development. In
30 particular, there is the problem of finding the weights W_d and W_c . Using so-called interactive goal
31 programming approaches (see e.g. Masud and Hwang, 1981) which allow the decision-maker to
32 gradually develop the priorities of goals, may solve this problem. Secondly, while heuristic C
33 prescribes the *shape* of the supplier selection process, it does not specify the absolute *scale* of the
34 process in terms of the number of suppliers to involve. Perhaps a more dynamic procedure will
35 allow for a gradual 'trial and error' approach in this respect or perhaps absolute time and/or cost
36 constraints can be elicited and included in the model. Thirdly, the current version of heuristic C
37 does not explicitly take into account possible economies of scale when choosing between
38 different criteria (although a value of $\beta < 1$ suggests decreasing marginal costs). Including
39 separate weights for fixed costs of using a certain criterion in the goal programming formulation
40 may be one way of addressing this problem. Finally, the modeling of marginally decreasing
41 contributions and costs must be tested empirically and may also be improved by exploring
42 formulations other than the current formulations used in this paper. The current formulations may
43 perhaps favor criteria with values for α_i and of β_i lower than 1. These are all issues for further
44 research.
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52 Ruud Egging for his support and for verifying the numerical example in the paper.
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56 Figure 1: Three basic shapes of the supplier selection process
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59 Figure 2: Different search and evaluation routes in supplier selection
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7 Figure 3: Relative value and cost of using a criterion
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10 Figure 4: Plotting the criteria in an XY-diagram
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14 Figure 5: Constant versus decreasing marginal contributions from additional evaluations
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17 Figure 6: Interpretation of the outcome of the GP model
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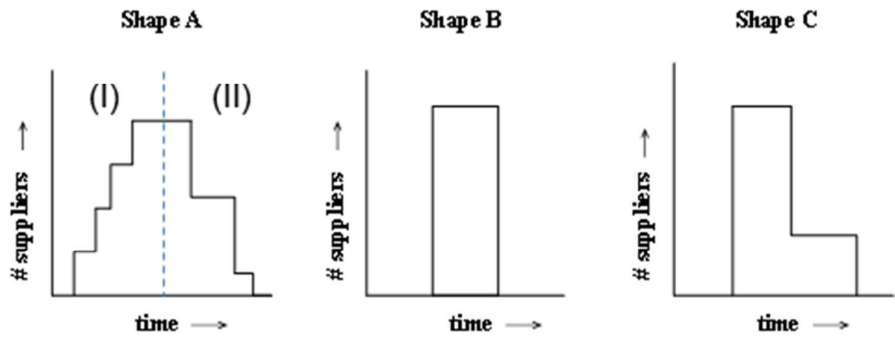


Figure 1: Three basic shapes of the supplier selection process

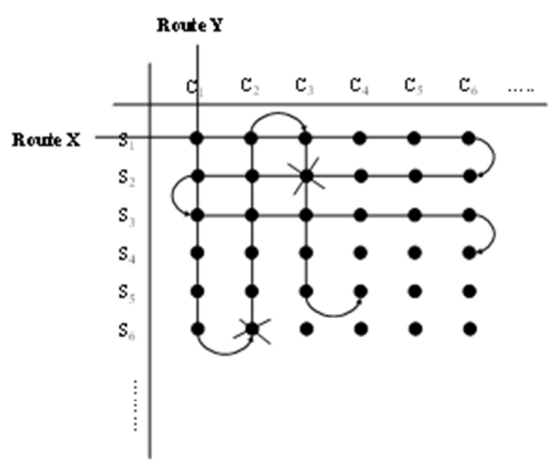


Figure 2: Different search and evaluation routes in supplier selection

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Management Decision

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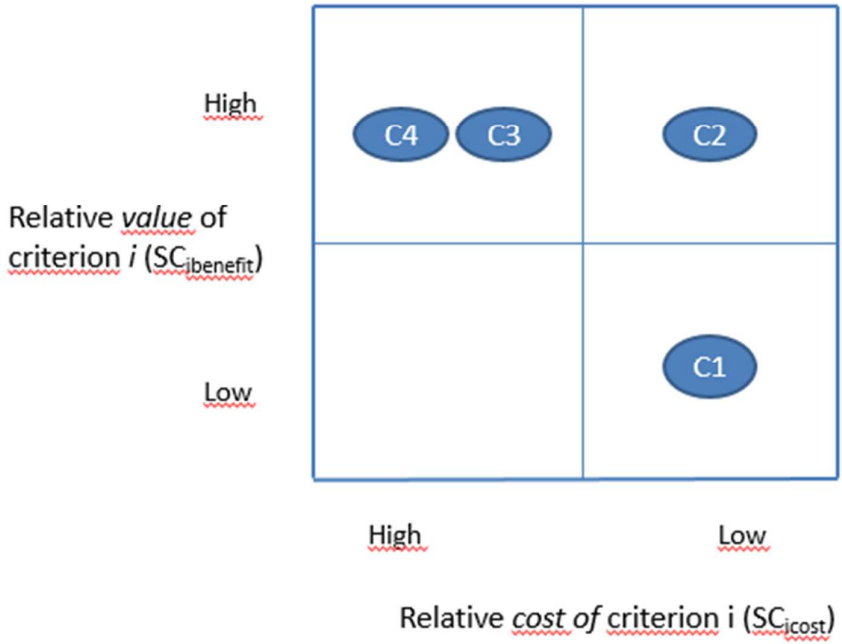


Figure 3: Relative value and cost of using a criterion

cision

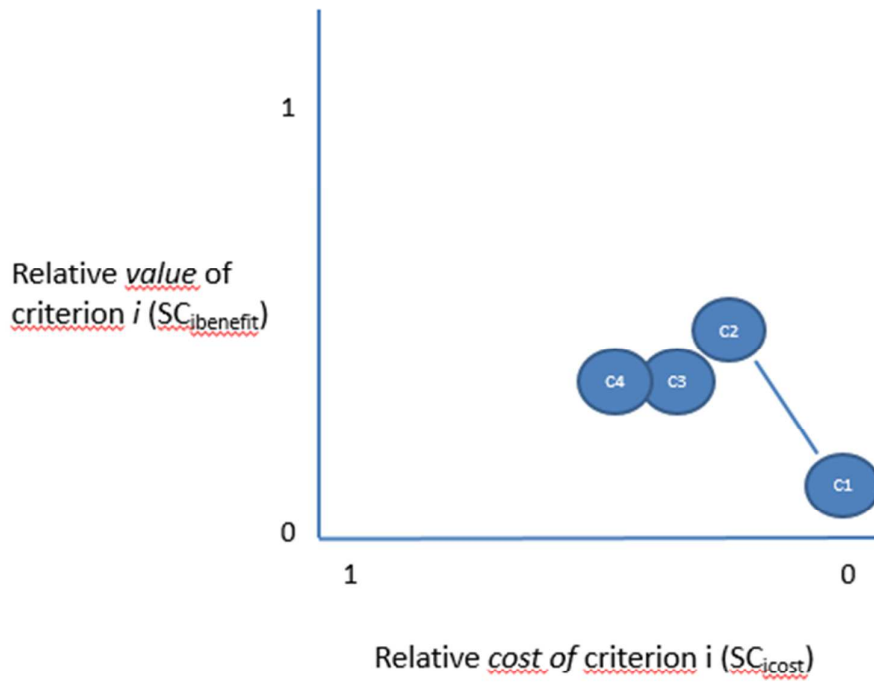


Figure 4: Plotting the criteria in an XY-diagram

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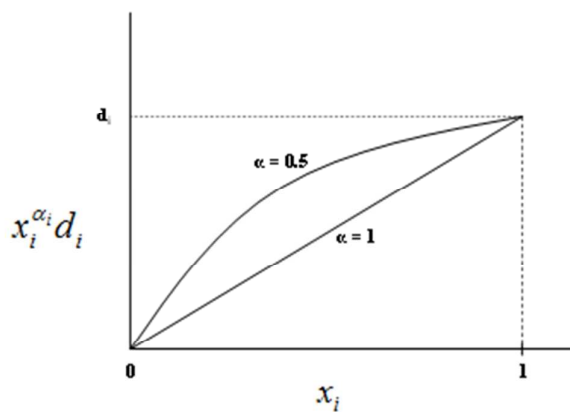


Figure 5: Constant versus decreasing marginal contributions from additional evaluations

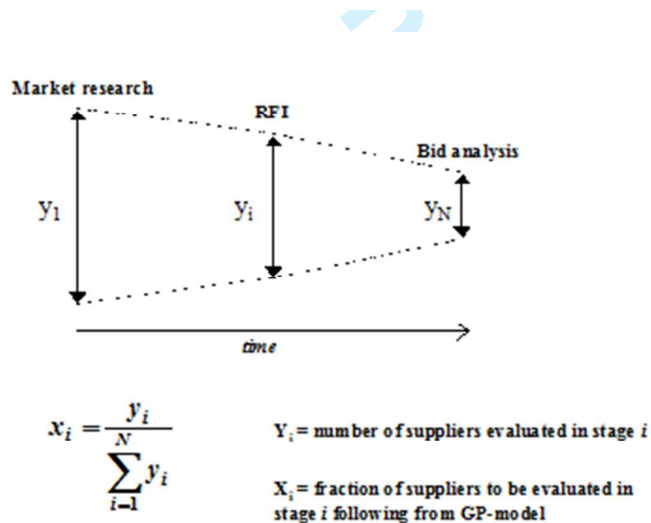


Figure 6: Interpretation of the outcome of the GP model

Stage	From (# suppliers)	To (# suppliers)	Criteria applied	Data source / evaluation method
Initial screening	Many	Circa 8	(a) Reputation (b) Quality of response to Request for Information (RFI)	Desk research Internal experts Consultants Sales personnel Request for information (RfI)
Qualification	Circa 8	2-3	(c) Quality of response to Request for Proposal (RfP). Those passing service requirements are evaluated on cost	Request for proposal (RfP), based on a scenario containing projected volumes and demands
Final selection	2-3	1	(d) Trust (compatibility with management intentions, validation of performance)	Site visits, both at suppliers and customers, communication

Table 1: Typical stages, criteria and evaluation methods in selection 3PL service providers (adapted from Sink and Langley, 1997)

Author(s)	Multiple criteria?	Cost functions required?	Probability functions required?	Route followed in supplier selection process
Barua et al. (1997)	Yes	Yes	Yes	X (each supplier assessed on all criteria, once)
De Boer et al. (2000)	No (price versus transaction costs)	Yes	Yes	Single stage selection
Berger et al. (2004)	No (operating cost)	Yes	Yes	N.a.
This paper	Yes	Only in one of the three heuristics	No	Y (suppliers may be assessed on different criteria in different stages)

Table 2: Existing heuristics for supplier selection compared to the approach taken in the current paper

Statements required from the purchaser		
Regarding the value of using a criterion	Regarding the cost of using a criterion	Corresponding numerical value on Saaty's ratio scale
Criterion i and criterion j are equally valuable	Criterion i and criterion j are equally costly	1
Criterion i is slightly more valuable than criterion j	Criterion i is slightly more costly than criterion j	3
Criterion i is much more valuable than criterion j	Criterion i is much more costly than criterion j	5
Criterion i is by far more valuable than criterion j	Criterion i is by far more costly than criterion j	7
Criterion i is definitely much more valuable than criterion j	Criterion i is definitely much more costly than criterion j	9

Table 3: Statements on the AHP-scale adapted for heuristic B

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	SC_{icost}	$SC_{ibenefit}$
C1	0,05	0,10
C2	0,25	0,40
C3	0,30	0,25
C4	0,40	0,25

Table 4: AHP-type scores expressing the value and the cost of criteria C1 – C4

Management Decision

Criterion	c_i	d_i	α_i	β_i
Criterion1	0.05	0.10	0.5	0.5
Criterion2	0.25	0.40	0.5	0.5
Criterion3	0.30	0.25	0.5	0.5
Criterion4	0.40	0.25	0.5	0.5

Table 5: parameter values for the numerical example

Management Decision

	$W_d = 0.5$ $W_c = 1$	$W_d = 1$ $W_c = 1$	$W_d = 1.5$ $W_c = 1$	$W_d = 2$ $W_c = 1$	$W_d = 3$ $W_c = 1$
x_1	1.0	0.5	0.47	0.42	0.34
x_2	0.0	0.5	0.47	0.42	0.34
x_3	0.0	0	0.06	0.13	0.19
x_4	0.0	0	0	0.03	0.12
Objective function	0.22	0.35	0.44	0.49	0.55
d^-	0.44	0.19	0.14	0.08	0.05
c^+	0.00	0.16	0.23	0.33	0.40

Table 6: Results of solving the GP-model for different sets of weights W_d and W_c