Proposition d'une approche d'aide à la décision multicritère basée sur le principe de la Pareto-dominance

Article 3 - *Possibilistic Pareto-dominance approach to support technical bid selection under imprecision and uncertainty in the bidding process. (Soumis à un journal)*

Cet article, soumis à une revue, propose une approche d'aide à la décision multicritère basée sur le principe de Pareto-dominance. Cette approche utilise les indicateurs de confiance proposés dans notre deuxième article [Sylla+2017c] et la théorie des possibilités. Le but est d'aider l'entreprise soumissionnaire à sélectionner l'offre technique la plus intéressante tout en tenant compte des incertitudes et imprécisions sur les valeurs des critères de décisions et également de la confiance dans chaque offre potentielle. Dans cet article, les critères de décision sont supposés être indépendants et non compensables. De plus, une même importance est donnée à tous les critères. Dans la section 3.3.1, nous introduisons les propositions de cet article. Dans la section 3.3.2, nous présentons les futures recherches.

3.3.1 Contributions principales de l'article [Sylla+2018a]

L'approche proposée est décrite dans la section 3 de l'article *(Possibilistic Pareto-dominance approach for technical bid selection)*. Dans ce mémoire, tout d'abord nous présentons le cadre général de l'approche dans la partie A. Ensuite, nous introduisons les différentes propositions constituant l'approche dans les parties B, C et D.

A. Cadre général de l'approche

L'approche proposée est constituée de trois étapes principales (voir Figure 3.3) : (i) la modélisation des valeurs imprécises et incertaines des critères de décision avec des distributions de possibilité, (ii) la comparaison par paires des offres techniques potentielles au regard d'un seul critère de décision pour établir des relations de dominance possibilistes entre elles, (iii) la comparaison par paires des offres au regard de tous les critères de décision et la construction d'un front de Pareto prenant en compte les exigences du soumissionnaire par rapport aux degrés d'incertitudes et d'imprécisions permis sur chaque critère de décision. Chaque étape est supportée par une méthode constituant une contribution de l'article. Ces méthodes sont introduites dans les parties suivantes.

B. Modélisation des valeurs des critères avec des distributions de possibilité

Pour la première étape, une méthode est proposée dans la section 3.1 de l'article pour modéliser les valeurs imprécises et incertaines des critères de décision au moyen de distributions de possibilité. Cette méthode utilise : (i) des intervalles de valeurs pour modéliser l'imprécision des valeurs des critères comme un ensemble de valeurs possibles, et (ii) les indicateurs de confiance proposés dans l'article [Sylla+2017c] et la théorie des possibilités pour déterminer la possibilité de chaque valeur. La

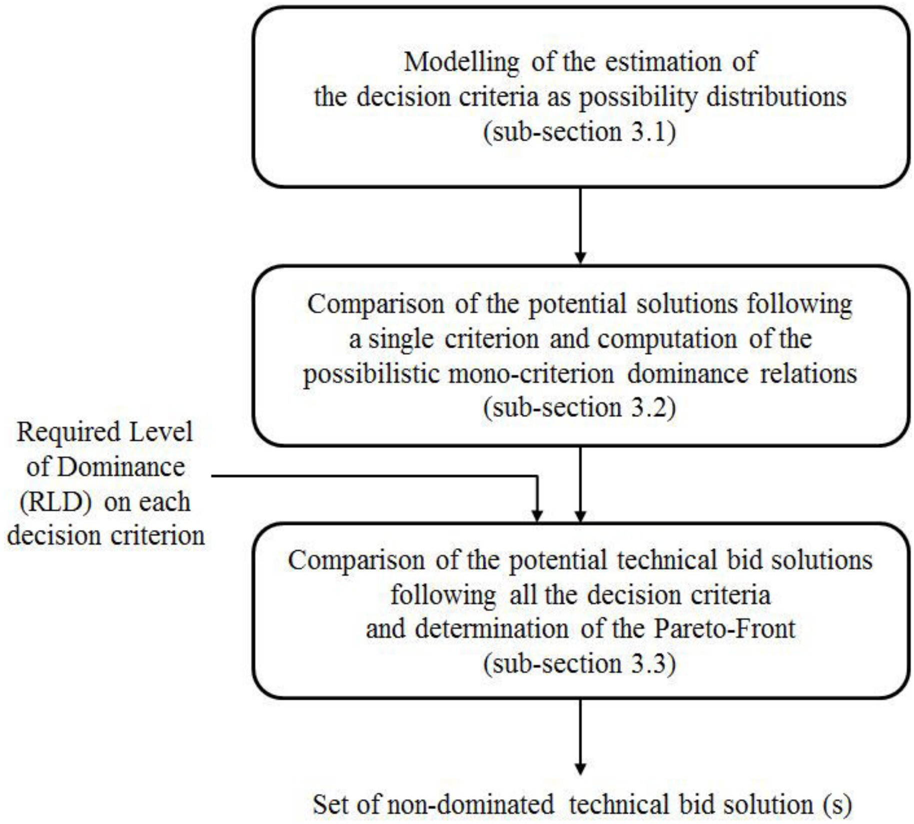

Figure 3.3 – Cadre général de l'approche d'aide à la décision

modélisation permet ainsi de prendre en compte simultanément les incertitudes et imprécisions liées aux valeurs des critères de décision mais également la confiance du soumissionnaire dans chaque offre lors de la comparaison des offres potentielles. La Figure 3.4 illustre la manière dont ces valeurs sont modélisées sous forme de distributions de possibilité. L'axe des abscisses représente les valeurs possibles d'un critère k pour une offre technique j. Les intervalles [a,d] et [b,c] représentent respectivement : le domaine d'évaluation et les valeurs les plus plausibles du critère k pour l'offre j. L'axe des ordonnés représente la possibilité de chaque valeur. Le paramètre e représente la possibilité d'avoir une valeur hors de l'intervalle [b,c]. Il est déterminé à l'aide d'une fonction utilisant les indicateurs de confiance OCS *(Overall Confidence in System)* et OCP *(Overall Confidence in Process)* proposés dans l'article [Sylla+2017c]. Cette fonction est décrite dans l'article, section 3.1.

C. Les relations de dominance mono-critère possibilistes

Concernant la deuxième étape, nous avons proposé dans la section 3.2 de l'article quatre relations de dominance possibilistes : *Certain Dominance* (CD), *Strong Possibility of Dominance* (SPD), *Weak Possibility of Dominance* (WPD) et *Indifference* (IND) pour permettre au soumissionnaire de comparer chaque paire d'offres techniques et de définir lesquelles sont les meilleures au regard d'un seul critère de décision. Ces relations de dominance sont basées sur les indices de dominance proposés dans [Dubois+1983 ; Dubois+1988] pour comparer et classer deux nombres

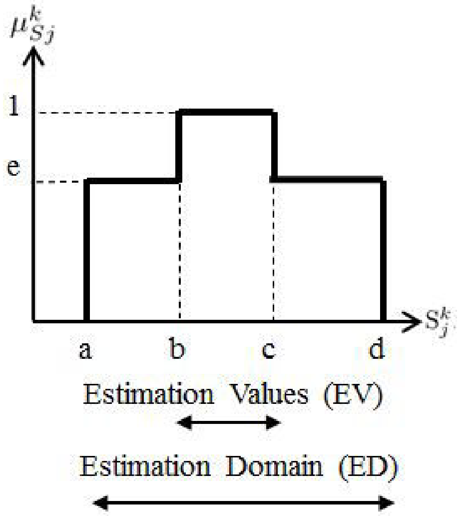

Figure 3.4 – Modélisation des valeurs imprécises et incertaines

flous. Ces indices de dominance sont présentés dans la section 2.3 de cet article. Un algorithme permettant de calculer et d'établir la relation de dominance entre deux offres est également proposé et décrit dans la section 3.4 (page 25). Toutes ces propositions permettent à l'entreprise soumissionnaire (ou au décideur) de connaitre, au regard de chaque critère de décision si une offre domine une autre et, le cas échéant, de quantifier le niveau de certitude de la dominance.

D. Méthode proposée pour construire le front de Pareto

Pour la troisième étape, une méthode basée sur le principe de Pareto-dominance est proposée dans la section 3.3 de l'article. Elle permet au soumissionnaire de comparer chaque paire d'offres techniques au regard de tous les critères de décision et de déterminer un ensemble restreint d'offres les plus intéressantes constituant le front de Pareto. Cette méthode intègre un concept de niveau de dominance nécessaire noté RLD (*Required Level of Dominance*) qui permet au soumissionnaire de définir ses exigences par rapport au degré d'incertitude et d'imprécision permis pour chaque critère de décision. Différents fronts de Pareto peuvent être obtenus en fonction du niveau de RLD défini pour chaque critère de décision. Un algorithme permettant de comparer les offres et de construire un front de Pareto tout en prenant en compte le RLD de chaque critère est proposé et décrit dans l'article, section 3.4 (page 26). L'ensemble de ces propositions permet au soumissionnaire de construire progressivement l'ensemble des offres techniques les plus intéressantes tout en tenant compte de ses exigences par rapport aux niveaux d'incertitudes et d'imprécisions autorisés sur les critères de décision.

L'approche proposée est appliquée sur un exemple portant sur l'élaboration d'une offre technique concernant le développement d'une grue. Les résultats de cette application sont aussi présentés et discutés dans cet article, section 4.

3.3.2 Synthèse des contributions et perspectives

Les contributions principales de cet article sont : (i) la méthode proposée pour modéliser simultanément les incertitudes, les imprécisions et la confiance du soumissionnaire caractérisant les valeurs des critères de décision avec des distributions de possibilité, (ii) les quatre relations de dominance possibilistes permettant de comparer deux offres techniques au regard d'un seul critère de décision en tenant compte des incertitudes, des imprécisions et de la confiance du soumissionnaire, et (iii) la méthode proposée pour comparer les offres techniques au regard de tous les critères de décision et construire un ensemble restreint d'offres les plus intéressantes.

Ces propositions permettent au soumissionnaire de sélectionner l'offre technique la plus intéressante sur la base des critères de décision pertinents tout en tenant compte des incertitudes, des imprécisions et de la confiance caractérisant les valeurs de ces critères. Ce qui permet de choisir l'offre la plus compétitive et la plus réalisable parmi un panel d'offres techniques potentielles.

Dans cet article, nous avons fait l'hypothèse que les critères de décision ont la même importance. Cette hypothèse est pertinente pour des situations où le décideur considère une même importance pour les critères de décision ou ne peut pas fournir explicitement un coefficient d'importance pour chaque critère de décision. Cependant, dans certaines situations, le décideur a la connaissance du coefficient d'importance de chaque critère de décision. Dans un tel contexte, il est nécessaire et utile de prendre en compte ces coefficients lors de la comparaison des solutions (offres techniques) au regard de tous les critères de décision. Par conséquent, dans nos futurs travaux nous envisageons d'étendre l'approche proposée à de telles situations. Une méthode intégrant les relations de dominance mono-critère proposées avec une méthode de surclassement de type PROMETHEE ou ELECTRE pourrait ainsi être développée afin de classer les offres techniques potentielles.

Notre troisième article, soumis à une revue, détaille l'approche proposée dans les pages suivantes.

Possibilistic Pareto-dominance approach to support technical bid selection under imprecision and uncertainty in the bidding process

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Abstract

Successfully bidding to several customers' projects is a key factor for the systems contractors to increase their business volume and to remain competitive. Moreover, it implies to define relevant potential technical bid solutions with regards to the customers' requirements and to select the most interesting ones for the commercial offers. However, in the Engineer-To-Order (ETO) industrial contexts, the selection of the most interesting technical bid solution is challenged by imprecision and uncertainty on the values of the decision criteria. They are due to the lack of accurate and complete knowledge about some parts of the technical bid solutions which have to be designed. They are taken into account in this article by intervals and by confidence measures. Therefore, in order to help the bidders to make the right decision when selecting the most interesting technical bid solution, a multi-criteria decision support approach which takes into account imprecision and uncertainty (and moreover the confidence of the bidder in each technical bid solution), is proposed. The proposed approach gathers three stages. First, a method is proposed to model the imprecise and uncertain values of the decision criteria as possibility distributions. Second, four possibilistic mono-criterion dominance relations (mono-CDR) are developed to compare two potential solutions following a single decision criterion. Finally, a method is proposed to compare the potential solutions following all the decision criteria and to determine the Pareto front which takes into account: (i) the uncertainty and imprecision related to the values of the decision criteria and (ii) the bidder's requirements about the level of acceptance of imprecision and uncertainty on each decision criterion. An application is presented to show the applicability and effectiveness of the proposed approach.

Keywords: Bidding process; Technical bid selection; Uncertainty and imprecision, Possibilistic Pareto-dominance

1. Introduction

The business of systems contractors is mostly based on performing projects obtained through the submission of successful bids to several customers Chapman et al. (2000); Arslan et al. (2006). Therefore, in order to increase their business volume and to remain competitive, the systems contractors (or bidders) must successfully bid to several customers Arslan et al. (2006). Moreover, to submit a bid to a customer, a bidder must perform five main activities in very short period Krömker et al. (1998); Weber et al. (2000). As shown in Fig .1, once a bidding opportunity is detected, it is first analyzed (A1), which enables to decide to bid (or not) to a particular customer's project. Afterward, if it was decided to bid, based on the customer's requirements and the company's capabilities, several potential technical bid solutions are defined and estimated (A2). Each of these potential technical bid solutions is supposed to comply with the technical and functional requirements of the customer. Then, from this panel of potential technical bid solutions, the

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bidder must select the most interesting technical bid solution (A3) in order to elaborate the commercial bid solution (A4) and transmit a bid proposal to the customer (A5), expecting that the bid will be successful Krömker et al. (1998); Chalal & Ghomari (2008).

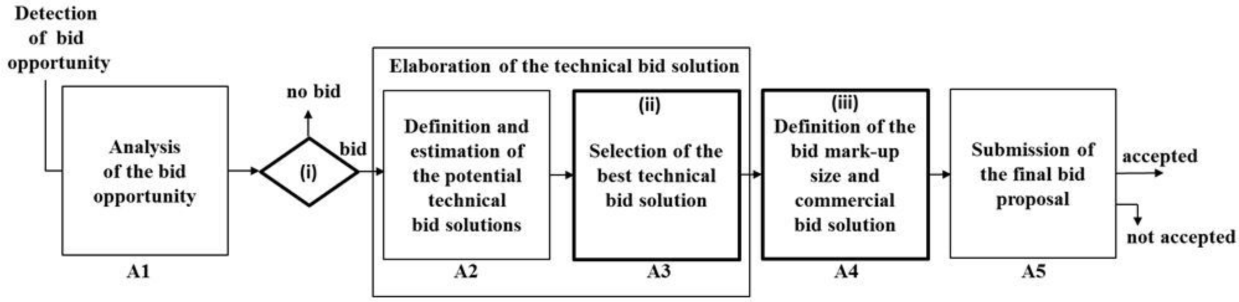


Fig. 1. Bidding process adapted from Chalal & Ghomari (2008)

A successful bid implies that: (a) the bid proposal is accepted by the customer, (b) the technical system relevant to the bid proposal is developed and delivered according to the customer's expectations (e.g. cost and delivery date) and, (c) the project is profitable to the bidder Arslan et al. (2006); Krömker et al. (1998). However, as shown in Fig. 1, this is challenged by three major decision making problems: (i) to bid or not to bid to a particular customer's project, (ii) to select the most interesting technical bid solution for a project and, (iii) to *estimate* the bid mark-up size. Each decision making problem is further complicated by imprecision and uncertainty due to the lack of reliable and complete information Chapman et al. (2000).

In the scientific literature, several efforts have been dedicated to the bid/no bid and the bid mark-up size decision making problems. For the bid/no bid decision making problem, various approaches (see Lin & Chen (2004); Chua & Li (2000); Sonmez & Sözgen (2017), for instance) have been developed to help the bidders to make the right decision in order to devote bid preparation efforts on projects that, when accepted, satisfy their objectives. For the bid mark-up size estimation, some authors Dikmen et al. (2007); Egemen & Mohamed (2008); Cheng & Cheng (2011) have also developed approaches to assist bidders. The aim is to help the bidders to choose the optimum bid price that will lead them to win the project and maximize the profit. These two decision making problems are out of the scope of this contribution.

Indeed, this article deals with the elaboration of a technical bid solution in a bidding process. The focus is made on the selection of the most interesting solutions among a panel of several potential technical bid solutions under imprecision and uncertainty (activity A3 and decision making problem iii of the bidding process, see Fig. 1). In the context of the bidding process, an interesting solution is a solution that combines both the attractiveness (good values for the evaluation criteria) and the feasibility (few uncertainty about the values of the evaluation criteria). In the remainder of this article, the term decision criteria is interchangeably used with that of evaluation criteria.

The elaboration process of a technical bid solution consists in defining and estimating some potential technical bid solutions and selecting the most interesting one to be considered for the bid proposal Krömker et al. (1998); Chalal & Ghomari (2008). As Krömker et al. (1998) and Yan et al. (2006), we consider that a technical bid solution is composed of two interconnected parts: (1) a technical system (a set of sub-systems and components) and (2) its delivery process (a set of required activities and resources to implement the technical system). Therefore, as already noticed by Krömker et al. (1998) and Sylla et al. (2017a), each technical bid solution must be defined and estimated both on its technical system and its delivery process. In order to do that, configuration software are commonly used. Configuration software are knowledge-based systems that, given a kind of generic model of the technical bid solutions, allow the bidder to instantiate or customize specific solutions according to customer's requirements Felfernig et al. (2014); Hvam & Ladeby (2007); Aldanondo & Vareilles (2008). In this article, this task is supposed done and, consequently, the focus is made on the selection, under imprecision and uncertainty, of the most interesting solution from a panel of potential technical bid solutions. The selection is done based upon several decision criteria. They are assumed to be independent and not compensable. Moreover, the same importance is given to each of them in the decision process.

When elaborating a technical bid solution in the context of a bidding process, two kinds of industrial situations can be considered. The first kind is Assemble/Make-To-Order (AMTO) industrial situations. In AMTO situations, the relevant technical bid solutions have been studied in detail and completely defined before launching the elaboration of a technical bid solution Olhager (2003). Complete and accurate knowledge is then available to estimate the potential technical bid solutions Chandrasekaran (1986); Sylla et al. (2017a). Therefore, the uncertainty and imprecision on the values of the evaluation criteria are quite low. The potential technical bid solutions can be compared, using various standard multi-criteria decision support approaches (Dyer & Forman (1992); Brans & Mareschal (1994); Opricovic & Tzeng (2004); Hsu & Hu (2009); Giannoulis & Ishizaka (2010) to cite only a few). On the other hand, the second kind is Engineer-To-Order (ETO) industrial situations. In ETO situations, the relevant technical bid solutions have not been studied yet in detail and not completely defined before launching the elaboration of a technical bid solution. Relevant knowledge to estimate the potential technical bid solutions is thus less available Sylla et al. (2017a); Olhager (2003); Chandrasekaran (1986). In such situations, the values of the evaluation criteria are imprecise and uncertain Dantan et al. (2013); Sylla et al. (2017b). Therefore, in order to make the right decision when selecting a technical bid solution, it is necessary to consider uncertainty and imprecision related to the estimation of the decision criteria. In this article, we consider the ETO industrial contexts and develop a multi-criteria decision support approach to support technical bid selection, under imprecision and uncertainty, in the bidding process.

In Sylla et al. (2017c), two confidence indicators, named Overall Confidence in System (OCS) for the technical system and Overall Confidence in Process (OCP) for its delivery process, have been proposed. They allows to quantify the ability of a technical system to fulfill the customer's expectations (e.g. cost and delivery date) after its design and implementation. The OCS indicator is based on the readiness (or maturity) of the technical system as well as the confidence of the bidder in the technical system. Whereas the OCP indicator is based on the feasibility of the delivery process as well as the confidence of the bidder in the delivery process. Both OCS and OCP are measured on a nine level scale (1 is the lowest level and 9 the highest). More details about the computation method of OCS and OCP are provided in Sylla et al. (2017c).

By representing confidence in a technical bid solution, the OCS and OCP indicators allow to characterize uncertainty corresponding to this technical bid solution and then, to the evaluation criteria Sylla et al. (2017b). In this article, using these confidence indicators (OCS and OCP) and the possibility theory Dubois & Prade (1983, 2012), we develop a multi-criteria decision support approach based on the Pareto-dominance principle. It allows the bidders to make the right decision when selecting the most interesting solution to propose during the bidding process, taking into account imprecision and uncertainty (and moreover her/his confidence in each technical bid solution) (activity A3 and decision making problem iii of the bidding process, see Fig. 1). In this approach, first, a method is proposed to model the imprecise and uncertain values of the decision criteria as possibility distributions. This method is based on the use of intervals of values and of the confidence indicators OCS and OCP to quantify the imprecision and uncertainty related to the values of the decision criteria by means of possibility distributions. That allows to take imprecision, uncertainty and bidder's confidence into account when comparing two potential technical bid solutions. Then, a possibilistic Pareto-dominance approach is proposed to compare the potential solutions and to determine the restricted set of the most interesting ones (the Pareto front). It is based on: (i) four possibilistic mono-criterion dominance relations (mono-CDR) which are used to perform a pairwise comparison of the potential solutions with regard to a single criterion, and (ii) a method based on the notion of Required Level of Dominance (RLD) on each decision criterion to construct the Pareto front. A RLD represents the acceptable level of imprecision and uncertainty on a decision criterion. Different combinations of RLD allow to obtain different Pareto fronts depending on the level of imprecision and uncertainty allowed on the criteria.

The main contributions of this article are then: (i) the method proposed to model the imprecise and uncertain values of the decision criteria by means of possibility distributions taking into account the confidence indicators (ii) the possibilistic dominance relations for the comparison of the potential solutions and (iii) the construction of the Pareto front for the decision making.

The remainder of this article is organized as follows. In section 2, an adequate background related to uncertainty and imprecision in the context of the elaboration of technical bid solutions is presented. Existing literature related to the multi-criteria decision making support approaches under imprecision and uncertainty and the comparison of imprecise uncertain values, is also reviewed. In section 3, the proposed multi-criteria decision support approach along with the supporting algorithms are described. In section 4, the application of the proposed approach on an example is presented and discussed in order to validate the contributions. Conclusion and future research are provided in section 5.

2. Research Background

2.1. Imprecision and uncertainty when selecting the best technical bid solution

From the the bid/no bid decision-making problem to the bid mark-up size estimation one through the selection of the most interesting technical bid solution, every decision making problem of the bidding process is influenced by imprecision and uncertainty Chapman et al. (2000). These imprecision and uncertainty may have various natures (epistemic or aleatory) and take various forms (e.g. confidence, reliability, variation or inaccuracy) Dantan et al. (2013); Sylla et al. (2017b); Dubois & Prade (2012). They add much more difficulty in the decision making process and to ignore them may lead to deceptive decisions Chapman et al. (2000).

As the contribution presented in this article focuses on the selection of the most interesting technical bid solutions, we only consider the uncertainty and imprecision related to the design solutions in Engineer-To-Order (ETO) industrial contexts. They are due to the lack of relevant knowledge and to incomplete description of the technical system and its delivery process which compose a technical bid solution. They affect the values of the design parameters and then the evaluation criteria that characterize the technical system (e.g. cost and performance) and the delivery process (e.g. cost and duration).

In the context of a technical bid solution estimation, an estimation can be expressed as a quadruplet (item, attribute, value, confidence). The item is whether the technical system or the delivery process. The attribute represents any characteristic (a design parameter or an evaluation criterion) of the item. The value is the predicate of the attribute and the confidence is related to the conformity of the value to the reality Sylla et al. (2017b); Dubois & Prade (2012). In this perspective, as in Dubois & Prade (2012), we distinguish the two concepts of imprecision and uncertainty as follows: imprecision concerns the the values of the design parameters or the evaluation criteria whereas the uncertainty is relative to the confidence in these values. For example, let us consider the estimation of the cost of a crane technical bid solution. An imprecise and uncertain estimation can be for instance: the cost of the crane (cost = [75, 85] K$), the confidence in this value (confidence = 0.70, where 1 is the maximum value in the scale of the confidence measure). Thus the imprecision is modeled by the interval [75, 85] K$ and the uncertainty is characterized by the value of the confidence which is equal to 0.70 in this example.

Accordingly, in this article, the imprecision related to the estimation of a decision criterion is represented as an interval of possible values and the confidence indicators (OCS, OCP) developed in Sylla et al. (2017c) are used to quantify and characterize the uncertainty related to these values as possibility distributions. In the next sub-sections, a panorama of approaches that take imprecision and uncertainty into account in multi-criteria decision making is presented.

2.2. Multi-criteria decision making under imprecision and uncertainty

In the context of multi-criteria decision making, among several potential solutions, the decision-maker has to choose the best solution based on the estimation of the potential solutions following several decision criteria Korhonen et al. (1992). In many real world decision problems, due to the lack of accurate and complete information, that estimation is imprecise and uncertain Durbach & Stewart (2012); Zandi & Roghanian (2013); Beg & Rashid (2017). Therefore, the comparison of the potential solutions leads to the comparison of imprecise and uncertain numbers Nowak (2004). In this perspectives, various approaches have been developed in order to help the decision maker. They differ in two aspects: (i) the way the imprecision and uncertainty are modeled, and (ii) the method used to compare the potential solutions and to model the preference (or dominance) relations Durbach & Stewart (2012). The most common approaches used to model imprecision and uncertainty in decision analysis are probability theory and fuzzy set theory (and possibility theory) (see the reviews in Durbach & Stewart (2012); Broekhuizen et al. (2015); Kangas & Kangas (2004)).

With the probability theory, the imprecise and uncertain values of each potential solution S_j following a decision criterion k, is modeled with a probability distribution function F_j^k. Two methods are very often used to compare the potential solutions: (i) Muti-Attributes Utility Theory (MAUT) (see Von Neumann & Morgenstern (1953); Grabisch et al. (2008); Wilson & Quigley (2016)) and (ii) Stochastic Dominance approach (SD) (see Nowak (2004); D'Avignon & Vincke (1988); Zhang et al. (2010)). In MAUT, based on the probability distributions of all the criteria, a function permits to compute the expected utility of each solution. Then a solution S_j is preferred to another one S_i if and only if the expected utility of S_j is greater than that of S_i. In the SD approach, a pairwise comparison of probability distributions is first performed in order to compare the potential solutions and to establish preference (or dominance) relations between them, following each decision criterion. Then, a method is used to built deterministic/stochastic preference (or dominance) relations following all the decision criteria.

With the fuzzy set theory, the imprecise and uncertain values of the decision criteria are modeled with fuzzy numbers. Then, a fuzzy numbers ranking method is used to compare the potential solutions and to establish preference (or dominance) relations between them Durbach & Stewart (2012). Many decision methods use fuzzy set theory to deal with imprecision and uncertainty (see the reviews in Chen & Hwang (1992); Kahraman & Sezi (2007); Chuu (2009); Mardani et al. (2015)). According to the review presented in Broekhuizen et al. (2015); Mardani et al. (2015), the Analytic Hierarchy Process (AHP) is the most common method which uses fuzzy set. Indeed, the estimation of the weights and the values of the decision criteria is based on judgments. These judgments have a qualitative nature and may be inconsistent Durbach & Stewart (2012). Therefore, the fuzzy set theory is very often used: (i) to model the weight and/or values of the decision criteria with fuzzy numbers, and (ii) to perform the aggregation of these values into a global score for each potential solution. Fuzzy Pareto-dominance approach is also used to compare potential solutions (see Mario et al. (2005); Ganguly et al. (2013); Sahoo et al. (2012)). It is based on the conventional Pareto-dominance principle. The difference between them is that in the fuzzy Pareto-dominance, a degree of dominance characterizes the dominance relations between two solutions. Therefore, the potential solutions can be ranked following their mutual degree of dominance (see Ganguly et al. (2013)).

In this paper, the decision criteria are supposed to be independent and not compensable. Moreover, a same importance is given to each decision criterion in the decision process. Therefore, multi-criteria decision support approaches (such as AHP or MAUT) which aggregate the values of all the decision criteria into a global value for the comparison of the potential solutions, are not relevant. Moreover, we consider the possibility theory framework to cope with uncertainty and imprecision related to the values of the decision criteria. The possibility theory is known to be a very good framework to simultaneously deal with imprecision and uncertainty due to a lack of accurate and complete information Dubois & Prade (2012); French (1995). Moreover, it also permits to easily and effectively take into account expert's points of view (thus to take into account the confidence of the bidders in each technical bid solution).

The approach developed in this article is thus based on the Pareto-dominance principle and possibility theory. The Pareto-dominance method is a multi-criteria decision support approach. First, given a set of potential solutions and several decision criteria, it allows to perform a pairwise comparison of the potential solutions, following a single decision criterion, in order to establish mono-criterion dominance relations between them. Second, based on the mono-criterion dominance relations, it allows to compare the potential solutions following all the decision criteria and to establish an overall Pareto-dominance relation between them. Finally, it allows to determine the set of non-dominated potential solutions (Pareto front). The conventional Pareto-dominance and Pareto front hypothesis is formulated as follows. A solution S_j Pareto-dominates another solution S_i (denoted by $S_j \prec S_i$), if the values of the decision criteria for the solution S_j are not greater than those of the solution S_i, and at least for one decision criterion, the value of the decision criterion for the solution S_j is smaller than that of the solution S_i. In addition, a solution S^* belongs to the set of non-dominated solutions (named Pareto front), if and only if no other solution Pareto-dominates it.

The main difference between the Pareto-dominance approach proposed and the conventional one are as follows. The imprecise and uncertain values of the decision criteria are modeled with possibility distributions. They take into account the confidence of the bidder in the solution (by mixing factual and subjective points of view, see sub-section 2.3). The proposed approach considers different levels of dominance that allow to take into account the possibility level of dominance of a solution S_j over another solution S_i. Different Pareto fronts can be obtained depending on the level of uncertainty allowed on each decision criterion.

2.3. Comparison of uncertain and imprecise numbers

In the scientific literature, numerous methods have been proposed to compare two fuzzy numbers for a ranking purpose (see Dubois & Prade (1983); Yagger (1981); Iskander (2002); Tran & Duckstein (2002)). The four dominance indexes (two possibility of dominance and two necessity of dominance) suggested in Dubois & Prade (1983), provide possibilistic valued dominance relations for the ranking of fuzzy numbers defined with possibility distributions. Several authors (see Dubois & Prade (2012); Bortolan & Degani (1985); Iskander (2005)) have shown that these four dominance indexes are completely able to clearly describe any situation in order to indicate the possibility and necessity of a fuzzy number being greater (or smaller) than another one. Therefore, in a decision making problem where the imprecise and uncertain estimation of the potential solutions are modeled with possibility distributions, they can be used to compare two potential solutions with regard to a single decision criterion.

In this article, the four dominance indexes of Dubois & Prade (1983, 2012) are used to develop the possibilistic mono-criterion dominance relations (mono-CDR). They allow to perform a pairwise comparison of the potential technical bid solutions with regard to a single decision criterion (the mono-CDR are presented in sub-section 3.2). These four dominance indexes are presented in the following.

Let us consider that the values of the estimation of two solutions S_j and S_i with regard to a decision criterion k are denoted S_j^k and S_i^k respectively. The possible values of the two solutions S_j and S_i are restricted by the possibility distributions μ_{Sj}^k and μ_{Si}^k. If we consider situations where small values are preferred for the decision criteria, the four dominance indexes are expressed in the following (for more details, see Dubois & Prade (1983, 2012)).

1. Possibility Of Dominance (POD). It is the possibility that the values of S_j^k are not greater than the values of S_i^k.

$$POD_{Sj\prec Si}^k = \sup_{x\in S_i^k}[\min(\mu_{Si}^k(x), \sup_{y\leq x}[\mu_{Sj}^k(y)])] \tag{1}$$

2. Possibility of Strict Dominance (PSD). It is the possibility that the values of S_j^k are smaller than the values of S_i^k.

$$PSD_{Sj\prec Si}^k = \sup_{x\in S_i^k}[\min(\mu_{Si}^k(x), \inf_{y\geq x}[(1-\mu_{Sj}^k(y)])] \tag{2}$$

3. Necessity Of Dominance (NOD). It is the necessity that the values of S_j^k are not greater than the values of S_i^k.

$$NOD_{Sj\prec Si}^k = \inf_{x\in S_i^k}[\max((1-\mu_{Si}^k(x)), \sup_{y\leq x}[\mu_{Sj}^k(y)])] \tag{3}$$

4. Necessity of Strict Dominance (NSD). It is the necessity that the values of S_j^k are smaller than the values of S_i^k.

$$NSD_{Sj\prec Si}^k = \inf_{x\in S_i^k}[\max((1-\mu_{Si}^k(x)), \inf_{y\geq x}[(1-\mu_{Sj}^k(y)])] \tag{4}$$

Moreover, the four dominance indexes satisfy the following axioms Dubois & Prade (1983, 2012).

$$POD_{Sj\prec Si}^k = 1 - NSD_{Si\prec Sj}^k \tag{5}$$

$$\max(POD_{Sj\prec Si}^k, POD_{Si\prec Sj}^k) = 1 \tag{6}$$

$$POD^k_{Sj \prec Si} \geq \max(PSD^k_{Sj \prec Si}, NOD^k_{Sj \prec Si}) \tag{7}$$

$$NSD^k_{Sj \prec Si} \leq \min(PSD^k_{Sj \prec Si}, NOD^k_{Sj \prec Si}) \tag{8}$$

Based on this background, in the following section, the multi-criteria decision making support approach proposed to support the bidder in the selection of the most interesting technical bid solutions is described.

3. Possibilistic Pareto-dominance approach for technical bid selection

In this section, the possibilistic Pareto-dominance approach to compare the potential technical bid solutions and to obtain the set of non-dominated solutions (Pareto front) is developed. The obtained Pareto front takes into account: (i) uncertainty and imprecision related to the estimation of the decision criteria and (ii) the Required Level of Dominance (RLD) which corresponds to the bidder's requirements about the level of acceptance of uncertainty and imprecision on each decision criterion. As shown in Fig. 2, the approach is organized following three main stages.

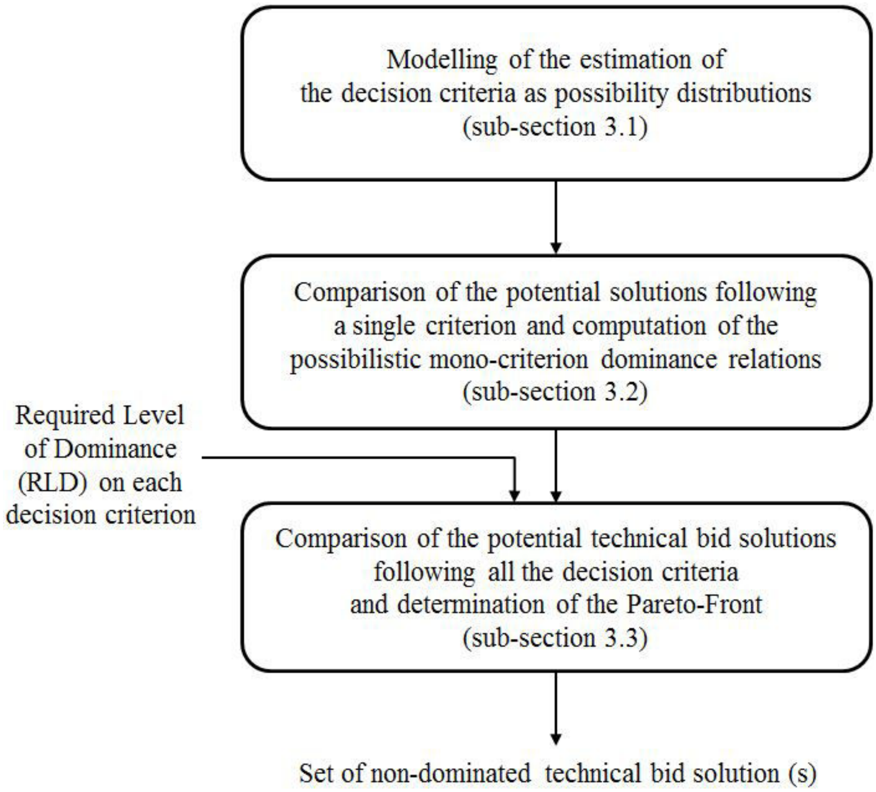


Fig. 2. Multi-criteria decision support approach

1. At the first stage, using the confidence indicators developed by Sylla et al. (2017c), a method is used to obtain the possibility distribution of each imprecise and uncertain decision criterion (see section 3.1).
2. At the second stage, for each decision criterion, and for each pair of technical bid solutions, the four dominance indexes of Dubois & Prade (1983, 2012) are used to compare the two solutions and to define the possibilistic mono-criterion dominance relation (mono-CDR) between them (see section 3.2).

3. At the third stage, the person in charge of the elaboration of the technical bid solution sets up the Required Level of Dominance (RLD) for each decision criterion. The RLD corresponds to the bidder's requirements about the level of acceptance of uncertainty and imprecision for each decision criterion. Then, based on the possibilistic mono-CDR established between the potential solutions and the RLD of each decision criterion, the potential technical bid solutions are compared following all the decision criteria and the set of non-dominated solutions (Pareto front) is determined.

In the following sub-sections, we describe all the three stages and the algorithms that support the proposed approach.

3.1. Modelling of the possibility distributions for the criteria

The possibility theory together with the confidence indicators offer a good opportunity to easily model the imprecise and uncertain estimation of the decision criteria as possibility distributions. For a solution S_j, the possibility distribution μ^k_{Sj} corresponding to the possible values of the decision criterion k, is characterized with five parameters: a, b, c, d and e (see Fig. 3). Moreover, it can be formally defined by the equation 9 below. For every value of the decision criterion k for the solution j (denoted S^k_j), $\mu^k_{Sj}(S^k_j)$ is the possibility of the value S^k_j.

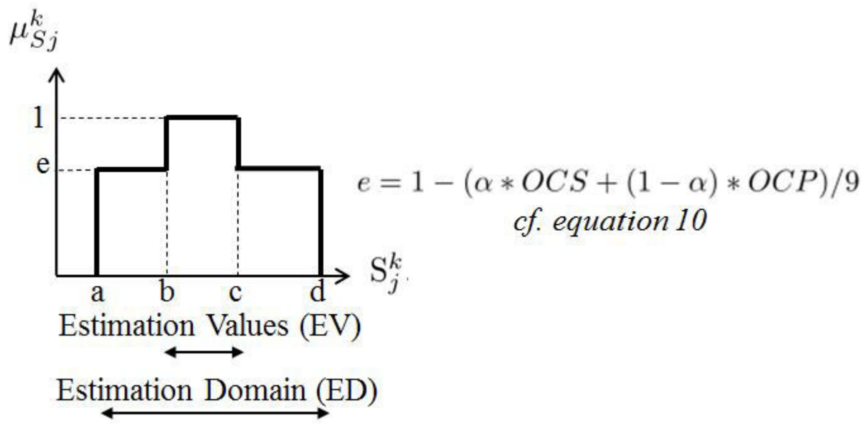


Fig. 3. Possibility distribution $\mu^k_{Sj}(S_j)^k$ of a criterion k for a solution S_j

$$\mu^k_{Sj}(S^k_j) = \begin{cases} 0 & \text{if} \quad (S^k_j < a) \vee (S^k_j > d) \\ e & \text{if} \quad (a \leq S^k_j < b) \vee (c < S^k_j \leq d) \\ 1 & \text{if} \quad (b \leq S^k_j \leq c) \end{cases} \tag{9}$$

- The parameters a and d represent respectively the lower and upper bounds of the Estimation Domain (ED) of a criterion. This domain is supposed certain. It means that the value of a criterion for a technical bid solution, is with certainty included in this domain.
- The parameters b and c represent respectively the lower and upper bounds of the interval of the Estimation Values (EV). The interval EV corresponds to the most possible values (the values that have their possibility level at the maximum level). Given the estimation domain of a criterion, based on experiences, an expert (or a computerized system) estimates the interval of the most possible values. For instance, a configuration software can be used to compute these intervals Sylla et al. (2017c).
- The parameter e represents the possibility to have a value out of the interval EV. It depends on the confidence indicators (OCS and OCP) that characterizes the technical bid solution. It is calculated

using the equation 10. The value (9) in this equation, represents the maximum level in the OCS and OCP scale. Thus the values of e are ranged in the real interval [0, 1].

$$e = 1 - (\alpha * OCS + (1 - \alpha) * OCP)/9 \quad (10)$$

The parameter α makes it possible to take into account the relative importance of each item (technical system and delivery process) according to the criterion in consideration. In the context of the elaboration of the technical bid solution in the bidding process, for a criterion that characterizes the two items (e.g. the *cost* of the technical bid solution), both the OCS and OCP indicators are relevant. Therefore, assuming that the two items have the same importance, α is equal to 0.5. For a criterion, that characterizes only the delivery process (e.g. the *duration* of the delivery process), only the OCP indicator is relevant, α is equal to 0. For a criterion, that characterizes only the technical system (e.g. a *technical performance* of the technical system), only the OCS indicator is relevant, α is equal to 1.

For example, let us consider again the example of the estimation of the cost of a crane technical bid solution (which is composed of the crane technical system and its delivery process). As this criterion characterizes both the crane technical system and its delivery process, α is equal to 0.5. In this estimation, it is known with certainty that the Estimation Domain (ED) of the crane technical bid solution is equal to [60, 100] *k*$. Based on the available information, an expert (or a computerized system) indicates that it is more plausible that the cost of this crane technical bid solution be equal to [75, 85] k$. This interval [75, 85] k$ represents the interval of the Estimation values (EV). The system also provides the values of the confidence indicators OCS and OCP.

- If OCS = 9 and OCP = 9, then according to the equation 10, e = 0. It means that the technical system and its delivery process are, with certainty, able to meet the expectations (e.g. the cost of the technical bid solution). Therefore, it is certain that the cost of this crane technical bid solution will be in the interval of the Estimation Values (EV) [75, 85] k$. The possibility (e) to have a value out of this interval [75, 85] k$ is then equal to 0.
- If OCS = 7 and OCP = 6, then according to the equation 10, e = 0.28. It means that it is not certain that the technical system and its delivery process are able to meet the expectations (e.g. the cost of the technical bid solution). Therefore, there is a possibility that the cost of the technical bid solution to be out of the interval of the EV [75, 85] k$. This possibility (e) is equal to 0.28.

For a technical bid solution, given the four parameters (a, b, c and d) and the confidence indicators (OCS and OCP), this method allows to build the corresponding possibility distributions for each criterion. In the next sub-section, the possibilistic mono-criterion dominance relations (mono-CDR) developed to compare the potential technical bid solutions following a single decision criterion are presented.

3.2. Comparison of technical bid solutions following a single criterion

In this sub-section, four possibilistic mono-Criterion Dominance Relations (mono-CDR) which allows to compare the potential technical bid solutions following a single decision criterion are presented.

Let us consider two potential technical bid solutions S_j and S_i. For each solution, a variable (S_j^k, with possibility distribution μ_{Sj}^k for the solution S_j and S_i^k, with possibility distribution μ_{Si}^k for the solution S_i), represents the estimation of the decision criterion *k*.

In order to develop the mono-CDR, all possible configurations of the possibility distributions μ_{Sj}^k and μ_{Si}^k, have been generated and studied. For each configuration, and for each technical bid solution, the four dominance indexes (POD^k, PSD^k, NOD^k and NSD^k) are calculated and summarized in a vector (denoted by: $D_{Sj \prec Si}^k$ for the solution S_j and $D_{Si \prec Sj}^k$ for the solution S_i). $D_{Sj \prec Si}^k$ provides the possibility and necessity of dominance of the solution S_j over the solution S_i whereas $D_{Si \prec Sj}^k$ provides the possibility and necessity of dominance of the solution S_i over the solution S_j. The two vectors are described by the equations 11 and 12.

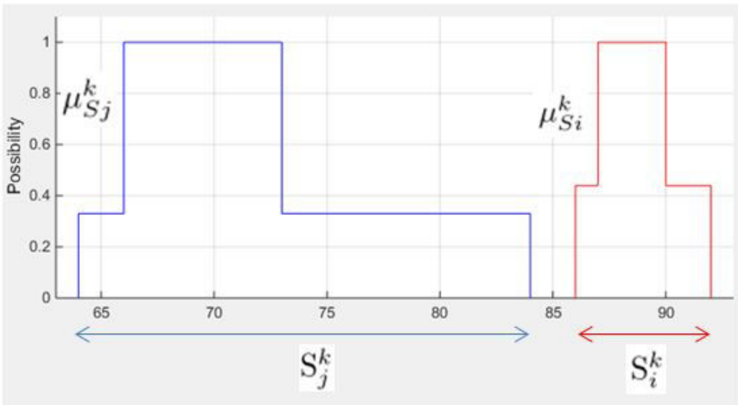
$$D_{Sj \prec Si}^k = [POD_{Sj \prec Si}^k, PSD_{Sj \prec Si}^k, NOD_{Sj \prec Si}^k, NSD_{Sj \prec Si}^k] \quad (11)$$

$$D^k_{Si \prec Sj} = [POD^k_{Si \prec Sj}, PSD^k_{Si \prec Sj}, NOD^k_{Si \prec Sj}, NSD^k_{Si \prec Sj}] \quad (12)$$

For each configuration, the values of the two vectors have been analyzed with regard to the definition and the axioms of the four dominance indexes presented in sub-section 2.3. This analysis allows to define three categories of dominance (certain dominance, strong possibility of dominance, weak possibility of dominance) and one category of indifference. The four categories are formalized with four possibilistic dominance relations. Considering a single decision criterion, they allow: (i) to indicate if a technical bid solution S_j dominates (or not) another one S_i and (ii) if it dominates it, to indicate the possibility level of dominance (certain, strong and weak). They are presented as follows.

1. Certain Dominance (denoted $\prec_{CD}$). This relation corresponds to situations where the two possibility distributions (μ^k_{Sj} for the solution S_j and μ^k_{Si} for the solution S_i) are completely disjoint (see Fig. 4). Whatever the value of each variable, one of them is with certainty smaller than the other one. Therefore, one solution certainly dominates the other one following the criterion k. A solution S_j certainly dominates a solution S_i, if the value of $NSD^k_{Sj \prec Si}$ (Necessity of Strict Dominance of S_j over S_i) is equal to 1 (see equation 13 and Fig. 4). Then, $S_j \prec_{CD} S_i$ if:

$$D^k_{Sj \prec Si}(4) = 1 \quad (13)$$

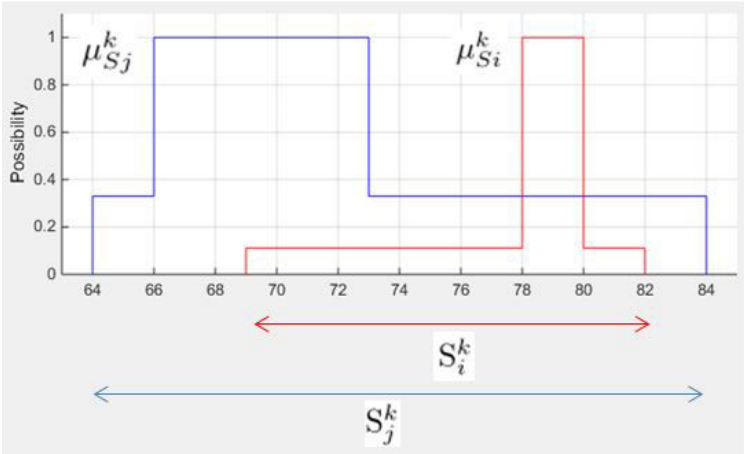


	POD	PSD	NOD	NSD
$D^k_{Sj \prec Si}$	1	1	1	1
$D^k_{Si \prec Sj}$	0	0	0	0

Fig. 4. Certain Dominance of S_j over S_i ($S_j \prec_{CD} S_i$)

2. Strong Possibility of Dominance (denoted $\prec_{SPD}$). This relation corresponds to situations where the two possibility distributions (μ^k_{Sj} for the solution S_j and μ^k_{Si} for the solution S_i) are not disjoint (see Fig. 5). However, all the four dominance indexes of the two vectors $D^k_{Sj \prec Si}$ and $D^k_{Si \prec Sj}$ are consistent for the comparison of the two variables S^k_j and S^k_i. They indicate that one variable is generally smaller than the other one. Accordingly, one solution dominates the other one, not certainly, but with a strong possibility. A solution S_j uncertainly, but with a strong possibility, dominates a solution S_i, if all the values of the four elements of the vector $D^k_{Sj \prec Si}$ are respectively greater than those of the vector $D^k_{Si \prec Sj}$ (see equation 14 and Fig. 5). Then, $S_j \prec_{SPD} S_i$ if:

$$[D^k_{Sj \prec Si}(4) < 1] \wedge [\forall t \in \{1, ..., 4\}; D^k_{Sj \prec Si}(t) > D^k_{Si \prec Sj}(t)] \quad (14)$$



	POD	*PSD*	*NOD*	*NSD*
$D^k_{Sj \prec Si}$	1	0.67	1	0.67
$D^k_{Si \prec Sj}$	0.33	0.33	0	0

Fig. 5. Strong Possibility of Dominance of S_j over S_i ($S_j \prec_{SPD} S_i$)

3. Weak Possibility of Dominance (denoted $\prec_{WPD}$). The two possibility distributions (μ^k_{Sj} for the solution S_j and μ^k_{Si} for the solution S_i) are not disjoint. However, in contrast to the $\prec_{SPD}$ relation, all the dominance indexes of the two vectors $D^k_{Sj \prec Si}$ and $D^k_{Si \prec Sj}$ are not consistent for the comparison of the two variables S^k_j and S^k_i. Most of the indexes of the two vectors indicate that one variable is generally smaller than the other one, but some of them are not consistent with that. Three cases have been identified:
a) In the first case, formalized in equation 15, three indexes (POD^k, NOD^k and NSD^k or POD^k, PSD^k and NSD^k) indicate that the variable S^k_j of the solution S_j is generally smaller than the variable S^k_i of the solution S_i, and one index (PSD^k or NOD^k) indicates whether: (i) the variable S^k_i of the solution S_i is generally smaller than that of the solution S_j or (ii) the variable S^k_i of the solution S_i is equal to that of the solution S_j.
b) In the second case, formalized in equations 16 and 17, two indexes (POD^k and NSD^k or PSD^k and NOD^k) indicate that the variable S^k_j of the solution S_j is generally smaller than the variable S^k_i of the solution S_i and the two other indexes (PSD^k and NOD^k or POD^k and NSD^k) indicate that the variable S^k_j of the solution S_j is equal to that of the solution S_i.
c) In the third case, formalized in equation 18, one of the indexes PSD^k or NOD^k indicates that the variable S^k_j of the solution S_j is generally smaller than the variable S^k_i of the solution S_i and the other indexes (POD^k, NSD^k and NOD^k or POD^k, NSD^k and PSD^k) indicate that the variable S^k_j of the solution S_j is equal to that of the solution S_i.
Therefore, a solution S_j uncertainly dominates, but with a weak possibility, a solution S_i (denoted $S_j \prec_{WPD} S_i$), if it satisfies one of the four equations 15, 16, 17 and 18 below.

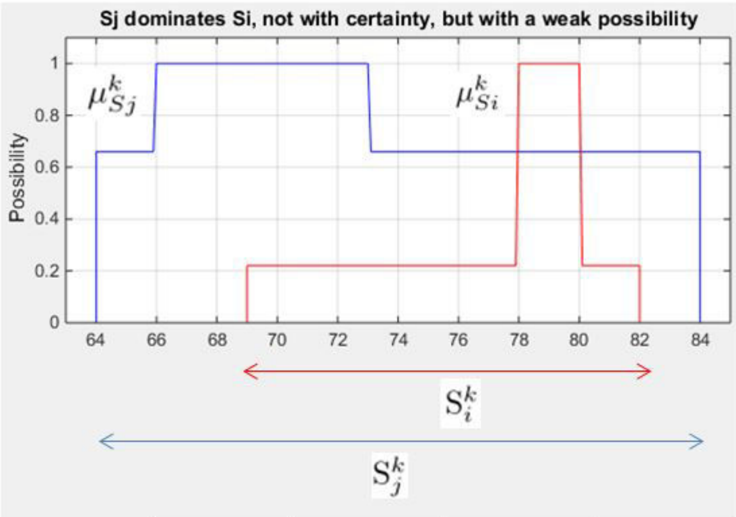
$$[\exists\, t \in \{1, ..., 4\} : D^k_{Sj \prec Si}(t) \le D^k_{Si \prec Sj}(t)] \wedge [\forall\, l \neq t : D^k_{Sj \prec Si}(l) > D^k_{Si \prec Sj}(l)] \quad (15)$$

$$[\forall\, t \in \{1, 4\} : D^k_{Sj \prec Si}(t) = D^k_{Si \prec Sj}(t)] \wedge [\forall\, l \neq t : D^k_{Sj \prec Si}(l) > D^k_{Si \prec Sj}(l)] \quad (16)$$

$$[\forall\, t \in \{1, 4\} : D^k_{Sj \prec Si}(t) > D^k_{Si \prec Sj}(t)] \wedge [\forall\, l \neq t : D^k_{Sj \prec Si}(l) = D^k_{Si \prec Sj}(l)] \quad (17)$$

$$[\exists\, t \in \{1, ..., 4\} : D^k_{Sj \prec Si}(t) > D^k_{Si \prec Sj}(t)] \wedge [\forall\, l \neq t : D^k_{Sj \prec Si}(l) = D^k_{Si \prec Sj}(l)] \quad (18)$$

The example shown in the Fig. 6 corresponds to the first case (equation 15). It can be seen through this Fig. 6 that the two distributions μ^k_{Sj} and μ^k_{Si} have almost the same positions as in the Fig. 5. The only difference is that, in the Fig. 6, the possibility to have a value of S^k_j that is greater than S^k_i has been increased. That is why the strength of the dominance of S_j over S_i has been decreased from $\prec_{SPD}$ (in Fig. 5) to $\prec_{WPD}$ (in Fig. 6).



	POD	PSD	NOD	NSD
$D^k_{Sj \prec Si}$	1	0.34	1	0.34
$D^k_{Si \prec Sj}$	0.66	0.66	0	0

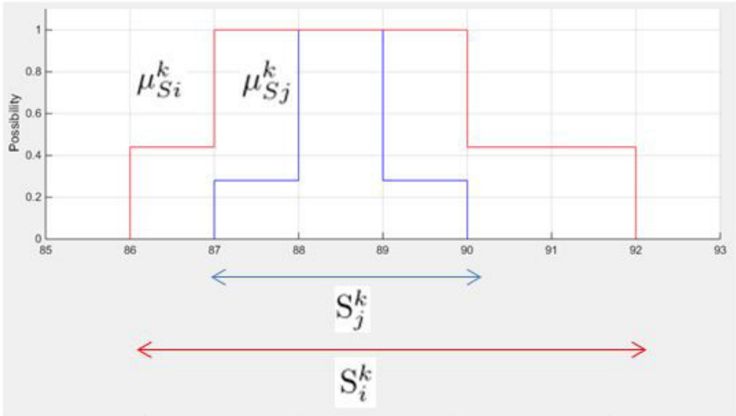
Fig. 6. Weak Possibility of Dominance of S_j over S_i ($S_j \prec_{SPD} S_i$)

4. Indifference (denoted IND). This relation corresponds to situations where the two possibility distributions μ^k_{Sj} and μ^k_{Si} strongly overlap (see Fig. 7). The dominance indexes of the two vectors $D^k_{Sj \prec Si}$ and $D^k_{Si \prec Sj}$ are not consistent for the comparison of the two variables S^k_j and S^k_i. In addition, in contrast to the previous dominance relations, none of the two variables exceeds the other one in number of dominance indexes that indicate that it is smaller than the other one. Two cases have been identified:
a) In the first case, formalized in the equation 19, the four dominance indexes (POD^k, PSD^k, NOD^k and NSD^k) indicate that the two variables S^k_j and S^k_i are equal.
b) In the second case, formalized in the equations 20 and 21, two dominance indexes (POD^k and NSD^k) indicate that the two variables S^k_j and S^k_i are equal and for the two others, each variable has one dominance index (PSD^k or NOD^k) that indicates that it is smaller than the other one. The example shown in Fig. 7 corresponds to this case.
Therefore, two technical bid solutions S_j and S_i are indifferent (denoted S_j IND S_i) if one of the three equations (19, 20 and 21) is true:

$$[\forall t \in \{1, ..., 4\} : D^k_{Sj \prec Si}(t) = D^k_{Si \prec Sj}(t)] \tag{19}$$

$$[\forall t \in \{1, 4\} : D^k_{Sj \prec Si}(t) = D^k_{Si \prec Sj}(t)] \wedge [D^k_{Sj \prec Si}(2) > D^k_{Si \prec Sj}(2)] \wedge [D^k_{Sj \prec Si}(3) < D^k_{Si \prec Sj}(3)] \tag{20}$$

$$[\forall t \in \{1, 4\} : D^k_{Sj \prec Si}(t) = D^k_{Si \prec Sj}(t)] \wedge [D^k_{Sj \prec Si}(2) < D^k_{Si \prec Sj}(2)] \wedge [D^k_{Sj \prec Si}(3) > D^k_{Si \prec Sj}(3)] \tag{21}$$



	POD	PSD	NOD	NSD
$D^k_{Sj \prec Si}$	1	0	1	0
$D^k_{Si \prec Sj}$	1	0.72	0.28	0

Fig. 7. S_j is indifferent to S_i (S_j IND S_i)

In the proposed approach, these relations ($\prec_{CD}$, $\prec_{SPD}$, $\prec_{WPD}$ and IND are used to compare two solutions S_j and S_i with regards to a single decision criterion. The equations 13 to 21 described above, present the conditions to be satisfied for a solution S_j: (i) to dominate another solution S_i (equation 13, 14, 15, 16, 17 and 18), or (ii) to be indifferent to a solution S_i (equations 19, 20 and 21). In the following parts, the possibilistic mono-criterion dominance relation of a solution S_j over a solution S_i is denoted mono-CDR(S_j, S_i). It can take one of the four mono-CDR values (Certain Dominance(CD), Strong Possibility of Dominance (SPD), Weak Possibility of Dominance (WPD) and Indifference (IND)). Comparing two solutions S_j and S_i, if none of the four mono-CDR is applicable (which means that the solution S_j is dominated by the solution S_i), the mono-CDR(S_j,S_i) takes the value "NA" (Not Applicable) and it is denoted by $S_j \not\prec S_i$. In the following sub-section, the method proposed to compare the potential solutions following several decision criteria and to build the Pareto front is developed.

3.3. Comparison of technical bid solutions following several decision criteria - Elaboration of the Pareto front

In this sub-section, the method which allows to compare technical bid solutions following several decision criteria and to determine the set of non-dominated solutions (Pareto front) is described. The resulting Pareto front takes into account uncertainty and imprecision related to the values of the decision criteria and the bidder's requirement about the Required Level of Dominance on each decision criterion (RLD). The RLD is given by the person in charge of the elaboration of the technical bid solution.

In the context of the bidding process, when selecting the most interesting technical bid solutions, in situations where the values of the decision criteria are imprecise and uncertain, it is necessary to take into account the point of view of the bidder about the level of acceptance of uncertainty and imprecision on each decision criterion. Therefore, the concept of Required Level of Dominance for a decision criterion (RLD) is introduced to capture and take this point of view into account in the decision making process. For a decision criterion k, the required level of dominance is noted RLD^k. In this article, we consider four possible values for RLD^k. These values correspond to the four possibilistic mono-CDR (CD, SPD, WPD and IND). For n decision criteria (n > 1), all possible combinations of the four values are allowed, except that combining only the value IND. Indeed, in that case, none of the two solutions Pareto-dominates the other one.

Accordingly, let us consider two technical bid solutions S_j and S_i to be compared following n decision criteria (n > 1). Given RLD^k for each decision criterion k, a technical bid solution S_j Pareto-dominates another technical bid solution S_i (denoted $S_j \prec S_i$), if and only if, for each decision criterion k, the possibilistic mono-criterion dominance of the solution S_j over S_i (mono-CDR$^k(S_j, S_i)$) is at least stronger (denoted by $\geq$) than the required level of dominance on this decision criterion (RLD^k). The mono-CDR value CD is stronger than SPD, which is stronger than WPD, which is also stronger than IND which in turn is stronger than NA (CD > SPD > WPD > IND > NA).

Equation 22 represents the Pareto-dominance relation of a solution S_j over S_i following n decision criteria. Moreover, as mentioned in sub-section 2.2, a solution belongs to the Pareto Front (PF) if there is no other solution that Pareto-dominates it. Let S be the set of m potential technical bid solutions. Let PF be the Pareto front. PF is defined by the equation 23.

$$S_j \prec S_i \; if \; \forall k \in \{1, ..., n\}, mono\text{−}CDR^k(S_j, S_i) \geq RLD^k \tag{22}$$

$$PF = \{S_l, \, S_l \in S, \nexists \, S_t \, / \, S_t \prec S_l\} \tag{23}$$

Therefore, by performing a pairwise comparison of the potential solutions using the equation 22, the Pareto front is built based on the the equation 23. Thus, this method enables the bidder to determine the set PF (which is the set of the most interesting technical bid solutions) according to the required level of dominance on each decision criterion. In the next sub-section, the algorithms that support the proposed approach are described.

3.4. Description of the algorithms to support the proposed approach

In this sub-section, the algorithms which support the proposed approach are described. The first algorithm (Algorithm 1) allows to compute the possibilistic mono-criterion dominance of the solution S_j over the solution S_i. It corresponds to the function mono-CDR^k(S_j, S_i).

Algorithm 1 $Mono\text{−}CDR^k(S_j, S_i)$

Compute $D^k_{Sj \prec Si}$ *# Dubois and Prade's dominance indexes for Sj*
Compute $D^k_{Si \prec Sj}$ *# Dubois and Prade's dominance indexes for Si*
if (equation 13 is TRUE) **then**
  return CD *# Sj certainly dominates Si* ($S_j \prec_{CD} S_i$)
else if (equation 14 is TRUE) **then**
  return SPD *# Sj dominates Si, with a strong possibility* ($S_j \prec_{SPD} S_i$)
else if ((equation 15 is TRUE) $\vee$ (equation 16 is TRUE) $\vee$ (equation 17 is TRUE) $\vee$ (equation 18 is TRUE)) **then**
  return WPD *# Sj dominates Si, with a weak possibility* ($S_j \prec_{WPD} S_i$)
else if ((equation 19 is TRUE) $\vee$ (equation 20 is TRUE) $\vee$ (equation 21 is TRUE)) **then**
  return IND *# Sj is indifferent to Si* ($S_j \; IND \; S_i$)
else
  return NA *# Sj is dominated by Si* ($S_i \prec S_j$)
end if

The function mono-CDR^k(S_j, S_i) has two arguments S_j and S_i. First the vectors $D^k_{Sj \prec Si}$ and $D^k_{Si \prec Sj}$ are computed using the equations 1, 2, 3 and 4 (see sub-section 2.4) and the equations 11 and 12 (see sub-section 3.2). Then, using the equations 13 to 21 described in the sub-section 3.2, the mono-CDR value is selected among Certain Dominance (CD), Strong Possibility of Dominance (SPD), Weak Possibility of Dominance (WPD), Indifference (IND) and Not Applicable (NA) when S_j is dominated by S_i.

The second algorithm (Algorithm 2) defines the function Pareto-front(S, $\{RLD^1, RLD^2, ..., RLD^n\}$) which returns the set of non-dominated solutions (i.e. the Pareto-front). This function has several arguments: (i) S, the set of the potential technical bid solutions, (ii) $\{RLD^1, RLD^2, ..., RLD^n\}$, the set of n required levels of dominance corresponding to the n decision criteria. The function Pareto-front realizes a pairwise comparison of the potential technical bid solutions of the set S. Each solution is compared to each other. For

Algorithm 2 Pareto-front(S, $\{RLD^1, RLD^2, ..., RLD^n\}$)

```
PF ← S                  # The initial Pareto front includes all the solutions
for Si ∈ S do
  for Sj ∈ S / Sj ≠ Si do
    NbDom ← 0    # Number of decision criteria by which Sj dominates Si
    for k ∈ {1, ..., n} do
      if Mono-CDR^k(Sj,Si) ≥ RLD^k then
        NbDom ← NbDom + 1                # NbDom is increased by 1
      end if
    end for
    if NbDom = n then
      PF ← PF − {Si}    # Si is removed from PF because it is dominated
    end if
  end for
end for
return PF       # The most interesting solutions with regard to the RLDs
```

each pair (S_j,S_i) of solutions (with i $\neq$ j) and for each decision criterion k (with k $\in \{1, 2, ..., n\}$), the function mono-CDR^k(S_j, S_i) is called. The result is the possibilistic mono-criterion dominance of the solution S_j over S_i with regard to the decision criterion k. If for any decision criterion k, the RLD^k is not stronger than the corresponding mono-CDR^k(S_j,S_i), then the solution S_j Pareto-dominates the solution S_i, and consequently S_i is removed from the set PF. At the end, the resulted PF is returned by the function Pareto-front.

4. Illustrative application of the proposed approach

4.1. Description of the example

This section illustrates the proposed approach by means of an application on an example presented in Table 1. This example concerns the elaboration of a crane technical bid solution. It is considered that eleven potential technical bid solutions have been built and estimated using for instance a configuration software Sylla et al. (2017d). The bidder has now to select one crane technical bid solution from this panel of eleven potential solutions. For more simplicity and clarity, only two decision criteria are considered: (i) the cost of the technical bid solution (cost) which gathers both the technical system cost and the delivery process cost ($\alpha = 0.5$ in equation 10 for this criterion), and (ii) the duration of the delivery process (duration) (for this criterion $\alpha = 0$ in equation 10). Each technical bid solution is characterized with six parameters as described in the following.

- For each decision criterion:
  - two parameters a and d which are the lower and upper bounds of the estimation domain (ED),
  - two parameters b and c which are the lower and upper bounds of the interval of the estimation values (EV),
- Confidence indicators:
  - Overall Confidence in System (OCS) which is the confidence level in the technical system
  - Overall Confidence in Process (OCP) which is the confidence level in the delivery process

These values are gathered in Table 1. The proposed multi-criteria decision support approach is used to provide the bidder with a set of the most interesting technical bid solutions while taking into account: (i) the uncertainty and imprecision related to the values of the decision criteria, and (ii) the acceptable level of uncertainty on each decision criterion defined in this article as a required level of dominance on a decision criterion. The application is performed using the Matlab software (MATLAB R2014b). In the following sub-section, the main results are presented and discussed.

Table 1: The ten potential technical bid solutions

S	Cost (K$)					Duration (days)					Confidence [1, 9]	
	a	b	c	d	e	a	b	c	d	e	OCS	OCP
S_1	64	66	73	84	0.33	63	65	74	83	0.33	6	6
S_2	63	67	74	83	0.5	52	53	56	60	0.55	5	4
S_3	67	80	82	84	0.28	57	60	63	65	0.22	6	7
S_4	72	76	79	85	0.11	55	57	58	59	0.11	8	8
S_5	87	88	89	90	0.28	64	66	67	70	0.33	7	6
S_6	67	68	75	81	0.22	53	54	57	58	0.11	6	8
S_7	86	87	90	92	0.44	68	70	72	75	0.44	5	5
S_8	68	73	76	85	0.17	49	55	58	65	0.22	8	7
S_9	69	78	80	82	0.11	60	61	64	65	0.11	8	8
S_{10}	86	88	90	95	0.22	66	67	70	72	0.33	8	6
S_{11}	85	89	92	94	0.28	50	52	54	63	0.33	7	6

4.2. Results and discussion of the experiments

In this sub-section, first, the possibility distributions are defined as the model of the imprecise and uncertain values of the decision criteria. Second, the possibilistic mono-criterion dominance relations (mono-CDR) established between the potential solutions are computed. Finally, three scenarios of Pareto-dominance and the corresponding Pareto-front are presented. Each scenario corresponds to a particular combination of the required levels of dominance (RLD) on the two decision criteria.

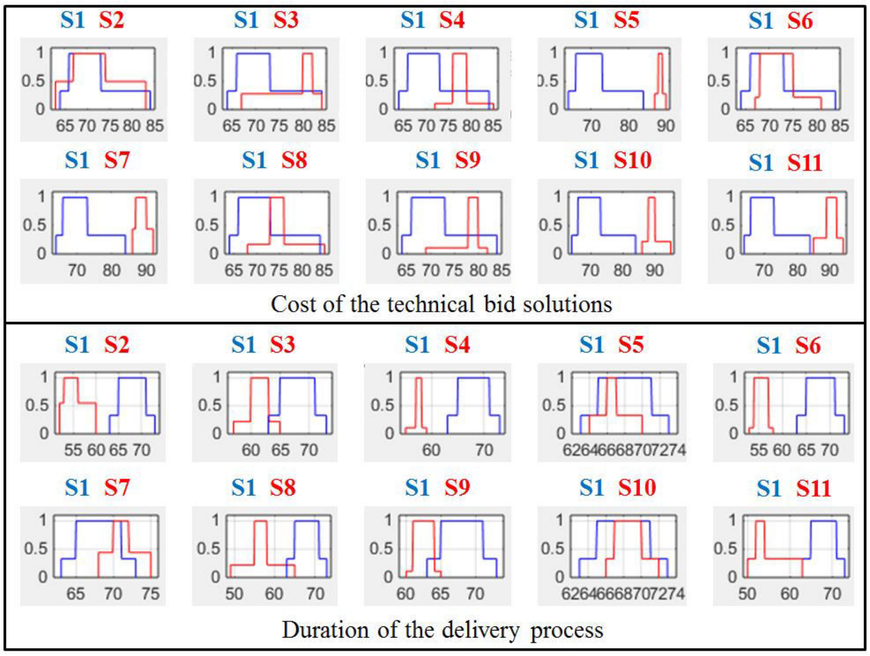
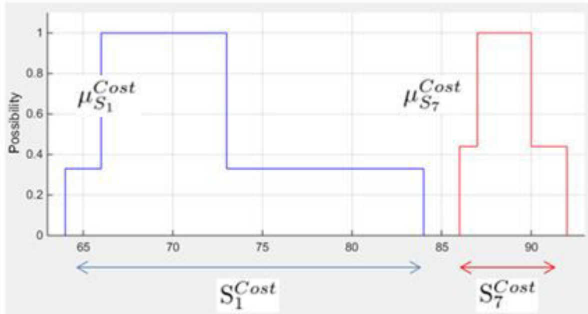


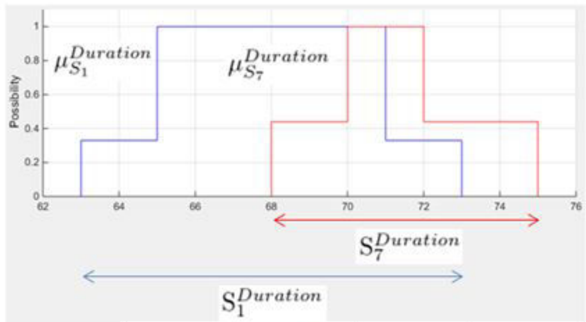
Fig. 8. Example of generated possibility distributions

1. The possibility distributions of the estimation of the decision criteria. In order to generate the possibility distributions, the method presented in the sub-section 3.1 is used. First, the parameter e of each technical bid solution is computed for each decision criterion using the equation 10. The values are reported in Table 1. Then, the possibility distributions have been computed using equation 9. In Fig. 8, the possibility distributions are presented by pairs of technical bid solutions. As the same method is used for all the pairs, for each decision criterion, we have only presented the possibility distributions of the following pairs: (S_1, S_2), (S_1, S_3), (S_1, S_4), (S_1, S_5), (S_1, S_6), (S_1, S_7), (S_1, S_8), (S_1, S_9), (S_1, S_{10}) and (S_1, S_{11}). The possibility distribution for the cost of the technical bid solutions are presented at the upper level whereas those of the duration of the delivery processes are presented at the lower level.



	POD	PSD	NOD	NSD
$D_{S_1 \prec S_7}^{Duration}$	1	1	1	1
$D_{S_7 \prec S_1}^{Duration}$	0	0	0	0

Cost of the technical bid solutions



	POD	PSD	NOD	NSD
$D_{S_1 \prec S_7}^{Duration}$	1	0.89	1	0
$D_{S_7 \prec S_1}^{Duration}$	1	0.11	0	0

Duration of the delivery process

Fig. 9. The vectors $D^k_{Sj \prec Si}$ and $D^k_{Si \prec Sj}$ for the pair (S_1, S_7)

These possibility distributions are used as inputs to compute the two vectors $D^k_{Sj \prec Si}$ and $D^k_{Si \prec Sj}$ for each pair (S_j, S_i) and for each decision criterion k. In the Fig. 9, for each decision criterion, we have only presented the vectors $D^k_{Sj \prec Si}$ and $D^k_{Si \prec Sj}$ for the pair (S_1, S_7). The vectors are further used to compute the mono-criterion dominance relations presented in the following paragraph.

2. The mono-CDR between the potential solutions. The mono-CDR for each decision criterion have been computed using Algorithm 1 presented in sub-section 3.4. They are shown in the Fig. 10. The matrix at the upper level represents the possibilistic dominance of the solution S_j over the solution S_i with regard to the cost. The matrix at the lower level, represents the possibilistic dominance of the solution S_j over the solution S_i with regard to the duration. They indicate for each pair (S_j, S_i), if S_j dominates (or not) S_i, and if S_j dominates S_i, they also indicate the possibility level of dominance. For instance, the solution S_1 certainly dominates (CD) the solution S_7 with regard to the cost. Then, mono-CDR^{cost}(S_1, S_7) is equal to CD. However, with regard to the duration, S_1 dominates S_7, not certainly, but with a weak possibility (SPD). Then, mono-CDR^{duration}(S_1, S_7) is equal to WPD. Consequently, S_7 is dominated by S_1 with regards to the two decision criteria. That is why mono-CDR^{cost}(S_7, S_1) and mono-CDR^{duration}(S_7, S_1) are equal to NA. Moreover, as the dominance of a solution over itself is not relevant, it is not computed, and consequently it is not shown in Fig. 10.

S_i \ S_j	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
S1		WPD	SPD	SPD	CD	WPD	CD	WPD	SPD	CD	CD
S2	NA		WPD	WPD	CD	WPD	CD	WPD	WPD	CD	CD
S3	NA	NA		NA	CD	NA	CD	NA	NA	CD	CD
S4	NA	NA	SPD		CD	NA	CD	NA	WPD	CD	SPD
S5	NA	NA	NA	NA		NA	IND	NA	NA	WPD	WPD
S6	NA	NA	SPD	SPD	CD		CD	WPD	SPD	CD	CD
S7	NA	NA	NA	NA	IND	NA		NA	NA	IND	WPD
S8	NA	NA	SPD	WPD	CD	NA	CD		SPD	CD	SPD
S9	NA	NA	WPD	NA	CD	NA	CD	NA		CD	CD
S10	NA	NA	NA	NA	NA	NA	IND	NA	NA		WPD
S11	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	

Mono-criterion dominance relations for the cost

S_i \ S_j	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
S1		NA	NA	NA	IND	NA	WPD	NA	NA	IND	NA
S2	CD		SPD	WPD	CD	IND	CD	IND	SPD	CD	NA
S3	SPD	NA		NA	SPD	NA	CD	NA	WPD	CD	NA
S4	CD	NA	SPD		CD	NA	CD	IND	CD	CD	NA
S5	IND	NA	NA	NA		NA	SPD	NA	NA	WPD	NA
S6	CD	IND	SPD	WPD	CD		CD	WPD	CD	CD	NA
S7	NA	NA	NA	NA	NA	NA		NA	NA	NA	NA
S8	SPD	IND	SPD	IND	SPD	NA	CD		SPD	CD	NA
S9	SPD	NA	NA	NA	SPD	NA	CD	NA		CD	NA
S10	IND	NA	NA	NA	NA	NA	WPD	NA	NA		NA
S11	SPD	WPD	SPD	SPD	CD	WPD	CD	SPD	SPD	CD	

Mono-criterion dominance relations for the duration

Fig. 10. The possibilistic mono-criterion dominance relations

In the next paragraph, these two matrices are used as inputs to computes the Pareto-dominance and to determine the Pareto-front.

3. The Pareto-dominance and the Pareto-front. The eleven potential technical bid solutions are represented in Fig. 11. Each solution is represented with two lines in a unique color. The X-axis represents the duration of delivery processes whereas the Y-axis represents the cost of the technical bid solutions. The solid part of the lines represents the interval of the estimation values (EV) which are the most possible values. The possibility level of a value of the interval EV is equal to 1. This value is not shown in Fig. 11. The dotted parts of the lines represent the values that are out of the interval EV. The possibility of these values is equal the parameter e which is shown in the Table 1 and near to the dotted lines of Fig . 11.

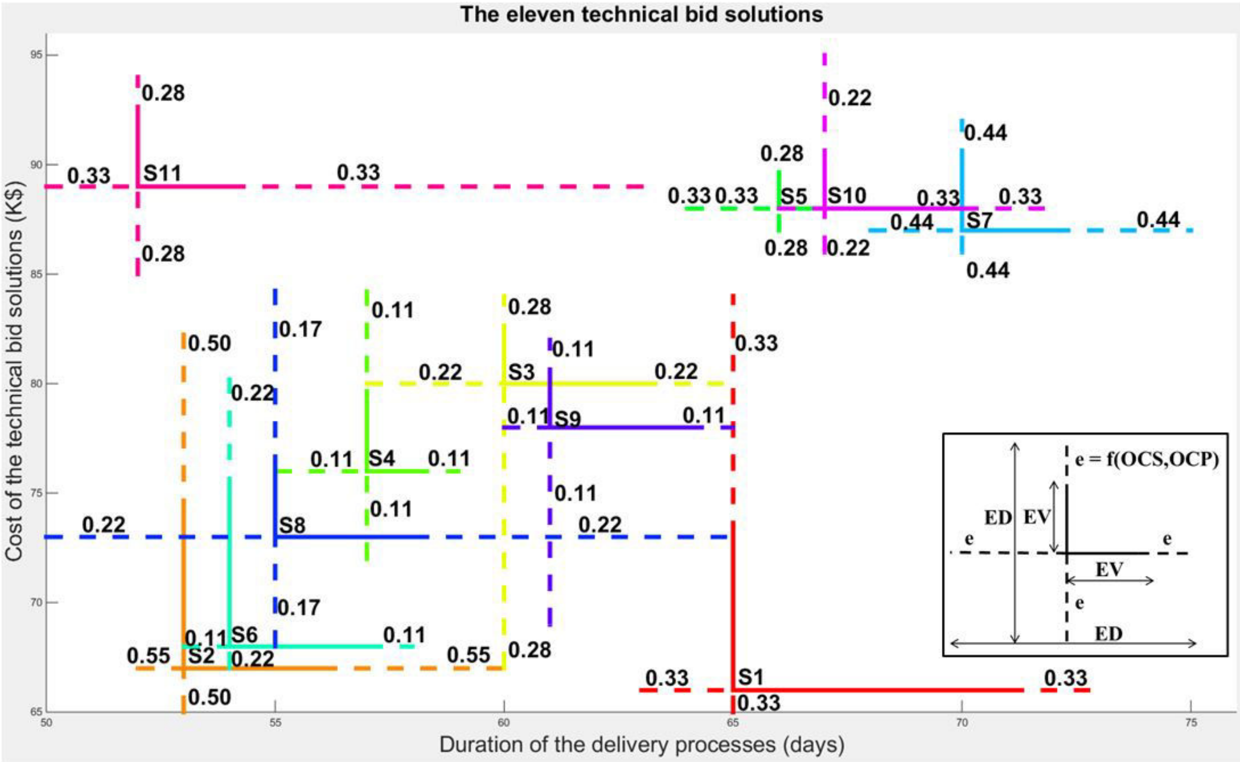


Fig. 11. The eleven potential technical bid solutions

The Algorithm 2 is used to compare the potential solutions following the two decision criteria and to determine the set of non-dominated solutions (Pareto front). At this stage, the person in charge of the elaboration of the technical bid solution (or the bidder) provides the Required Level of Dominance (RLD^k) for each decision criterion k. As two decision criteria are considered, fifteen combinations of RLD^k are allowed (see the left part of Fig. 12). However, we consider only three combinations in this example. They are shown in the right part of Fig. 12, and correspond to the three scenarios which are presented and discussed in the following.

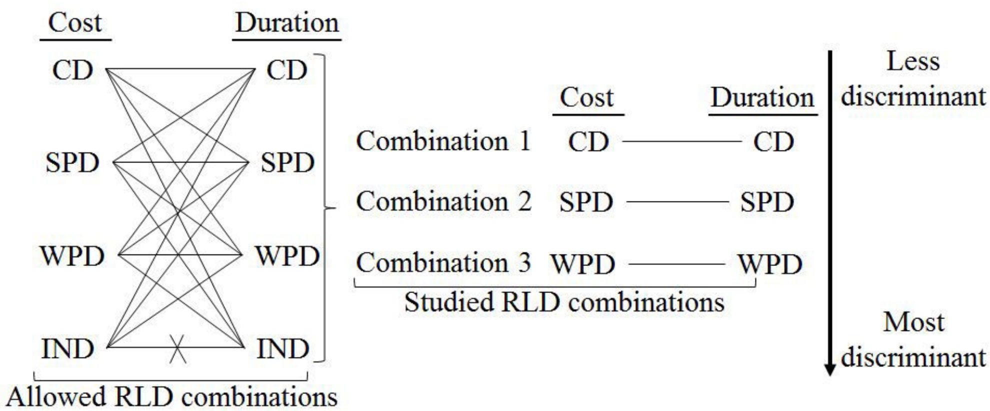


Fig. 12. Allowed and studied combinations of RLD

1. Combination 1 (CD-CD). In this scenario, the bidder has used the Certain Dominance relation (CD) as the RLD for each decision criterion (cost and duration). This RLD combination is the less discriminating one. In order that a solution S_j Pareto-dominates another solution S_i, for each decision criterion (cost and duration), the dominance relation of S_j over S_i must be certain CD. From the Fig. 13, it can be seen that only three solutions (S_5, S_7 and S_{10}) are dominated with regard to this RLD combination (CD-CD). The non-dominated solutions are then: S_1, S_2, S_3, S_4, S_6, S_8, S_9 and S_{11}. They are shown in the Pareto front in Fig. 13.

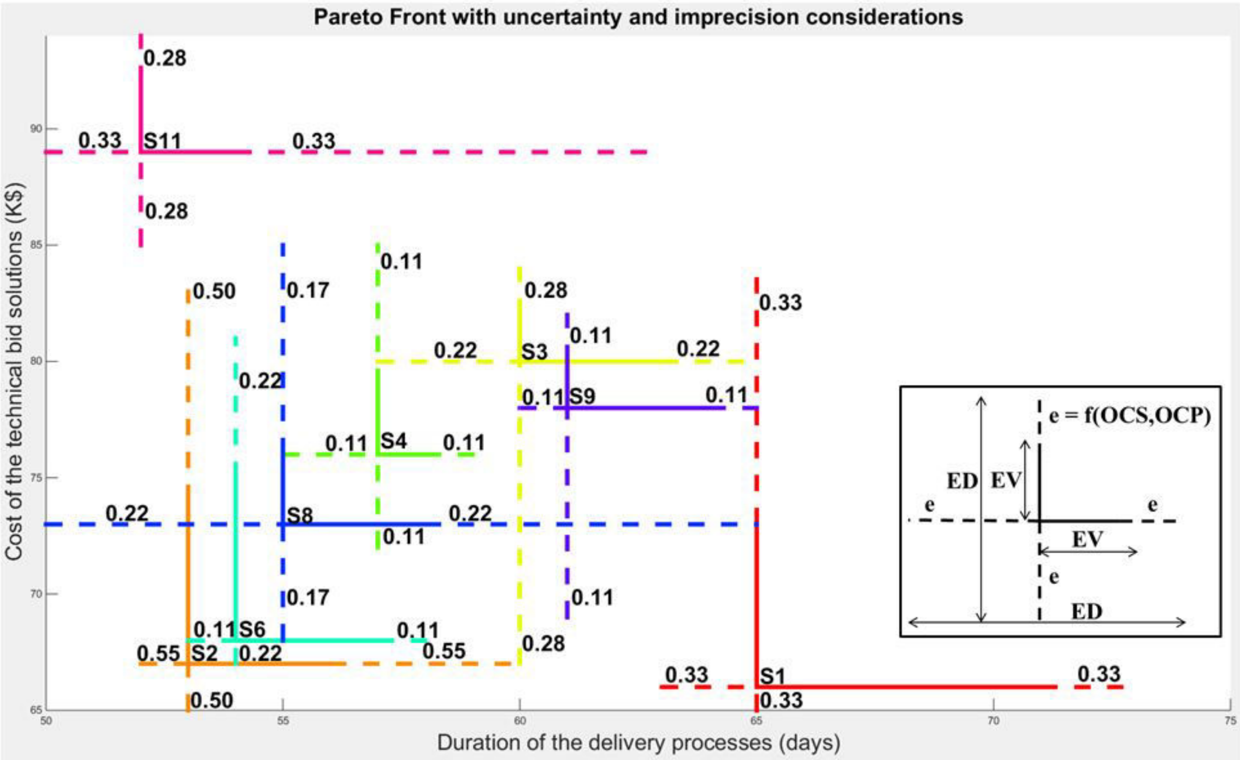


Fig. 13. Combination 1 (CD-CD): Pareto front

With this scenario, the resulting non-dominated solutions are the most interesting ones. However, the number of potential solutions is still too large (seven solutions). In order to allow a higher level of discrimination, the bidder has to reduce her/his requirements about the required level of dominance on the decision criteria, and then, accepts some uncertainties and imprecision.

2. Combination 2 (SPD-SPD). The bidder has reduced its requirements level by reducing the RLDs on the decision criteria. A strong possibility of dominance (SPD) has been selected for the RLD of each decision criterion (cost and duration). This second RLD combination is more discriminating than the first one. Indeed, in order that a solution S_j Pareto-dominates another solution S_i, for each decision criterion (cost and duration), the dominance relation of S_j over S_i must be certain (CD) or uncertain, but with strong possibility (SPD). Five solutions (S_3, S_5, S_7, S_9 and S_{10}) are dominated with regard to this RLD combination (see Fig. 14). Consequently, the non-dominated solutions are: S_1, S_2, S_4, S_6, S_8 and S_{11}. They are shown in the Pareto-front presented in Fig. 14.

Compared to the first scenario, this second scenario has reduced the number of non-dominated solutions. Even if the resulting set of non-dominated solutions is not certain with the defined RLDs, the bidder has the knowledge that it is most plausible that these six solutions (S_1, S_2, S_4, S_6, S_8) and S_{11} be the six most interesting ones. The bidder can further reduce her/his requirements about the RLDs on the decision criteria and, then, accepts more uncertainty and imprecision, to allow more discrimination of solutions.

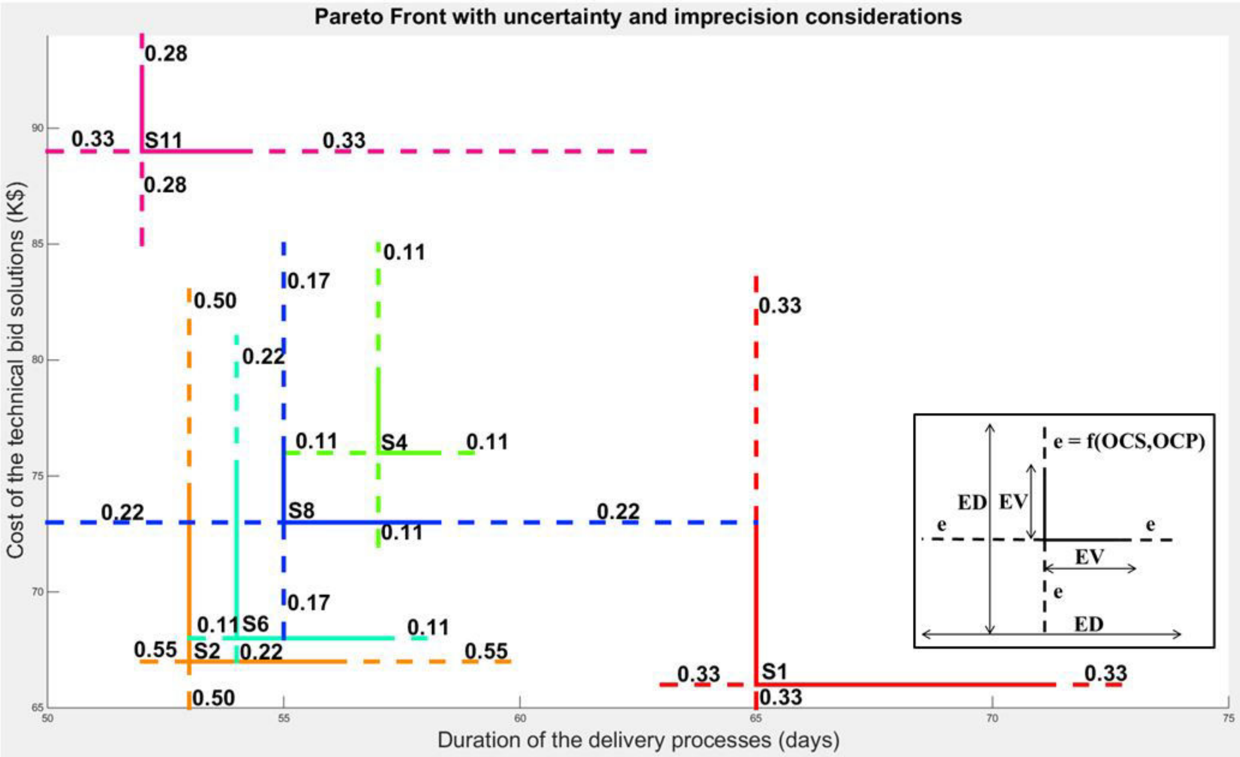


Fig. 14. Combination 2 (SPD-SPD): Pareto front

3. Combination 3 (WPD-WPD). The bidder has further reduced the requirements about the RLDs on the decision criteria. At present, the RLD combination is WPD-WPD which is more discriminating than the previous combinations. In order that a solution S_j Pareto-dominates another solution S_i, for each decision criterion (cost and duration), the dominance of S_j over S_i must be either: certain (CD) or uncertain, but with a strong possibility (SPD) or uncertain with a weak possibility (WPD). As shown in Fig. 15, four solutions S_1, S_2, S_6 and S_{11} are non-dominated with regard to this RLD combination.

Even if it is not certain that these solutions S_1, S_2, S_6 and S_{11} are the best ones, with this RLD combination, the bidder knows that it is most plausible that these four solutions be the most interesting ones.

As it can be seen in this last combination (WPD-WPD), in some cases, several potential solutions may be indifferent to each order with regards to all the criteria. In such a case, no solution is dominated whatever the RLD combination. Therefore, it is the responsibility of the bidder to select the most interesting solution. One can observe that the Required Levels of Dominance (RLDs) are very useful in the decision making process. By setting them at the higher level (CD-CD), they enables the bidder to make the choice of the most interesting technical bid solution from a Pareto front which is certainly the set of the most interesting solutions. Indeed, as the dominance relations are required to be certain, any solution that are in the Pareto front, is certainty better than any solution that have been removed. They also allow the bidder, by reducing the RLDs (WPD-WPD for instance), to make the choice of the most interesting solutions from a smallest Pareto front while having the knowledge about the level of uncertainty.

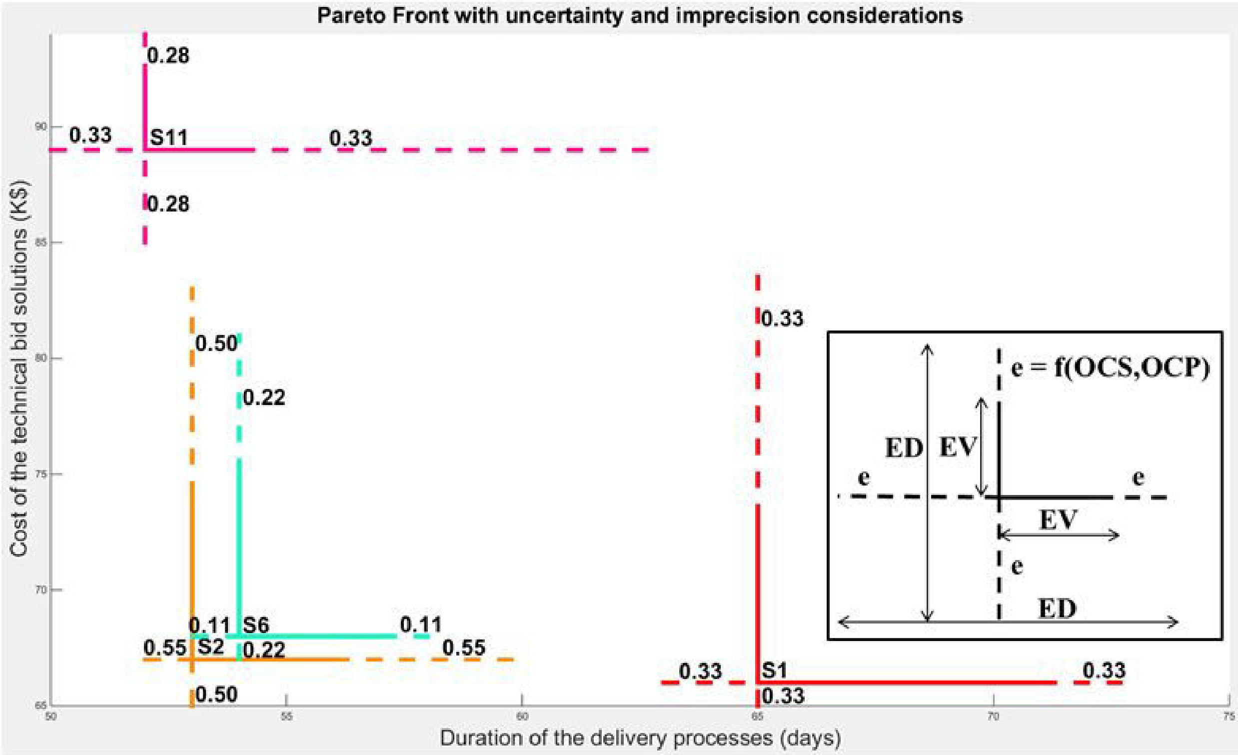


Fig. 15. Combination 3 (WPD-WPD): Pareto front

5. Conclusion and further research

In this article, we have studied the elaboration of technical bid solutions as part of a bidding process in the context of Engineer-To-Order (ETO) industrial situations. In such a context, when a company has to prepare a bid proposal to a potential customer, the design of a technical bid solution has to be done. In our work, a technical bid solution is composed of a technical system (a structure of sub-systems and components) to deliver and its realization process (a set of activities and resources). Some parts of a technical bid solution have been designed in the past and can be reused without changes. However, some other parts have to be designed in order to fulfill the customer's requirements. That leads to imprecision and uncertainty on the design parameters and consequently on the evaluation criteria, due to the lack of accurate and complete knowledge about the design of these elements. In this perspective, in a previous work, a configuration model which deals with the design (or definition) of technical bid solutions in ETO industrial contexts have been proposed in Sylla et al. (2017d). This model associated with a relevant configuration software, enables the bidder to define several technical bid solutions relevant to the customer's requirements. Each solution is characterized with relevant evaluation criteria but also with the confidence indicators (which reflect the confidence of the bidder in the technical bid solution) Sylla et al. (2017c).

From this panel of technical bid solutions, the bidder has to select the most interesting one to consider for the bid proposal. There are many criteria to take into account (e.g. the cost of the solution and the duration of its realization) but also the imprecision, the uncertainty and the bidder's confidence about the solution. In practice, the bidders consider the criteria independently and they give the same importance to each of them in the decision process. Thus, this is a multi-criteria decision making problem under imprecision and uncertainty. A solution which has the best values of the evaluation/decision criteria and good level for the confidence indicators can be selected. Therefore, in this article, a multi-criteria decision support approach to help the bidder to select the most interesting solution has been proposed. The proposed approach is based on the Pareto-dominance principle: the set of the most interesting solutions corresponds to the Pareto front (set of non-dominated solutions), built taking into account the imprecision, the uncertainty and the confidences about the solutions. The possibility theory is used to compare the solutions and to define relations of dominance between them. The proposed approach gathers three main stages, each one supported by a method that represents a key contribution of this article.

The first contribution corresponds to a method to model the uncertain and imprecise values of the decision criteria by means of possibility distributions. This method is based on the confidence indicators developed in Sylla et al. (2017c). It enables to simultaneously and effectively take into account the uncertainty and imprecision related to the values of the decision criteria when comparing the potential solutions, but also the bidder's confidence.

The second contribution deal with the comparison of two potential solutions with regard to a single decision criterion: four possibilistic mono-criterion dominance relations (Certain Dominance (CD), Strong Possibility of Dominance (SPD), Weak Possibility of Dominance (WPD) and Indifference (IND)) have been proposed. They are based on the four dominance indexes suggested in Dubois & Prade (2012). An algorithm allows to compute the relevant mono-criterion dominance relations (mono-CDR) between two solutions. That enables the bidder to know, with regard to a single decision criterion: (i) if a solution dominates another one, and (ii) where appropriate, how it is certain that it dominates it.

The third contribution corresponds to a method to compare the potential solutions following several decision criteria and to determine the set on non-dominated solutions (Pareto front). By integrating the concept of Required Levels of Dominance on the decision criteria, this method, supported by an algorithm, enables the bidder to progressively build the set of the most interesting solutions while taking into account the requirements about the level of acceptance of uncertainty and imprecision on the decision criteria. By this way, the confidence of the bidder is taken into account to select solutions.

An application of the approach has been presented in order to validate the contributions. The results have shown that the proposed approach is appropriate to assist the bidder in the process of the selection of the most interesting technical bid solution in the context of ETO industrial situations where the estimations of the decision criteria are imprecise and uncertain.

In a bidding process, when selecting the most interesting technical bid solutions, this method can be very useful for systems contractors (bidders). By defining the Required Levels of Dominance, the decision maker can give more or less importance to the imprecision and uncertainty. The higher the RLDs are, the more it is certain that the Pareto front contains the most interesting solutions. As a consequence, the decision maker can have a good confidence in the choice of the most interesting technical bid solution. At the opposite, when the Pareto front is large, the bidder can reduce the RLDs in order to facilitate the choice of the most interesting solution while being aware of the level of uncertainty.

Future research should consider performing a benchmark of the proposed approach with selected existing approaches in the scientific literature. Moreover, in this article, it is supposed that the decision criteria have the same importance. This assumption is relevant for situations where the decision maker considers a same importance for decision criteria or in situations where he/she cannot explicitly provide the importance coefficient for each decision criterion. However, in some situations, the decision maker has the knowledge about the importance coefficient of each decision criterion. In such a context, it is necessary and useful to take these importance coefficients into account when comparing the potential solutions following all the criteria. Therefore, a future research should also consider extending the proposed approach to such situations. A method could be developed to integrate the possibilistic mono-CDR with a relevant outranking method (e.g. PROMETHEE or ELECTRE) in order to rank the potential solutions.

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