An APS software selection methodology integrating experts and decisions-maker’s opinions on selection criteria: A case study

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Abstract: With important advancements achieved in information technology, wide varieties of advanced planning and scheduling (APS) software has emerged in recent decades. Each of those APS software uses their own techniques, algorithms and logic to plan and schedule operations, which makes the task of evaluating them very difficult. However, choosing the right APS software is critical for companies because of significant resources engaged and risk of disturbing operations. Presently, a clear, structured and rational approach is lacking in the literature for APS software selection. The main contribution of this paper is to fill this gap by developing an APS software selection methodology. The methodology is based on fuzzy quality function deployment (QFD) and two well-known multiple criteria decision-making (MCDM) techniques, analytic hierarchy process (AHP) and VIKOR. This work considers both company needs and APS selection criteria to build a hybrid hybrid.
hierarchical decision structure. House of quality helps in translating the relevance of
the company needs in the evaluation of criteria. Triangular fuzzy numbers are also
used to reduce uncertainties in the process. An application of the proposed meth-
ology to an aero-derivative gas turbine case company is carried out to demon-
strate the useful and easy implementation of the proposed methodology.

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Keywords: Advanced planning and scheduling (APS); selection; multiple criteria decision-
making (MCDM); fuzzy AHP; fuzzy QFD; fuzzy VIKOR

1. Introduction
APS system is used by manufacturers for planning and meeting customer demand using finite
material availability and resource capacity constraints at enterprise level as well as at plant level
(Hvolby & Steger-Jensen, 2010). In practice, companies can either develop their own customized
APS system based on their activities specifications or select and implement existing APS software
available on the market. Due to the lack of professional expertise and experience in developing
such in-house systems, many companies preferred the second option (Ayaga & Ozdemir, 2007).
Developing a clear, structured approach for APS software selection is therefore a major concern for
firms in a wide range of industries. Selecting an inappropriate APS software could lead to incorrect
and costly results, adversely affecting the organisational performance. Unfortunately, there is not
yet such approach in the literature to assist company in the selection of APS software among the
huge number available on the market with different strengths and weaknesses. The purpose of this
paper is to design for company decision-makers (DM) involved in APS software selection, a clear,
structured methodology that will help them select the APS software that best satisfies company
needs (CNs).

To ensure the success of the selection process, it is crucial to identify the APS software selection
criteria (Cs) and to prioritize them. Analytic hierarchy process (AHP) is often used to achieved this
through pair-wise comparison matrices from experts evaluation (Lai, Wong, & Cheung, 2002).
However, the prioritizing of Cs in the conventional AHP contain vagueness and impreciseness
such as linguistic judgments on the Cs relevance, which affect the accuracy of the Cs importance
evaluation. This makes the conventional AHP not suitable for prioritizing Cs. In the literature, some
researchers have applied fuzzy set theory to improve conventional AHP by reducing vagueness and
impreciseness (Ayaga & Ozdemir, 2007). As examples, we have triangular fuzzy numbers (TFNs;
Azadeh, Shirkouhi, & Rezaie, 2010), (Hicdurmaz, 2012), (Ashtiani & Abdollahi Azgomi, 2016),
trapezoidal fuzzy numbers (Kahraman, Beskese, & Kaya, 2010), interval-valued fuzzy numbers
(Chuang, Kung, Lin, & Ku, 2011) and intuitionists fuzzy numbers (Otyay, Oztaysi, Cevik Onar, &
Kahraman, 2017). In the literature, some authors such as Ali Azadeh, Nazari-Shirkouhi, Samadi,
and Nazari-Shirkouhi (2014) combined fuzzy AHP with other technique to build robust selection
approaches. Ali Azadeh et al. (2014) proposed an approach base on fuzzy AHP and fuzzy technique
for order performance by similarity to ideal solution (fuzzy TOPSIS) for simulation software
packages selection. With this approach of Ali Azadeh et al. (2014), only Cs and their relevance
from the expert assessment are considered in the selection process. Experts being external to the
company, they are not always aware of the real situation and needs of the company. Thus, the
conventional AHP, fuzzy AHP or approaches such as the ones proposed in Ali Azadeh et al. (2014),
cannot effectively integrate all the fundamental elements for an effective selection with the least
risk possible. To overcome that, it is necessary to capture relevant CNs and to challenge them with
 Cs. This is often achieved in the literature by using QFD through the house of quality (HoQ) (Akao &
Mazur, 1990). Thus, we can conclude that integration of fuzzy AHP and fuzzy QFD can help to
effectively prioritize Cs, by capturing all important factors from both sides, company feeling and
experts’ judgments. This is essentially what is done in this work for APS software selection problem.
The approach proposed in this paper for APS software selection integrates fuzzy AHP, fuzzy QFD and fuzzy VIKOR (VIseKriterijumska Optimizaciji I Kompromisno Resenje). In the fuzzy AHP, fuzzy Cs relevance are computed while in the fuzzy QFD, the relationships among CNs and Cs resulting from fuzzy AHP are mapped to compute the fuzzy Cs importance. In the fuzzy VIKOR, intrinsic fuzzy alternatives (As) capacity to satisfy criteria is merged to Cs fuzzy importance to rank alternatives. Thus, DMs can make reasonable decisions with vague, subjective, and limited information. In contrary to Ali Azadeh et al. (2014), fuzzy VIKOR is preferred here to fuzzy TOPSIS as ranking method because it allows to build consensus between all DMs needs and then to cover as much as possible CNs.

However, the question of the real need of integrating all these techniques for a software selection problem, which seems to be nothing more than a constraint satisfaction problem can be addressed. Only, beyond the constraint satisfaction, the problem that we pose integrates a subjective dimension, human opinions with uncertainties, which very often are not considered in the resolution of such problems in the literature. Moreover, beyond putting in place a selection methodology, this study also aims to analyse the behaviour of the different selection methods when they are integrated. We should also note that such integration of these three methods that are the AHP, QFD and VIKOR method, all with fuzzy number logic associated is a first in the literature, to the best of the authors’ knowledge. This study clarifies what can be the impact of such techniques integration on the result and try to build a selection methodology that integrates all relevant factors as CNs, Cs, expert judgement on Cs, and compromise between utility and regret. The analysis of such integration, again to our best knowledge, has never been done in the literature. The complexity of such problem comes from the fact that the number of factors to consider is very important. In addition, the necessary data are not available at the beginning of the process and requires a well-structured collection and processing approach to be confident that nothing is left behind in the selection. In addition, integrating different techniques requires thorough studying them, as well as developing means of integration to ensure the validity of the resulting method, and its effectiveness.

The rest of the paper is structured as follows. In Section 2, a briefly review of the related work is conducted. In Section 3, the proposed approach for APS software selection based on fuzzy AHP, fuzzy QFD and fuzzy VIKOR is presented along with all the detailed steps. In Section 4, the proposed approach is applied to a real aero-derivative gas turbines manufacturing company case in order to demonstrate its applicability and its effectiveness. A discussion is also conducted in this section and the proposed methodology is validated through comparison with alternative approaches in the literature. In Section 5, we conclude with the research.

2. Background

2.1. Selection methods and approaches

Methods regularly used in the literature to address selection problems can be grouped in four different categories namely MCDM, mathematical programming methods, artificial intelligence methods and integrated approaches (Hanine, Boutkhoum, Tikniouine, & Agouti, 2016). Regarding MCDM methods, they most used ones are AHP, ANP, ELECTRE (ELimination and Choice Expressing Reality), TOPSIS, PROMETHEE (PReference ranking Organization Method for Enrichment Evaluations) and VIKOR. Eastham, Tucker, Varma, and Sutton (2014) developed a methodology utilizing AHP to assist with selection of product lifecycle management (PLM) software. Lai et al. (2002) used AHP technique to support the selection of a multimedia authorizing system (MAS). Cherrared, Zekiouk, and Chocat (2011) applied AHP for assessing the functional performance of urban Sewer Systems (SS). Chuang et al. (2011) used TOPSIS method to build an expert decision-making approach. Zaini and Quqandi (2015) proposed an improve process for software selection method based on TOPSIS approach. San Cristóbal (2011) applied VIKOR method in the selection of renewable energy project. Vetschera and de Almeida (2012) used PROMETHEE method for portfolio selection problems. As mathematical programming methods, we have data envelopment
analysis (DEA), linear programming and multi-objective programming. Baldin (2017) proposed a DEA approach for selecting a bundle of tickets for performing arts events. Li, Chen, Cook, Zhang, and Zhu (2018) used a two-stage network DEA method to rank alternatives and find the leader. Artificial intelligence methods include genetic algorithm, artificial neural network (ANN) and data mining methods. Guo, White, Wang, Li, and Wang (2011) applied genetic algorithms approach to optimize feature selection in software product lines. Yazgan, Boran, and Goztepe (2009) introduced a new method for ERP software selection using ANN model that is trained by results obtained from ANP to build priorities for the selection of the best ERP software. Concerning integrated approaches, those bring together several methods. In the literature, there is a very large number of works using this type of technique. Integration is done using either MCDM methods only or a mix of different categories of methods. As examples of works related to this technique, Hanine et al. (2016) developed a decision-making application based on AHP and TOPSIS for Extract Load Transform (ETL) software selection purpose. Martin-Utrillas, Reyes-Medina, Curiel-Esparza, and Canto-Perello (2015) used a combination of AHP based on expert data obtained from Delphi method and VIKOR method to reach a consensus solution for choosing the optimal combination of techniques to depollute leachate. Yu, Xu, and Ma (2013) developed a methodology using PROMETHEE and linear optimization models to overcome the drawbacks of the existing MCDM methods.

By the way, besides all those selection methods presented, fuzzy logic has been integrated into many works in the literature to overcome uncertainties and vagueness from human judgments. According to Aydin and Kahraman (2013), the major contribution of the fuzzy set theory to selection problems is its ability to quantify the subjectivity in human judgments. As examples of works, Hicdurmaz (2012) introduced MCDM method in software lifecycle model (SLCM) selection and proposed a fuzzy methodology to conduct the process using fuzzy AHP and fuzzy TOPSIS. Aydin and Kahraman (2013) proposed a fuzzy AHP approach for tackling vendor selection problem. They used a triangular fuzzy scale containing also negative fuzzy numbers to establish fuzzy comparison decision from multiple experts. On their side, D’Aniello, Gaeta, Tomasiello, and Rarità (2016) proposed a fuzzy consensus approach for group decision-making with variable importance of experts. Their approaches integrated objective and subjective elements in the decision-making process and lead to a consensus decision between those.

2.2. APS software selection
APS system is considered as an extension of MRP II and ERP (Patrik, Linea, & Martin, 2007), (Sadowski, 1998). APS deals with the optimal allocation of production resources in manufacturing environment, while ensuring that production constraints are met and that the main production objective is achieved (Chen, Ji, & Wang, 2011). With APS systems, it is possible to simultaneously plan, and schedule operations based on available materials, labour and plant capacity. APS is especially well-suited to environments addressing complex trade-offs between competing priorities and where production scheduling is intrinsically very difficult due to the factorial dependence of the size of the solution space on the number of items to be manufactured. As with most engineering software, there are large number of APS software available on the market, each with its own strengths and weaknesses. There is therefore a selection problem for companies wishing to implement such solution.

In the literature, software selection has been largely addressed. For example, Sen, Baracli, Sen, and Basligil (2009) developed a decision support model for enterprise software selection considering qualitative and quantitative objectives in a multi-objective mathematical programming model. Ashu, Brijesh, and Rakesh (2017) proposed a methodology for software effort estimation models evaluation and selection. Azadeh et al. (2010) presented a robust decision-making methodology for evaluating and selecting simulation software package. Eastham et al. (2014) developed an approach to serve as a guide to assist with selection of product lifecycle management (PLM) software. Lai et al. (2002) worked on the selection of MAS. Concerning ERP software, Torsten and Sven (2013) brought out recommendations for selecting, implementing and sustainably operating
ERP systems using Architecture of Integrated Information Systems (ARIS) concept. Yazgan et al. (2009) introduced a method for ERP software selection using ANN. Kahraman et al. (2010) developed an ERP outsourcing selection methodology.

However, very little attention has been paid to APS software selection. Some of the rare research papers with relevant elements on APS software selection are Sadowski (1998), Efe (2016) and Bozik (2012), which highlighted some criteria that must be taken into account when selecting APS software. Sadowski (1998) highlighted five criteria that are “features”, “integration”, “technology”, “platform” and “price”. Efe (2016) developed a selection methodology for ERP software and as one of the results, they built a list of selection criteria among which two are pertinent for APS software selection. Those are “vendor specifications” and “ease of use”. In his work, Bozik (2012) compared a set of APS software regarding the following criteria, “interactive Gantt chart”, “resource calendar editor”, “advanced planning algorithms” and “report generator”. In his side, Hagazi and Guo (2013) provided an overview of the main steps involved in the process, with important indicators for choosing and using APS software.

Concerning software selection, several approaches have been developed in the literature, either by using basic methods or by integrating them in order to benefit from the strengths of several methods that generally complement each other. As an example of software selection approach, we have the one proposed by Azadeh et al. (2010), which is a decision-making methodology based on fuzzy AHP for evaluating and selecting simulation software package. In this approach, there is no consideration on CNs and criteria are directly weighted from experts’ assessment. DMs of the company are not involved in the selection process while they are the most informed about the situation of the company and its real needs. Those limitations are also present in the integrated approach developed by Haiqing, Bouras, Ouzrout, and Sekhari (2014), which is based on the integration of the fuzzy AHP and the VIKOR. Haiqing et al. (2014) proposed an approach for product lifecycle system selection. They used VIKOR method in order to build an approach that leads to a final decision corresponding to a maximum “group utility” and a minimum regret of the “opponent” into the DMs group (Rao, 2008). An approach that does not have the above-mentioned limitations is the one developed by Bevilacqua, Ciarapica, and Giacchetta (2006), who applied fuzzy QFD for supplier selection. This approach directly consider in the selection process, the needs directly expressed by the DMs of the company. However, the relevance of the sub-criteria is not considered here. Furthermore, pairwise comparison matrices from experts are not used. Only the survey addressed to DMs for the relevance of CNs is used. Those limitations are also present in the selection approach developed by Wu, Ahmad, and Xu (2016) for machine tool selection using linguistic information. Wu et al. (2016) integrated fuzzy QFD and fuzzy VIKOR. Finally, we observe in the literature that whether integrative approaches or individual approaches, there is a problem of taking into account all the fundamental elements for an effective selection, presenting the least risk possible. These elements are the CNs expressed by the DMs and the selection criteria evaluated by the experts in the field considered, who can be professionals, professor or consultants. In the case of the APS software selection problem, in addition to the fact that there is no selection approach developed in the literature, this problem also arises. Thus, a selection approach in which the aforementioned limitations are overcome should be developed for APS software, with the possibility to effectively handle vague and subjective information in the QFD.

2.3. AHP

According to Saaty (1987), AHP is an MCDM method that decomposes a complex multi-criteria decision-making problem into a hierarchy. The hierarchy is presented as the hierarchical decision structure of the problem. In selection problems, AHP usually served to calculate the weight of Cs by using pair-wise comparison matrices (Chuang et al., 2011), (Ashtiani & Abdollahi Azgomi, 2016), (Ashu et al., 2017). However, in order to overcome ambiguities and uncertainties in the decision-making process, traditional AHP is combined with fuzzy theory to become fuzzy AHP (Hanine et al., 2016). Fuzzy AHP has been extensively used for analysing and structuring complex decision problems in various research fields such as selecting and evaluating suppliers, choosing the best
robot, selecting the best projects and many others (Parameshwaran, Praveen Kumar, & Saravanan Kumar, 2015), (Bevilacqua et al., 2006), (Rao, 2008). Another point affecting conventional AHP technique is decision-making environment where judgments on criteria come from several experts (multi-experts’ environment). Two cases are then possible. In the first case, all experts are considered having the same background. Either fuzzy arithmetic or fuzzy geometric average can be used as an aggregation function to group all experts pair-wise comparison matrices (Otoy et al., 2017), (Chuang et al., 2011). In the second case, where experts are considered having different backgrounds, Kahraman et al. (2010) proposed to allocate weight to each expert and to use them in a fuzzy weighted sum as aggregation function.

2.4. QFD

In selection problem, considering the exact needs and the exact relevance in the selection process is very important. This is often achieved in the literature using QFD, which is a powerful and proactive decision support method belonging to the huge family of quality management methods (Karsak & Dursun, 2014). It aims to satisfy the customer at the product design phase by determining customer needs and by translating them into product designs through a structured and well-documented framework (Karsak & Dursun, 2014). From customer demand to the production phase, four matrices are used sequentially to cover the entire process (Hauser & Claussing, 1988). Those are the product planning, part deployment, process planning, and production/operation planning matrices (E. Ertugrul Karsak & Dursun, 2014). In selection problems, only the first matrix also called house of quality (HOQ) is used. HOQ correlates CNs to the Cs (Maritan, 2015), (Keramati, Ahmadizadeh Tourzani, Nazari Shirkouhi, Sharifi Teshnizi, & Ashjari, 2014). In its Conventional form, House of Quality consists of 6 main elements group in a framework (Bevilacqua et al., 2006). The first two elements positioned at the rows are the CNs also called the WHATs (Hauser & Claussing, 1988) and the relevance of WHATs. The third element place on the columns are the technical characteristics or Cs also called the HOWs (Hauser & Claussing, 1988). The fourth element placed on top of the framework (roof of the matrix) is correlation between the HOWs. The fifth element disposed at the centre of the framework contains symbols expressing correlation between the WHATs and the HOWs. The sixth element at the foundation of the framework is the weight of HOWs. In conventional QFD, the weights of WHATs and HOWs and the relationships between the WHATs and HOWs are determined based on human’s judgements, which are subjective or vague (Wu & Lin, 2012). The immediate consequence of this may be inaccurate results.

Therefore, in order to be able to handle vague and subjective information and to translate verbal variables in a mathematically well-defined way, fuzzy logic is introduced in QFD to form a new model called fuzzy QFD. For example, Ozogul and Karsak (2008) applied fuzzy QFD, fuzzy linear regression and zero-one goal programming to develop a novel decision framework for ERP software selection. Karsak and Ozogul (2009) also used a fuzzy regression-based optimization and fuzzy QFD to develop a decision model for ERP system selection.

2.5. VIKOR method

Developed by Serafim Opricovic, VIKOR is a Serbian MCDM method based on an aggregation function representing closeness to the ideal (Martin-Utrillas et al., 2015). It is a compromise ranking method that classifies a set of alternatives so that DMs obtains the maximum “group utility” and a minimum regret of the “opponent” (Rao, 2008). Indeed, through the normalization of the decision matrix and the $L_p$-metric aggregation function expressed by Equation (1), $L_{ij}$ and $L_{wij}$ are, respectively, used to formulate ranking measure $S_j$ (regarding the utility of the solution) and $R_j$ (regarding the regret of opponents):

$$L_{ij} = \left\{ \frac{\sum_{i=1}^{n} \left[ \frac{w_i (f_i + \Theta f_j)}{(f_i + \Theta f_j)} \right]^p}{p} \right\}^{1/p} 1 \leq p \leq \infty \quad i = 1, 2, \ldots, n \quad j = 1, 2, \ldots, m$$

(1)
where \( n \) is the number of criteria Cs and \( m \) is the number of alternatives As. \( f_{ji} \) is the fuzzy value of criteria \( i \) for the alternative \( j \) with the best and worst fuzzy values regarded as \( f^*_i \) and \( f_i^- \). \( w_i \) denotes the weight of the criteria \( i \). Finally, VIKOR provides a third ranking which is a compromise between the two previous ranking (Dammak, Baccour, & Alimi, 2015). Compromise means an agreement established by mutual concessions (Opricovic & Tzeng, 2004). As with other conventional method, fuzzy set theory is introduced in conventional VIKOR to produced an improved method call fuzzy VIKOR, which is able to deal with vague and subjective data (Ayağ & Özdemir, 2007), (Rezaie, Ramiyani, Nazari-Shirkouhi, & Badizadeh, 2014).

### 2.6. Fuzzy set theories and linguistic variables

Fuzzy set was first introduced by Zadeh (1978) to deal with vagueness and impreciseness of the data. It enhances the potential of conventional methods (Ayağ & Özdemir, 2007). There are several variants of fuzzy numbers. The most commonly used in selection problems are TFNs, because of the facility to deploy them. If \( M \) is a TFN, it can be expressed by a triplet of real numbers as \( M = (a, b, c) \) and its memberships function is defined by Maritan (2015).

\[
V(x) = \begin{cases} \frac{a - x}{a - b}, & a \leq x \leq b \\ \frac{b - x}{b - c}, & b \leq x \leq c \\ 0, & \text{Otherwise} \end{cases} \quad \text{where} \quad \begin{align*}
& a < b < c \\
& a, \text{ the lower bound of the } M \\
& b, \text{ the middle bound of the } M \\
& c, \text{ the upper bound of the } M \\
& V(x), \text{ the level of importance of the } M
\end{align*}
\]

where \( x \) is a real number. Let be \( \tilde{A} = (a_1, b_1, c_1) \) and \( \tilde{B} = (a_2, b_2, c_2) \) two TFNs. Table 1 summarizes arithmetical operations in triangular fuzzy set.

To generalize, let’s consider a set of fuzzy numbers \( \tilde{A}_i = (a_i, b_i, c_i) \) and \( \tilde{B}_i = (d_i, e_i, f_i) \) with \( a_i, b_i, c_i, d_i, e_i, f_i \) all positive real numbers and \( i = 1, 2, \ldots, n \), then:

\[
\tilde{A}_1 \oplus \tilde{B}_1 \oplus \tilde{A}_2 \oplus \tilde{B}_2 \oplus \ldots \oplus \tilde{A}_n \oplus \tilde{B}_n = \left( \sum_{i=1}^{n} a_i d_i, \sum_{i=1}^{n} b_i e_i, \sum_{i=1}^{n} c_i f_i \right)
\]

In addition, fuzzy set logic is generally used in combination with linguistic variables, which are variable expressed using words or sentences based on a natural language and Likert scale to describe the natural human language and to transform them into logical terms (Zadeh, 1975). Table 2 and Figure 1 illustrate those linguistic variables.

When using fuzzy set theories in selection approach, the result is always expressed as a fuzzy number. Therefore, in order to be able to rank the alternatives, the fuzzy number should be converted to its corresponding crisp number known as its best non-fuzzy performance (BNP) value. This process is called defuzzification (Tsaur, Chang, & Yen, 2002). In the literature there exists several defuzzification techniques among what the most used are mean-of-maximum, Centre-of-Area, and \( \alpha \)-cut Method (Zhao & Govind, 1991). Another defuzzification technique often used due to its simplicity is the median method, expressed by the following Equation (4) (Leekwijck & Kerre, 1999).

\[
\text{For a TFN } \tilde{\alpha} = (a^L, a^M, a^U), \text{ the corresponding crisp number is } a = \frac{a^L + 2a^M + a^U}{4}
\]

### 3. The proposed fuzzy selection approach based on AHP, QFD and VIKOR

In order to solve the APS software selection problem while ensuring real DMs feeling through CNs and accurate Cs from experts are considered in the selection process, and while dealing with vagueness and impreciseness in human’s judgment, a fuzzy approach based on QFD, AHP and VIKOR is proposed as shown in Figure 2. The proposed approach is composed of three phases. The first phase is the preparation. It is to capture CNs, identify Cs and As. The second phase is to calculate the weight of Cs. DMs evaluate the CNs importance while
experts build Cs pair-wise comparison matrices and evaluate the CNs-Cs relationships using linguistic variables and TFNs. The Cs Pair-wise comparison matrices are aggregated as per AHP method to calculate the initial Cs weight, which would serve in the HOQ to calculate the Cs final normalized weight. The third phase is to rank the As. Based on Cs final normalized weight and the Cs-As relationships evaluated by experts (assessment of As in respect with Cs), the As are ranked using fuzzy VIKOR.

3.1. Capture CNs, identity Cs and As

CNs, Cs and As are the main inputs of the selection process. DMs define the CNs, meanwhile experts provide Cs and As.

| Table 1. Equivalent operations between conventional real numbers and TFN adapted from (Maritan, 2015) |
|-----------------------------------------------|
| **Traditional operations**                     | **Fuzzy equivalent operations**                       |
| Addition                                       | $\hat{A} \hat{B} = (a_1 + b_1, a_2 + b_2, c_1 + c_2)$ |
| Subtraction                                    | $\hat{A} \hat{B} = (a_1 - b_1, b_2 - c_1 - c_2)$ |
| Scalar multiplication                          | $\beta \hat{A} = (\beta a_1, \beta b_1, \beta c_1)$ if $\beta > 0$ |
| Vectorial multiplication                       | $\hat{A} \otimes \hat{B} = (a_1 a_2, b_1 b_2, c_1 c_2)$ |
| Division                                       | $\hat{A} / \hat{B} = (a_1 / a_2, b_1 / b_2, c_1 / c_2)$ |

| Table 2. Example of fuzzy linguistic variables. Adapted from Ayağ and Özdemir (2007) |
|-----------------------------------------------|
| **Linguistic scales** | **Signification** | **Corresponding fuzzy number** | **Fuzzy notation** |
| Equally important (EI) | The two criteria contribute equally to the objective | $(1, 1, 1)$ | $\hat{1}$ |
| Weakly important (WI) | Judgment slightly favours one element over another | $(2, 3, 4)$ | $\hat{3}$ |
| Strongly important (SI) | One element is strongly favours over another | $(4, 5, 6)$ | $\hat{5}$ |
| Very strongly important (VSI) | One element very strongly favours over another | $(6, 7, 8)$ | $\hat{7}$ |
| Absolutely important (AI) | Judgment absolutely favours one element over another | $(8, 9, 10)$ | $\hat{9}$ |
| Intermediate values between two adjacent judgments | The evidence favouring one factor over another is of the highest possible order of affirmation. | $\hat{2}, \hat{4}, \hat{6}, \hat{8}$ |
Capture CNs: CN is an expression, in the company’s own words and feeling, of the benefit to be fulfilled by the product or service. In the case of APS software selection, the product is the APS software. There exist different tools and methods use to capture CNs, such as I-CAC (Industrial customer activity analysis cycle) (Geng, Chu, Xue, & Zhang, 2011), affinity diagram (Kwong & Bai, 2003) and Kano model (Kano et al.). In this paper, CNs are capture through a brainstorming session (Owen, 2008) combined to individual interviews addressed to all DMs. An initial list of CNs is built in a brainstorming session. That list is then presented to DMs during individual interviews for validation. The interview process is repeated until the empirical saturation reaches a level of 95% as recommended (Galvin, 2015). Empirical saturation means that new inputs are no longer provided during interviews and this marks the end of the data collection process (L. Strauss & Corbin, 1990).

DMs group is consisted of at least one member from all department involved in the decision-making process in order to have a valid sample. CNs are expressed as follows:

\[
CN = \{CN_1, CN_2, \ldots, CN_k, \ldots, CN_K\},
\]

where \(CN_k\) represents the \(k\)th CN and \(K\) is the number of CNs captured. \(\forall CN_i, CN_j, \exists CN_k \cap \cap N_j = \emptyset (i \neq j)\).

Identify Cs: Cs represent selection criteria and are usually grouped by levels. Cs identification is conducted the same way as with CNs. An initial Cs list is established using data in the literature. Then, experts are interviewed to validate the list. The interview process is repeated until the empirical saturation reaches a level of 95%. Cs are expressed as follows: \(C = \{C_1, C_2, \ldots, C_i, \ldots, C_n\}\), where \(C_i\) represents the \(i\)th criterion and \(n\) is the number of Cs identify.

\[
\forall C_i, C_j, \exists C_k \cap \cap = \emptyset (i \neq j)
\]
Identity As: There is several APS software available on the market. Thus, the set of alternatives (As) retain for the selection process can be expressed as follows: \( A = \{ A_1, A_2, \ldots, A_j, \ldots, A_m \} \), where \( A_j \) represents the \( j \)-th alternative and \( m \) is the number of alternatives As. \( \forall A_i, A_j, \exists A_i \cap A_j = \emptyset \) \( (i \neq j) \)

3.2. Calculate the Cs final fuzzy normalized weight

In the fuzzy AHP, Cs initial weight is calculated while the in the fuzzy QFD, the integration between CNs and Cs is made in order to calculated Cs final fuzzy normalized weight.

**Step 1:** Calculate Cs initial weight with fuzzy AHP

(a) Develop the hierarchical decision structure. The hierarchical decision structure helps in breaking the existing complex decision problem into manageable components of different levels (Azadeh et al., 2010). In the literature, we found in the hierarchy, the goal of the decision-making problem, the level of criteria, the level of sub-criteria and the level of alternatives. However, in order to bring in the decision-making process the needs of the company, another level that can be added to the Conventional hierarchical decision structure is the CNs. The obtained structure results into a modified hierarchical decision structure.

(b) Build fuzzy pair-wise comparison matrices from experts’ judgements. Experts evaluate Cs with the linguistic scale in Table 2. The pair-wise comparison matrices \( \hat{A}^e \) are obtained from expert:

\[
\hat{A}^e = (\hat{a}_{ire}) = \begin{pmatrix}
C_1 & \hat{a}_{12e} & \cdots & \hat{a}_{1ne} \\
\hat{a}_{21e} & C_2 & \cdots & \hat{a}_{2ne} \\
\vdots & \vdots & \ddots & \vdots \\
\hat{a}_{n1e} & \cdots & \hat{a}_{nn-1e} & 1
\end{pmatrix}
\]

with

\[
\hat{a}_{ire} = (\hat{a}_{ire}, \hat{a}_{ire}^M, \hat{a}_{ire}^L) \quad \hat{a}_{ire} = (\hat{a}_{ire})^{-1} = \left( \frac{1}{\hat{a}_{ire}^M}, \frac{1}{\hat{a}_{ire}^L}, \frac{1}{\hat{a}_{ire}^U} \right)
\]

if \( i \neq r \)

\[
\hat{a}_{ire} = 1 \quad \text{if} \quad i = r
\]

where \( \hat{a}_{ire} \) represents the judgment from eth expert concerning the relative importance of \( i \)-th criteria compared to \( r \)-th criteria, \( E \) is the number of experts, and \( n \) is the number of criteria in the matrix. The matrices \( \hat{A}^e \) are aggregated as follows (Kahraman et al., 2010) to calculate the final fuzzy pair-wise comparison matrix \( \hat{A} \):

\[
\hat{A} = (\hat{a}_{ir}) = \begin{pmatrix}
C_1 & C_2 & \cdots & C_n \\
1 & \hat{a}_{12} & \cdots & \hat{a}_{1n} \\
\hat{a}_{21} & 1 & \cdots & \hat{a}_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
\hat{a}_{n1} & \cdots & \hat{a}_{nn-1} & 1
\end{pmatrix}
\]

\[
\hat{a}_{ir} = \left( \prod_{e=1}^{E} \hat{a}_{ire}^M \right)^{1/E} \prod_{e=1}^{E} \hat{a}_{ire}^L \prod_{e=1}^{E} \hat{a}_{ire}^U
\]

For the final fuzzy pair-wise comparison matrix \( \hat{A} \), we verify the consistency by calculating the consistency ratio (CR) expressed by the Equation (7). Note that TFNs should be first defuzzified:

\[
CR = \frac{CI}{RCI} \quad CI = \frac{\lambda_{max} - n}{n - 1}
\]

where \( \lambda_{max} \) is the largest Eigen value of the matrix \( \hat{A} \), \( n \) is the number of Cs being compared, \( CI \) is the consistency index, and \( RCI \) is the random consistency index defined in Table 3. If \( CR \) is less than 0.1, the pair-wise comparison matrix \( \hat{A} \) is acceptable; otherwise, the data of the matrix \( \hat{A} \) should be revised to reduce incoherence.

The aggregate function of the importance of the ith criterion is then calculated as follows.
(c) Weight Cs in respect to their position in the hierarchical decision structure. Calculate the fuzzy weight $\hat{y}_i$ of sub-criteria with respect to their level in the decision hierarchy. Hierarchical decision structure being consisted of different levels of sub-criteria, the final fuzzy weight of each sub-criteria depends on its upper level criteria. Let considered a sub-criteria $i$ having $h$ ($h \in \mathbb{N}$) upper levels criteria and $\hat{y}_i(z = 1, 2, \cdots, h)$ the weight of the $z$th upper criteria. The final fuzzy weight $\hat{y}_i$ of the $i$th sub-criteria is calculated through the Equation (9).

$$\hat{y}_i = \hat{u}_i \otimes \prod_{z=1}^{h} \hat{u}_z$$

for $i = 1, 2, \cdots, n$ $z = 1, 2, \cdots, h$ ($h \in \mathbb{N}$) 

### Step 2: Calculate Cs final fuzzy normalized weights

(a) Evaluate CNs fuzzy importance. DMs evaluate the CN importance with linguistic variables and TFNs depicted in Table 4. The CN importance matrix $\hat{b}$ is obtained.

$$\hat{b} = \begin{pmatrix} \hat{b}_{1p} & \hat{b}_{12} & \cdots & \hat{b}_{1p} \\ \hat{b}_{21} & \hat{b}_{22} & \cdots & \hat{b}_{2p} \\ \vdots & \vdots & \ddots & \vdots \\ \hat{b}_{kp} & \hat{b}_{k2} & \cdots & \hat{b}_{kp} \end{pmatrix}$$

where $\hat{b}_{kp}$ represents the fuzzy importance of the $k$th CN from $p$th DM. The aggregate function of the importance of the $k$th CN is calculated as follows:

$$\hat{v}_k = (\hat{b}_{k1} \otimes \hat{b}_{k2} \otimes \cdots \otimes \hat{b}_{kp})^{1/p} = \left( \prod_{p=1}^{p} \hat{b}_{kp} \right)^{1/p} = \left( \prod_{p=1}^{p} \hat{b}_{kp} \right)^{1/p}$$

where $\hat{r}_{kp}$ represents the fuzzy relationship between the $k$th CN and the $i$th criteria. 

### Table 3. Average RCI values. Adapted from T. L. Saaty (1990)

| Number of criteria | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|-------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| RCI               | 0   | 0   | 0.58| 0.90| 1.12| 1.24| 1.32| 1.41| 1.45| 1.69|

(b) Evaluate CNs–Cs relationships. Experts are associated with DMs to evaluate the CNs–Cs relationship using the linguistic variables depicted in Table 4. The CNs–Cs relationship matrix are obtained:

$$\hat{R} = \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{kn} & \hat{r}_{k2} & \cdots & \hat{r}_{kn} \end{pmatrix}$$

where $\hat{r}_{kp}$ represents the fuzzy relationship between the $k$th CN and the $i$th criteria. 

(c) Bring CNs and Cs in the HOQ framework and calculate Cs final fuzzy relative weight. As illustrated in Figure 3, a seventh element is added to the standard HOQ framework in order to integrate CNs fuzzy importance and Cs fuzzy initial weight to calculate the Cs final fuzzy relative weight.
In the modified HOQ framework, the Cs final fuzzy absolute weight is expressed as follows:

\[
\tilde{s}_i = \left( \sum_{k=1}^{K} \tilde{r}_{ki} \odot \tilde{v}_k \right) \odot \tilde{y}_j \quad \text{for } i = 1, 2, \ldots, n
\]  

(13)

where \( \tilde{y}_j \) is the \( j \)th Cs initial fuzzy weight from fuzzy AHP, \( \tilde{r}_{ki} \) is the CNs–Cs relationship and \( \tilde{v}_k \) is the \( k \)th CNs importance. The Cs final fuzzy relative weight \( \tilde{w}_i \) is then obtained:

\[
\tilde{w}_i = \frac{\tilde{s}_i}{\sum_{q=1}^{n} \tilde{s}_q}
\]  

(14)

### 3.3. Rank alternatives As

In the fuzzy VIKOR, the As fuzzy weight (ability of the alternative to satisfy CNs) is calculated. The process is as follows.

**Step 3:** Evaluate As in respect with Cs and build the fuzzy decision matrix.

---

**Table 4. Linguistic variables used to capture the relevance of the “WHATs” Adapted from Bevilacqua et al. (2006)**

| Linguistic scales | Corresponding fuzzy number | Fuzzy notation |
|-------------------|-----------------------------|---------------|
| Very low (VL)     | (1, 1, 2)                   | 1             |
| Low (L)           | (2, 3, 4)                   | 3             |
| Medium (M)        | (4, 5, 6)                   | 5             |
| High (H)          | (6, 7, 8)                   | 7             |
| Very high (VH)    | (8, 9, 10)                  | 9             |

**Figure 3.** House of quality framework (conventional and modified version). Adapted from Bevilacqua et al. (2006).

---

(a) Standard framework

(b) Modified framework

In the modified HOQ framework, the Cs final fuzzy absolute weight is expressed as follows:

\[
\tilde{s}_i = \left[ \sum_{k=1}^{K} \tilde{r}_{ki} \odot \tilde{v}_k \right] \odot \tilde{y}_j \quad \text{for } i = 1, 2, \ldots, n
\]  

(13)

where \( \tilde{y}_j \) is the \( j \)th Cs initial fuzzy weight from fuzzy AHP, \( \tilde{r}_{ki} \) is the CNs–Cs relationship and \( \tilde{v}_k \) is the \( k \)th CNs importance. The Cs final fuzzy relative weight \( \tilde{w}_i \) is then obtained:

\[
\tilde{w}_i = \frac{\tilde{s}_i}{\sum_{q=1}^{n} \tilde{s}_q}
\]  

(14)
The decision matrix contains the dimension of each alternative with respect to selection criteria. APS software experts evaluate each alternative using linguistic variables presented in Table 5. The decision matrix is expressed as follows:

\[
\tilde{F} = \begin{pmatrix}
\tilde{f}_{11} & \tilde{f}_{12} & \cdots & \tilde{f}_{1m} \\
\tilde{f}_{21} & \tilde{f}_{22} & \cdots & \tilde{f}_{2m} \\
\vdots & \vdots & \ddots & \vdots \\
\tilde{f}_{n1} & \tilde{f}_{n2} & \cdots & \tilde{f}_{nm}
\end{pmatrix}
\]

where \( \tilde{f}_{ij} \) is the fuzzy dimension of the ith criteria regarding the jth alternative.

**Step 4:** Calculate the As weight using fuzzy VIKOR

(a) Determine the best and worst values of criteria. Find out the \( \tilde{f}^* \) and \( \tilde{f}^- \) for all criteria

\[
\begin{align*}
\tilde{f}^* &= \max_j \tilde{f}_{ij} \quad \text{for } i = 1, 2, \ldots, n \\
\tilde{f}^- &= \min_j \tilde{f}_{ij} \quad \text{for } i = 1, 2, \ldots, m
\end{align*}
\]

(b) Calculate the maximum group utility (S) and minimum of individual regret (R).

\[
\tilde{S}_j = \sum_{i=1}^{n} \tilde{w}_i \left( \tilde{f}_{ij} / \tilde{f}^* \right) \\
\tilde{R}_j = \max_i \left\{ \tilde{w}_i \left( \tilde{f}_{ij} / \tilde{f}^- \right) \right\}
\]

(c) Calculate the aggregating function (Q).

\[
\tilde{Q}_j = \nu \left( \tilde{S}_j \Theta \tilde{S}^* \right) / \left( \tilde{S}^* \Theta \tilde{S}^* \right) + (1 - \nu) \left( \tilde{R}_j \Theta \tilde{R}^- \right) / \left( \tilde{R}^- \Theta \tilde{R}^- \right)
\]

where \( \tilde{S}^* = \max_j \tilde{S}_j; \tilde{S}^- = \min_j \tilde{S}_j; \tilde{R}^* = \max_j \tilde{R}_j \) and \( \tilde{R}^- = \min_j \tilde{R}_j \). The parameter \( \nu \in [0, 1] \) denotes the weight of the strategy of maximum group utility, while \( 1 - \nu \) is the weight of regret. Usually, \( \nu \) is assumed to be 0.5 (Haiqing et al., 2014).

(d) Rank S, R and Q. First, the S, R and Q corresponding crisp values are calculated using the defuzzification Equation (4). S, R and Q ranked in decreasing order.

---

**Table 5. Linguistic variables used to evaluate the alternatives regarding criteria. Adapted from Kahraman et al. (2010)**

| Linguistic scales | Corresponding fuzzy number |
|-------------------|---------------------------|
| Very poor (VP)    | (1, 1, 3)                 |
| Poor (P)          | (1, 3, 5)                 |
| Fair (F)          | (2, 5, 8)                 |
| Good (G)          | (5, 7, 10)                |
| Very good (VG)    | (7, 10, 10)               |
(e) Rank Alternatives (As). Let \( \{A\} \) be the set of alternatives. The compromise solution is the alternative \( A^{(1)} \), which is the best ranked by the measure \( Q \) (minimum), if the two following conditions are satisfied:

1. **Acceptable advantage**: 
   \[
   Q(A^{(2)}) - Q(A^{(1)}) \geq DQ \quad \text{where} \quad A^{(2)} \text{ is the alternative with second position in the ranking list of } Q, \quad DQ = 1/(m - 1) \quad \text{and } m \text{ is the number of alternatives.}
   \]

2. **Acceptable stability in decision-making**: The alternative \( A^{(1)} \) should also be the best ranked by \( S \) and/or \( R \). This compromise solution is stable within a decision-making process, which could be the strategy of maximum group utility (when \( \nu > 0.5 \) is needed), or “by consensus” (\( \nu \approx 0.5 \)), or “with veto” (\( \nu < 0.5 \)).

If one of the above conditions is not satisfied, then the following compromise solution is proposed:

3. Alternatives \( A^{(1)} \) and \( A^{(2)} \) if only the condition 2 is not satisfied;
4. Alternatives \( A^{(1)}, A^{(2)}, \ldots, A^{(M)} \) if the condition 1 is not satisfied; with \( A^{(M)} \) determined by the formula 
   \[
   Q(A^{(M)}) - Q(A^{(1)}) < DQ \quad \text{for maximum } M \text{ (the position of these alternatives are “in closeness”).}
   \]

4. **Case study**
   In this section, the proposed APS software selection approach is applied step-by-step to a real company case in order to demonstrate its applicability and its effectiveness in selecting the best APS software alternatives. The company is a world leader in manufacturing of aero-derivative gas turbines that plan to select and implement an APS software in order to improve its planning and scheduling system. The steps to select the APS software that best meet the CNs are presented in the following section.

4.1. **Capture CNs, identity Cs and As**
   About CNs related to planning and scheduling, a team of 12 DMs from the company employee (including 3 from the repair Service, 3 from the planning service, 2 from continuous improvement, 2 from workshop and 2 from production management) has been constituted and it took more than one month to collect CNs. From a survey, an initial list of CNs have been built. This initial list has then been brought to the same DMs for reviewing through several groups interviews cycles. Each interview cycle reviewed the previous CNs list. New data were collected and the CNs list refined. A final list of 31 CNs has been established (Table 6) with an empirical saturation above 95% (Figure 4).

   To satisfy CNs, a team of six experts identified the Cs. From the initial list of 12 criteria identified in the literature, individual interviews cycles have been organized with experts to review and refine the initial list. After 9 interviews, a definitive list of 6 criteria (including 3 from the literature and 3 new ones) and 28 sub-criteria (including 6 from the literature and 22 new ones from this work) has been established (Table 7) with an empirical saturation above 95% (Figure 5). The first column provides the main criteria, and the second column to the list of related sub-criteria(s).

   Concerning alternatives As, after preliminary screening, 4 APS software have been retained for the selection process. Those are Preactor, SAP-APO, Oracle-ASCP and Infor. These alternatives are developed and hosted by world-renowned companies and listed among the 10 software having the biggest market share.

4.2. **Calculate the Cs final fuzzy normalized weight**
   The Cs final fuzzy normalized weight are calculated in the following steps:

   **Step 1**: Calculate Cs initial weight with fuzzy AHP
(a) Develop the hierarchical decision structure. The hierarchical decision structure groups the 6 main Cs, the 28 sub Cs, the 4 alternatives As and the 31 CNs (Figure 6).

(b) Build fuzzy pair-wise comparison matrices from expert’s judgements. 6 experts evaluated Cs and the pair-wise comparison matrix from each expert is aggregated to build the final pair-wise comparison matrices $A$ presented in Equation (20), for main criteria Cs ($C_1, C_2, C_3, C_4, C_5, C_6$).

| Table 6. List of company needs (CNs) |
|--------------------------------------|
| **Items** | **Company needs (CNs)** |
| CN1 | Integrate operator schedules over three years |
| CN2 | Integrate constraints on operators’ competencies |
| CN3 | Integrate constraints on spaces on the floor |
| CN4 | Integrate constraints on critical tooling |
| CN5 | Manage up to 100 engines at the same time |
| CN6 | Control the level of WIP |
| CN7 | Levels capacity and workload |
| CN8 | Allow “What-if” scenarios without impacting the schedule |
| CN9 | Measuring performance at the end of the project |
| CN10 | Capture the actual progress of tasks on the floor |
| CN11 | Adding information to a project in progress |
| CN12 | Connect to SAP, Excel, and to a MES system |
| CN13 | Be able to operate outside networks (at home for example) |
| CN14 | Simple to operate (adding projects, adding information, etc.) |
| CN15 | Consult the planning by levels (Engine, modules, sub-kit, resources, etc.) |
| CN16 | Built a database of completed projects |
| CN17 | Display the critical project path as required |
| CN18 | Provide KPIs (rate of absorption, use of resources, etc.) |
| CN19 | Reporting job conflicts and propose correction options |
| CN20 | Report Constraint Violations and propose correction Options |
| CN21 | Produce realistic and optimal schedules for the shop |
| CN22 | Allows extraction of data in text format |
| CN23 | Allows extraction of desired statistics |
| CN24 | Display capacity utilization (employee, spaces, materials) |
| CN25 | Possibility to have an overview of all projects on the Gantt chart |
| CN26 | Possibility to isolate on the Gantt chart, a particular project |
| CN27 | Possibility of manually entering job progress |
| CN28 | Track shortages |
| CN29 | View the actual and planned progress of tasks |
| CN30 | View Dates at risk and constraints |
| CN31 | Have an attractive visual appearance to enable quick decisions |
The consistency of those matrices is verified by calculating the consistency ratio (CR). As an example, for main criteria Cs (C₁, C₂, C₃, C₄, C₅, C₆), we find CR = 0.033, meaning that the matrix is consistent enough. By aggregating each line of the pair-wise comparison matrix, we obtain the Cs fuzzy importance. Table 8 shows results for main criteria.

(c) Weight Cs in respect to their position in the hierarchical decision structure. The results are shown in Table 9. The importance of Cs in the second and third level of the hierarchical decision structure is calculated using Equation (8), and the Cs initial fuzzy weight is calculated using Equation (9).

Step 2: Calculate Cs final fuzzy normalized weights

(a) Evaluate CNs fuzzy importance. The 12 DMs identified in the company evaluate the CNs importance with linguistic variables and TFNs depicted in Table 4. The result from each DM is shown in Table 10 and the aggregate function also, representing the CNs fuzzy importance.

(b) Evaluate CNs–Cs relationships. The 6 experts are associated with DMs to evaluate the CNs–Cs relationship using the linguistic variables depicted in Table 4. We observe that the Cs related to “cost” don’t have any relationship with CNs. Indeed, company wants the best APS software independently of the cost to pay.

(c) Bring CNs and Cs in the HOQ framework and calculate Cs final fuzzy relative weight. The modified HOQ framework is built with CNs and Cs. Figure 7 presents all elements of the framework, including the Cs initial fuzzy weight. The Cs final fuzzy absolute weight and the Cs final fuzzy normalized weight shown in the bottom part of the framework are, respectively, calculated using Equations (13) and (14). The results are presented in Table 11.

4.3. Rank alternatives As

Step 3: Experts evaluate alternatives and their judgment help in building the decision matrix as shown in Table 12.
| Criteria     | Sub-criteria                                      | Description                                                                 |
|-------------|--------------------------------------------------|-----------------------------------------------------------------------------|
| Personaliz-ability (C1) | Customizable fields (C11)                        | Ability to personalize the layout of package interface                      |
|             | Customizable reports (C12)                       | Ability to personalize the layout of reports produced by package            |
| Usability (C2) | User interface (C21)                             | Ease with which user can use interface of the software package              |
|             | User types (C22)                                 | Ability of the APS software to support beginners, intermediate, and advanced users |
|             | Data visualization (C23)                         | Capability of the APS software package to present data effectively          |
|             | Error reporting (C24)                            | Error reporting and messaging ability of the APS software package           |
|             | Ease of use (C25)*                               | Ease with which user can learn and operate the APS software package         |
| Reliability (C3) | Robustness (C31)                                 | Capability of the APS software package to run consistently without crashing |
|             | Backup and recovery (C32)                        | Capability of the APS software package to support backup and recovery feature |
| Vendor (C4)* | Training (C41)                                   | Availability of training courses to learn the package                       |
|             | Maintenance and upgrading (C42)                  | Vendor support for upgrading and maintenance of the APS software           |
|             | Consultancy (C43)                                | Availability of technical support and consultancy by the vendor             |
|             | Vendor popularity (C44)                          | Popularity of vendor in the market                                          |
|             | Past business experience (C45)                   | Past business experience with the vendor, if any                           |
|             | References (C46)                                 | Number of references of the existing customers using the product           |
|             | Length of experience (C47)                       | Experience of vendor about development of the software product             |
| Cost (C5)*  | Licence cost (C51)                               | Licence cost of the product in terms of number of users                    |
|             | Training cost (C52)                              | Cost of training to the users of the system                                |
|             | Installation and implementation cost (C53)       | Cost of installation and implementation of the product                    |
|             | Maintenance and updating cost (C54)              | Maintenance cost of the product when and when a new version will be launched |

(Continued)
| Criteria | Sub-criteria | Description |
|----------|--------------|-------------|
| Technology (C6)* | Interactive Gantt chart (C61)* | Possibility to play directly on the Gantt chart to edit data and move elements |
| Resource calendar editor (C62)* | Ability to build and manage calendar for each resource according to company context and plan. |
| Report generator (C63)* | Possibility to build report and personalize them to company needs |
| Advanced planning algorithms (C64)* | Powerful algorithm with a running time acceptable and advanced rules |
| Multi-constraint consideration (C65) | Ability to consider several constraints on operator competency, machine and tooling constraints, etc. |
| Multiple/customized schedule objectives (C66) | Possibility for scheduling operation under a set of different objectives |
| What if scenario module (C67) | Possibility to perform efficient and robust scenario analysis without impacting official plan |
| Integration (C68)* | Ability to connect to systems as ERP, MRP, MES, etc., for the data flow for data management |
Step 4: Calculate the $A_s$ weight using fuzzy VIKOR

$\tilde{f}_i$ and $\tilde{f}_i$ are determined using Equation (16), while the maximum group utility $\tilde{S}_j$ and the minimum of individual regret $\tilde{R}_j$ are, respectively, determined using Equations (17) and (18). The aggregating function $\tilde{Q}_j$ is calculated using Equation (19). $\tilde{S}_j$, $\tilde{R}_j$ and $\tilde{Q}_j$ value are defuzzified using Equation (4). Table 13 shows all the results obtained. We observed that Preactor software appear
as the alternative that has the minimum $Q$ value. This means, Preactor software is the best ranked alternative. SAP–APO in contrary is the worst ranked alternatives with the maximum $Q$ value.

5. Discussion and sensitivity analysis

In the present research, fuzzy QFD integrated with fuzzy AHP and fuzzy VIKOR is applied to solve the APS software selection problem. In the studied case, it is found in Table 11 that the software Preactor is ranked at the top position with the smallest $Q$ value of 0 while at the second position we have the software Oracle ASCP with a $Q$ value of 0.43. At least position we have Infor software with the higher $Q$ value of 1. Regarding the first condition of VIKOR method ($Q(A^{2}) - Q(A^{1})$ $\geq$ $DQ$), we found that $Q(A^{2}) - Q(A^{1}) = 0.43$ and $DQ = 0.33$. The first condition is then satisfied. Furthermore, Preactor software also has the smallest $R$ and $S$ values, meaning that it is also the best ranked alternative regarding $S$ and $R$ ranking. The second condition is then satisfied. The two conditions being satisfied, we can conclude that the solution obtained is a stable and compromise solution (Dammak et al., 2015).

To validate the proposed methodology, the APS software selection problem is also solved using three other approaches developed in the literature with the same dataset presented in the above case study. The three approaches are fuzzy AHP technique (Azadeh et al., 2010), integration of fuzzy AHP with fuzzy VIKOR (Haiqing et al., 2014) and integration of fuzzy QFD with fuzzy VIKOR (Wu et al., 2016). The particularity in fuzzy AHP is that there is no consideration on CNs, and Cs are weighted directly from experts’ assessment. Fuzzy QFD brings CNs importance in the Cs weighting. Table 14 shows the results obtained and Figure 8 presents a comparison of alternatives ranking from the different approaches.

The ranking comparison result shows that the ranking obtained from the proposed methodology is the same with the approaches (A) and (B) while in approach (C), there are changes observed. Indeed, with the approach (C), SAP–APO software is at least position while Infor software is at second position and Oracle ASCP software at the third position. This difference observed can be explained by the fact that the approach (C) uses the Conventional QFD method in contrary to the modified QFD proposed in this study. As mentioned above, the HOQ in the Conventional QFD is composed only of the CNs and the relationship CNs–Cs. The Cs initial fuzzy weight is not considered. Furthermore, the pair-wise comparison matrices from experts are not used here. Only the survey addressed to DMs to collect judgement on CNs importance is considered. Otherwise, Preactor remains the best choice for all the approaches. This demonstrates the validity of our proposed methodology (You, You, Liu, & Zhen, 2015).

Further, from the ranking differences (Table 14), the relationship between the three approaches (A), (B), (C) and the proposed methodology is determined using Spearman’s rank correlation test. The Spearman’s test used statistics (Table 14) to calculate the correlation rank factor of two ranking lists. If the Spearman’s rank is greater than 0.6, the relationship between the rankings is considered as good and significantly positive. In our case, it is observed (Table 15) that the Spearman’s correlation rank factor obtained between the approaches (A), (B) and the proposed one is 1. This confirms the strong positive relationship

| Criteria Cs | Personalizability $C_1$ | Usability $C_2$ | Reliability $C_3$ | Vendor $C_4$ | Cost $C_5$ | Technology $C_6$ |
|-------------|-------------------------|-----------------|------------------|-------------|-----------|-----------------|
| Cs fuzzy importance | (0.62, 0.60, 0.57) | (0.97, 0.99, 1.01) | (1.10, 1.12, 1.14) | (0.47, 0.38, 0.32) | (1.30, 1.31, 1.33) | (2.48, 3.02, 3.50) |
| Main criteria Cs | Main criteria Cs weight (Level 2) | Sub-criteria Cs | Sub-criteria Cs weight (Level 3) | Cs initial fuzzy weight |
|------------------|----------------------------------|-----------------|----------------------------------|------------------------|
| Personalizability (C1) | (0.62, 0.60, 0.57) | Customizable fields (C11) | (1.19, 1.19, 1.20) | (0.74, 0.71, 0.69) |
|                    |                                  | Customizable reports (C12) | (0.84, 0.84, 0.83) | (0.52, 0.50, 0.48) |
| Usability (C2)     | (0.97, 0.99, 1.01) | User interface (C21) | (1.33, 1.48, 1.60) | (1.29, 1.47, 1.61) |
|                    |                                  | User types (C22) | (0.66, 0.57, 0.52) | (0.64, 0.57, 0.52) |
|                    |                                  | Data visualization (C23) | (1.12, 1.20, 1.26) | (1.08, 1.20, 1.28) |
|                    |                                  | Error reporting (C24) | (1.41, 1.42, 1.45) | (1.36, 1.42, 1.46) |
|                    |                                  | Ease of use (C25) | (0.72, 0.69, 0.66) | (0.69, 0.69, 0.67) |
| Reliability (C3)   | (1.10, 1.12, 1.14) | Robustness (C31) | (1.26, 1.31, 1.35) | (1.38, 1.47, 1.54) |
|                    |                                  | Backup and recovery (C32) | (0.79, 0.76, 0.74) | (0.87, 0.86, 0.85) |
| Vendor (C4)        | (0.47, 0.38, 0.32) | Training (C41) | (2.00, 2.48, 2.91) | (0.94, 0.94, 0.94) |
|                    |                                  | Maintenance and upgrading (C42) | (1.32, 1.39, 1.45) | (0.62, 0.53, 0.47) |
|                    |                                  | Consultancy (C43) | (1.11, 1.21, 1.29) | (0.52, 0.46, 0.42) |
|                    |                                  | Vendor popularity (C44) | (0.60, 0.52, 0.46) | (0.28, 0.20, 0.15) |
|                    |                                  | Past business experience (C45) | (0.81, 0.77, 0.74) | (0.38, 0.29, 0.24) |
|                    |                                  | References (C46) | (0.74, 0.66, 0.60) | (0.35, 0.25, 0.19) |
|                    |                                  | Length of experience (C47) | (0.94, 0.91, 0.89) | (0.44, 0.34, 0.29) |
| Cost (C5)          | (1.30, 1.31, 1.33) | Licence cost (C51) | (0.96, 1.00, 1.02) | (1.25, 1.31, 1.36) |
|                    |                                  | Training cost (C52) | (0.94, 0.96, 0.97) | (1.23, 1.26, 1.29) |
|                    |                                  | Installation and implementation cost (C53) | (1.20, 1.20, 1.20) | (1.57, 1.57, 1.60) |
|                    |                                  | Maintenance and updating cost (C54) | (0.92, 0.87, 0.84) | (1.20, 1.14, 1.11) |
| Main criteria Cs | Main criteria Cs weight (Level 2) | Sub-criteria Cs | Sub-criteria Cs weight (Level 3) | Cs initial fuzzy weight |
|------------------|----------------------------------|-----------------|---------------------------------|------------------------|
| Technology (C6)  | (2.48, 3.02, 3.50)               | Interactive Gantt chart (C61) | (0.67, 0.60, 0.55) | (1.65, 1.80, 1.92) |
|                  |                                  | Resource calendar editor (C62) | (0.75, 0.70, 0.67) | (1.85, 2.12, 2.35) |
|                  |                                  | Report generator (C63)       | (0.83, 0.79, 0.76) | (2.07, 2.38, 2.66) |
|                  |                                  | Advanced planning algorithms (C64) | (1.29, 1.49, 1.65) | (3.20, 4.51, 5.79) |
|                  |                                  | Multi-constraint consideration (C65) | (1.33, 1.40, 1.46) | (3.30, 4.23, 5.11) |
|                  |                                  | Multiple/customized schedule objectives (C66) | (1.10, 1.16, 1.20) | (2.72, 3.49, 4.20) |
|                  |                                  | What if scenario module (C67) | (1.15, 1.15, 1.16) | (2.85, 3.48, 4.06) |
|                  |                                  | Integration (C68)            | (1.12, 1.08, 1.06) | (2.77, 3.26, 3.72) |
| Decision Makers | DM1 | DM2 | DM3 | DM4 | DM5 | DM6 | DM7 | DM8 | DM9 | DM10 | DM11 | DM12 | CNs weight |
|----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|------------|
| Company Needs | CN1 | VL  | M   | VL  | M   | VH  | VH  | M   | VL  | VH  | VH   | VH   | M   | (3.78, 4.27, 5.64) |
| CN2 | M   | M   | M   | M   | VH  | VH  | VH  | VH  | VH  | VH  | VH   | VH   | M   | (5.99, 7.04, 8.08) |
| CN3 | VH  | M   | VH  | M   | VH  | VH  | VH  | VH  | VH  | VH  | VL   | VH   | VH  | (5.99, 6.79, 8.03) |
| CN4 | VH  | M   | M   | M   | VH  | VH  | VH  | VH  | VH  | VH  | VL   | VH   | VH  | (6.73, 7.77, 8.80) |
| CN5 | M   | M   | M   | M   | VH  | VH  | VH  | VH  | VL  | VH  | VL   | VH   | VH  | (4.49, 5.13, 6.45) |
| CN6 | M   | VL  | M   | VH  | VH  | VH  | VH  | VH  | VH  | VH  | M    | VH   | VH  | (4.49, 5.13, 6.45) |
| CN7 | VH  | M   | VH  | VH  | VH  | VH  | VH  | VH  | VH  | VH  | M    | VH   | VH  | (6.35, 7.40, 8.43) |
| CN8 | VH  | VH  | VH  | M   | VH  | VH  | VH  | VH  | VH  | VH  | M    | VH   | VH  | (6.73, 7.77, 8.80) |
| CN9 | M   | VH  | VH  | M   | VH  | VH  | VH  | VH  | VH  | VH  | M    | VH   | VH  | (6.35, 7.40, 8.43) |
| CN10 | M   | VH  | M   | VH  | VH  | VH  | VH  | VH  | VH  | VH  | M    | VH   | VH  | (6.73, 7.77, 8.80) |
| CN11 | VH  | VH  | VH  | VL  | VH  | VH  | VH  | VH  | VH  | VH  | M    | VH   | VH  | (5.66, 6.47, 7.70) |
| CN12 | M   | M   | M   | VL  | M   | M   | VH  | VH  | VH  | VH  | VL   | VH   | VH  | (4.24, 4.88, 6.18) |
| CN13 | VL  | VL  | VL  | VL  | VH  | VH  | VH  | VH  | M   | M   | M    | VL   | M   | (2.52, 2.82, 4.13) |
| CN14 | M   | VH  | VH  | VH  | VH  | VH  | VH  | VH  | M   | VH  | VH   | VL   | M   | (5.99, 6.79, 8.03) |
| CN15 | M   | M   | M   | VH  | VH  | VH  | VH  | VH  | M   | VH  | VH   | VL   | M   | (5.66, 6.71, 7.75) |
| CN16 | VL  | VL  | M   | M   | M   | M   | M   | VH  | VH  | VH  | VL   | M   | (3.17, 3.69, 4.96) |
| CN17 | M   | VH  | M   | VH  | VH  | VH  | VH  | VH  | VH  | VH  | VH   | VH   | VH  | (7.13, 8.16, 9.18) |
| CN18 | M   | VH  | M   | VH  | VH  | VH  | VH  | VH  | M   | M   | M    | VL   | M   | (4.24, 5.06, 6.22) |
| CN19 | M   | VH  | VH  | VH  | VH  | VH  | VH  | VH  | VH  | VL  | M    | M    | (5.66, 6.47, 7.70) |

(Continued)
| Decision Makers | CNs weight |
|-----------------|------------|
| DM1             | (6.73, 7.77, 8.80) |
| DM2             | (7.13, 8.16, 9.18) |
| DM3             | (2.24, 2.56, 3.80) |
| DM4             | (3.78, 4.43, 5.68) |
| DM5             | (4.76, 5.59, 6.77) |
| DM6             | (5.66, 6.71, 7.75) |
| DM7             | (6.73, 7.77, 8.80) |
| DM8             | (7.13, 8.16, 9.18) |
| DM9             | (4.49, 5.32, 6.49) |
| DM10            | (5.66, 6.71, 7.75) |
| DM11            | (5.66, 6.71, 7.75) |
| DM12            | (5.66, 6.71, 7.75) |

Table 10. (Continued)
between the rankings obtained from the proposed methodology and the two approaches (A) and (B) from the literature. Regarding the approach (C), the Spearman’s correlation rank factor is 0.4. This means that the correlation between the approach (C) and the proposed methodology is positive but not good. These results from the Spearman’s correlation test were predictable with regard to Table 14 and Figure 8.
In another hand, to check the influences of the strategy of the maximum group utility on the proposed APS selection methodology, a two-way sensitivity analysis is also carried out in the present research. The strategy of maximum group utility is expressed through the value \( v \), considered to be equal to 0.5 in the illustrative example. Thus, the sensitivity analysis is based on the value of \( v \) taken between 0 and 1. Table 16 contains the results (Q values) obtained for each value of \( v \) and Figure 9 presents the ranking differences.

| Su criteria (Cs)                              | Cs absolute fuzzy weight | Cs normalized fuzzy weight |
|----------------------------------------------|--------------------------|----------------------------|
| Customizable fields (C11)                    | (15.18, 25.76, 43.31)    | (0.0053, 0.0052, 0.0054)  |
| Customizable reports (C12)                   | (45.48, 60.72, 84.26)    | (0.0159, 0.0123, 0.0105)  |
| User interface (C21)                         | (273.89, 455.84, 699.03) | (0.0957, 0.0924, 0.0869)  |
| User types (C22)                             | (0.00, 0.00, 0.00)       | (0.0000, 0.0000, 0.0000)  |
| Data visualization (C23)                     | (156.57, 232.63, 329.61) | (0.0547, 0.0410, 0.0224)  |
| Error reporting (C24)                        | (75.38, 110.45, 156.53)  | (0.0264, 0.0224, 0.0195)  |
| Ease of use (C25)                            | (32.85, 46.37, 63.64)    | (0.0115, 0.0094, 0.0079)  |
| Robustness (C31)                             | (37.21, 52.69, 79.55)    | (0.0130, 0.0107, 0.0099)  |
| Backup and recovery (C32)                    | (5.52, 9.49, 16.85)      | (0.0019, 0.0019, 0.0021)  |
| Training (C41)                               | (0.00, 0.00, 0.00)       | (0.0000, 0.0000, 0.0000)  |
| Maintenance and upgrading (C42)              | (0.00, 0.00, 0.00)       | (0.0000, 0.0000, 0.0000)  |
| Consultancy (C43)                            | (0.00, 0.00, 0.00)       | (0.0000, 0.0000, 0.0000)  |
| Vendor popularity (C44)                      | (0.00, 0.00, 0.00)       | (0.0000, 0.0000, 0.0000)  |
| Past business experience (C45)               | (0.00, 0.00, 0.00)       | (0.0000, 0.0000, 0.0000)  |
| References (C46)                             | (0.00, 0.00, 0.00)       | (0.0000, 0.0000, 0.0000)  |
| Length of experience (C47)                   | (0.00, 0.00, 0.00)       | (0.0000, 0.0000, 0.0000)  |
| Licence cost (C51)                           | (0.00, 0.00, 0.00)       | (0.0000, 0.0000, 0.0000)  |
| Training cost (C52)                          | (0.00, 0.00, 0.00)       | (0.0000, 0.0000, 0.0000)  |
| Installation and implementation cost (C53)   | (0.00, 0.00, 0.00)       | (0.0000, 0.0000, 0.0000)  |
| Maintenance and updating cost (C54)          | (0.00, 0.00, 0.00)       | (0.0000, 0.0000, 0.0000)  |
| Interactive Gantt chart (C61)                 | (299.47, 500.38, 776.13) | (0.1047, 0.1014, 0.0965)  |
| Resource calendar editor (C62)               | (55.96, 81.65, 132.69)   | (0.0196, 0.0165, 0.0165)  |
| Report generator (C63)                       | (93.85, 143.90, 231.52)  | (0.0328, 0.0292, 0.0288)  |
| Advanced planning algorithms (C64)           | (512.27, 1034.91, 1889.23) | (0.1791, 0.2098, 0.2349)  |
| Multi-constraint consideration (C65)         | (512.23, 902.76, 1480.38) | (0.1791, 0.1830, 0.1840)  |
| Multiple/customized schedule objectives (C66)| (224.97, 454.36, 807.67) | (0.0786, 0.0921, 0.1004)  |
| What if scenario module (67)                 | (204.59, 315.10, 455.03) | (0.0715, 0.0639, 0.0566)  |
| Integration (C68)                            | (314.98, 506.79, 798.44) | (0.1101, 0.1027, 0.0993)  |
Table 12. Fuzzy evaluation matrix for the alternatives

| Criteria (Cs) | Preactor | SPA-APO | Oracle ASCP | Infor |
|---------------|----------|---------|-------------|-------|
| C11           | VG       | P       | VG          | VP    |
| C12           | VG       | F       | G           | VG    |
| C21           | VG       | G       | VG          | G     |
| C22           | VG       | F       | P           | VG    |
| C23           | VG       | F       | G           | VG    |
| C24           | F        | F       | G           | F     |
| C25           | VG       | F       | G           | G     |
| C31           | G        | F       | G           | VG    |
| C32           | F        | G       | G           | VG    |
| C41           | VG       | F       | G           | VG    |
| C42           | VG       | VG      | F           | F     |
| C43           | P        | P       | G           | P     |
| C44           | G        | VG      | G           | P     |
| C45           | VG       | G       | G           | P     |
| C46           | VG       | F       | VG          | VG    |
| C47           | VG       | G       | P           | G     |
| C51           | G        | VP      | P           | VP    |
| C52           | G        | F       | G           | G     |
| C53           | G        | G       | VG          | VP    |
| C54           | P        | G       | G           | VP    |
| C61           | VG       | P       | P           | VG    |
| C62           | VG       | F       | G           | VG    |
| C63           | G        | G       | G           | F     |
| C64           | VG       | G       | VG          | F     |
| C65           | VG       | G       | G           | F     |
| C66           | VG       | F       | G           | VG    |
| C67           | G        | G       | G           | F     |
| C68           | G        | P       | F           | F     |

Table 13. Fuzzy and crisp values of S, R, and Q and rank of alternatives

|          | S          | R          | Q          | Rank |
|----------|------------|------------|------------|------|
|          | Fuzzy value| Crisp value| Fuzzy value| Crisp value| Fuzzy value| Crisp value|      |
| Preactor | (0.08, 0.09, 0.02) | 0.07 | (0.04, 0.06, 0.02) | 0.05 | (0.00, 0.00, 0.00) | 0.00 | 1   |
| SPA-APO  | (0.57, 0.65, 0.39) | 0.56 | (0.10, 0.13, 0.10) | 0.11 | (0.66, 0.69, 0.49) | 0.63 | 3   |
| Oracle ASCP | (0.36, 0.43, 0.20) | 0.35 | (0.11, 0.11, 0.10) | 0.11 | (0.50, 0.45, 0.33) | 0.43 | 2   |
| Infor    | (0.65, 0.68, 0.63) | 0.66 | (0.18, 0.21, 0.23) | 0.21 | (1.00, 1.00, 1.00) | 1.00 | 4   |
| Approach (A) | Approach (B) | Approach (C) | Approach (D) | Ranking differences |
|-------------|-------------|-------------|-------------|---------------------|
| Fuzzy AHP   | Fuzzy AHP   | Fuzzy QFD + Fuzzy QFD + | Fuzzy VIKOR | d = A-D             |
|             |             | Fuzzy VIKOR |             | d = B-D             |
|             |             |             |             | d = C-D             |
|             |             |             |             | d = D               |

Azadeh et al. (2010)

Haiqing et al. (2014)

Wu et al. (2016) Proposed methodology

Rank

Preactor

SPA-APO

Oracle ASCP

Enfor

Piengang et al., Cogent Engineering (2019), 6: 1594509

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The sensitivity analysis reveals that the ranking is highly influenced by the value of \( v \). This was expected since, \( v \) expressed the tolerance of utility and regret expected from the solution. When looking at Equation (19) expressing the value of \( Q \), we can mathematically predict that the greater is \( v \), the ranking order obtained from \( Q \) should be closer to the one based on values of \( S \). On the contrary, less is \( v \), more the ranking order should be closer to the one based on values of \( R \). However, in the case study, despite there are significant changes observed regarding \( Q \) values, the ranking remains the same for the four alternatives independently of the values of \( v \).

6. Conclusion
The aim of this paper was to develop an APS software selection methodology to help DMs select the best alternative to meet their needs regarding planning and scheduling of operations. A review of available literature revealed a huge amount of selection approaches and methodologies for different engineering software (ERP software, PM software, PLM software, etc.), all based on MCDM techniques, mathematical programming, artificial intelligence or on the integration of those. This paper presents a simple approach in a fuzzy environment filled with uncertainty and ambiguity to overcome the complex APS software decision problem. The proposed approach integrates a modified version of fuzzy QFD to fuzzy AHP and fuzzy VIKOR.

Fuzzy AHP helps in dealing with large set of criteria as it decomposes a complex multi-criteria decision-making problem into a hierarchy. Fuzzy AHP also ensures strong and reliable results due to its pairwise comparison feature that allows calculation of the selection criteria initial fuzzy weight. QFD is a well-known and comprehensive method that has been tested successfully in practice while it comes to capture and assess customer needs or in this case CNs. Fuzzy QFD reduced ambiguities and uncertainties in the QFD method and improve the effectiveness of the APS software decisions for the company. It helps in integrating customer needs fuzzy importance into the calculation of the selection criteria final fuzzy normalized weight used in the ranking phase. Fuzzy VIKOR evaluates all alternatives through simple and rational calculations that come out with a compromise choice corresponding to a maximum “group utility” and a minimum regret of the “opponent”. The use of TFNs reduces vagueness, uncertainties and ambiguity in the process and enhances the potential of conventional methods.
| Q values | 0.0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Preactor | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| SPA-APO  | 0.423 | 0.465 | 0.507 | 0.549 | 0.590 | 0.632 | 0.674 | 0.716 | 0.758 | 0.800 | 0.842 |
| Oracle ASCP | 0.377 | 0.410 | 0.442 | 0.474 | 0.506 | 0.538 | 0.570 | 0.602 | 0.634 | 0.666 | 1.000 |
| Infor    | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
A case study shows that the proposed methodology is of utmost usefulness in ranking APS software with respect to multiple selection criteria and CNs. More than 30 CNs are identified, and four leading APS software (Preactor, SAP-APO, Oracle ASCP and Infor) are considered as alternatives. The case study demonstrates the easiness applicability and the capacity of the proposed approach to deal with decision problem in fuzzy environment including, multiple and conflicting needs, criteria, sub-criteria and with the aim of choosing an alternative from a known set of alternatives. We can then expect that this framework can be used by any other company or educational institution planning to purchase an APS software or to address any complex selection problem in similar environment in order to enhance effectiveness and efficiency of their decision-making. This makes the proposed approach a powerful decision support tool that attracts the attention of cross-functional team and different sectors. Validation and sensitivity analysis show that the weight of the strategy of maximum group utility value has a significant impact on the ranking. Finally, the proposed methodology is transferable and useful in a wide variety of application area considering specific CNs, criteria, and alternatives set.

As a result of the proposed methodology, we found that the integrated approach based on fuzzy QFD, fuzzy AHP and fuzzy VIKOR was a practical and efficient tool for evaluating and selecting APS software regarding their overall performance with respect to multiple criteria and CNs. Using fuzzy theory for APS software selection problem can reduce uncertainties and ambiguities due to human judgment in the decision-making. The superiority and advantages of the proposed methodology in comparison with other selection approaches in the literature reside in its ability to benefit from pairwise comparison between criteria and sub-criteria, experts’ judgment and company DMs’ need in decision-making, and hierarchical structure with five levels (the fifth level related to CNs) instead of four usual levels found in the literature. Other keys advantages of the approach are, flexibility and objectivity on the basis of assigning weights, easily understandable, easily applicable, a compromise solution between utility and regret expressed through needs assessment, ranking and experimentation capability, reducing uncertainty and ambiguities. Another contribution as results of this study was the identification of a set of six relevant criteria (including 3 from the literature) and almost 30 selection criteria (including six from the literature) to consider in APS software selection.

Concerning practical and managerial implications, firms applying the proposed selection methodology should put a cross functional team in place grouping all stakeholders (DMs) involve in operations planning and scheduling in the organization. Available experts should be identified and this can be sometime challenging depending of the sector. All the steps being described in the methodology, no particular expertise is required to run the deploy it. An external advisor or an employee of the company having experience with survey, meeting facilitation, basis on mathematics and knowledge on APS software, can lead the deployment of the selection process. For APS software selection, this work propose a set of criteria, a set of CNs related to operations planning and scheduling and a set of alternatives. Firms can then just assess them as per the methodology and compute the final ranking. An application can be developed to accelerate calculation. To
validate the solution, firm should perform a test with real data outside current operations management system. Future research revolves around investigating methods for weighting of the experts ‘evaluations to enhance the methodology efficiency, as well as integration and evaluation of other MCDM methods such as intuitionists’ fuzzy sets theories in the APS software selection problem. On the practical side, the development of an application interface will help in speeding up the evaluation process and simplifying the calculations.

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Page 33 of 34

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