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A 360-degree performance appraisal model dealing with heterogeneous information and dependent criteria

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ABSTRACT

A 360-degree performance appraisal process is used as a tool that provides an evaluation about employees' performance. It is based on the opinion of different groups of reviewers who socialize with evaluated employees. Multiple criteria are considered in performance appraisal that may have different nature and usually present uncertainty. Therefore, it seems necessary and appropriate to provide a heterogeneous framework adapted to the nature of such criteria. In this context, criteria can be assessed by reviewers, according to their background and degree of knowledge about evaluated employees. Furthermore, Human Resources Department demands the modeling and managing of the interaction among the evaluated criteria, as well as reviewers relevances to ensure an effective aggregation process of the information, providing interpretable, understandable and correct assessments. In this paper, we present an integrated model for 360-degree performance appraisal that can manage heterogeneous information and computes a final linguistic evaluation for each employee, applying an effective aggregation that considers the interaction among criteria and reviewers relevance by means of weights. We also present a real case study to show the usefulness and effectiveness of the proposed model.

1. Introduction

Performance appraisal is a key tool in companies that provides information about employees performance in order to make important decisions, such as salary adjustments, promotions, identification of training and development needs, documentation of performance levels or behaviors that may cause firing or sanctions. Furthermore, there is an evident link among performance appraisal and attitudes, efforts and behaviors of the employees, that implies improvements in the financial results obtained by companies [17].

Currently, performance appraisal process is based on the opinion of different groups of reviewers who socialize with evaluated employees, since they can truly respond to how an employee develops his/her job. Moreover, this process includes the opinion of employee about her/himself (see Fig. 1). This kind of performance appraisal process is so-called *360-degree appraisal* or *integral evaluation* (see [17,19,28,36,43], among others) and it overcomes some disadvantages from traditional evaluation such as lack of objectivity, prejudice or halo errors [2,17].

In the literature, we can find different evaluation frameworks to express reviewers' opinions in integral evaluation processes, they can be summarized in two different research lines. On the one hand, we can find the traditional lines, that offer a numerical evaluation framework, providing numerical results (see [3,15,17,58], for instance). On the other hand, we can find

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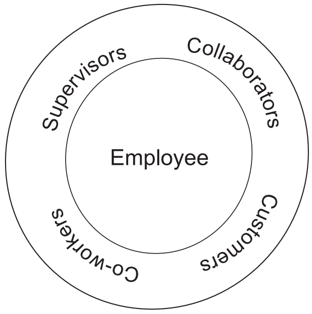

Fig. 1. Points of view in 360-degree performance appraisal.

other methods that provide a linguistic evaluation framework in which the assessments are provided in different linguistic scales according to the reviewers' knowledge [13,14].

Human Resources Departments point out several drawbacks or weak points that limit the 360-degree performance appraisal models proposed in the literature. These limitations are the following ones:

- The evaluation process is defined on a strict evaluation framework that only considers a type of expression domain, numerical or linguistic, despite evaluated criteria may have different nature and might adopt to different types of expression domains. As consequence, collected assessments do not allow to gather the richness of the information expressed by reviewers.
- It is assumed that the criteria are independent one another. However it is common the evaluation of criteria that are related to each other.
- Final and intermediate results are hard to interpret in a correct way because quantitative assessments not always represent qualitative information in an accurate way.

In order to improve and obtain a successful 360-degree performance appraisal process to make right decisions in the company, overcoming the drawbacks pointed out, in this paper we propose a novel heterogeneous integral evaluation model that considers the following needs demanded by the Human Resources Department:

- A flexible evaluation framework in which reviewers can provide their judgments within different domains (numerical, interval-valued and linguistic), according to the uncertainty, the nature of criteria and the background of each reviewer, i.e., a heterogeneous evaluation framework [22,30,34].
- An adequate set of aggregation operators that may integrate, when necessary, the interaction among criteria, the relevance and importance of the different collectives.
- Both intermediate and global results are provided by linguistic assessments close to human cognitive model easy to interpret and understand.

Therefore, the proposed model will be based on a decision analysis scheme [12], capable of managing heterogeneous information from several set of reviewers, according to criteria of diverse nature (quantitative and qualitative) and will provide intermediate and final outcomes for each employee, considering a multi-step aggregation procedure. Thus, the problem falls, in a natural way, into a group decision making context. Furthermore, we propose the use of the linguistic 2-tuple representation model [37] and its extended approach to deal with heterogeneous information [22] to obtain linguistic results close to human cognitive model. The processes of computing with words (CWW) [39,40] accomplished during the decision analysis process will be carried out, by a multi-step aggregation procedure that considers the interaction among the evaluated criteria and the relevance of the different reviewers. Finally, the paper shows a real case study to illustrate the usefulness and effectiveness of the proposed model.

The paper is organized as follows. Section 2 describes the relationship between decision analysis and evaluation problems. Section 3 reviews a CWW approach based on linguistic 2-tuple model to deal with heterogeneous information. Section 4 presents a novel heterogeneous model for 360-degree performance appraisal. Section 5 shows a real case study of the proposed model. Finally, in Section 6 some conclusions are pointed out.

2. Decision analysis and evaluation process

Decision analysis [12] is a discipline, belonging to Decision Theory, that has been successfully applied to solve evaluation problems in some different fields such as sustainable energy [25,44], promotion tools [24], supplier selection [10], quality of service [45], digital libraries [8], evaluation of systems [38,42] and new product development [32,33].

The goals of an evaluation process consist of computing a set of overall assessments that summarizes the information gathered and provides useful information about the set of evaluated elements. To do so, it is necessary to establish a set

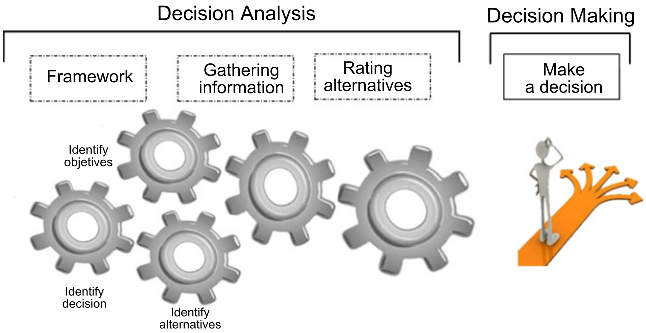

Fig. 2. Decision making scheme.

of evaluated elements in the evaluation framework, gather the information and finally, compute a final assessment for each element. Therefore, it is obvious that decision analysis is an excellent tool for evaluation, since it includes a wide variety of methods for evaluating a set of alternatives, considering all relevant criteria in a decision problem and involving experts [35].

Thereby, decision analysis methods provide a rational analysis in a simple and quick way, since the highest final assessment would normally correspond to the best evaluated element [27]. A classical decision analysis scheme consists of the following phases (see Fig. 2 [12]):

- *Framework*: It defines the structure of the problem and the expression domains in which the preferences can be assessed.
- *Gathering information*: Decision makers provide their information.
- *Rating alternatives*: This phase obtains a collective assessment for each alternative.

Our proposal for an integral performance appraisal model is based on the classical decision analysis scheme and its accommodation to our problem is showed in Fig. 4. It is remarkable that our model is not focused on the decision making phase in order to provide a flexible phase (no necessarily objective) [4,23] in which the Human Resources Department shall make corresponding decisions according to the results obtaining in the rating process, company's policies, subjective or emotional aspects, etc.

3. Computing with words in a heterogeneous framework

CWW is a methodology in which objects of computation are words or sentences from a natural language. This methodology is based on a procedure that includes a translation phase and a retranslation phase [39,40,53], emulating human cognitive processes to make reasoning processes and decisions in environments of uncertainty and imprecision [57]. One common approach to model the linguistic information is the fuzzy linguistic approach [56] that uses the fuzzy sets theory [55] to manage the uncertainty and model the information, using linguistic variables [56]. In order to deal with linguistic variables is necessary to choose the appropriate linguistic descriptors for the term set and their semantics. There are different possibilities to carry out these selections (see [51,56]).

The CWW methodology considers that inputs and output results should be expressed in a linguistic domain to be close to human cognitive model (natural language) and provide interpretable and understandable results. This fact is key in performance appraisal where evaluation results are used to make hard decisions by the Human Resources Department. The *linguistic 2-tuple model* [21] and its extended approaches (see [16,20,22,37]) provide methods to deal with complex decision making problems, following the CWW methodology.

In our proposal, we consider a heterogeneous framework, in which the reviewers could use numerical, linguistic and interval-valued information. In this section, we review the extended approach based on the linguistic 2-tuple representation model [21] to deal with heterogeneous information presented in [22].

Fig. 3 shows a basic scheme of this approach, it is based on the unification of the heterogeneous information into a linguistic domain to accomplish computing processes with words, generating linguistic results.

3.1. Unification process

In this step the heterogeneous information is conducted into a linguistic domain, carrying out the following states:

1. *Transformation of the information into fuzzy sets in* $\bar{S}$.
   The heterogeneous information will be unified into a specific linguistic domain, called *Basic Linguistic Term Set* (BLTS) and noted as $\bar{S} = \{\bar{s}_0, \bar{s}_1, \ldots, \bar{s}_g\}$, that is selected with the aim of keeping as much knowledge as possible (see [22]). Each real number, interval value and linguistic value is then transformed into a fuzzy set on $\bar{S}$, $\mathcal{F}(\bar{S})$, using the corresponding transformation function [22].

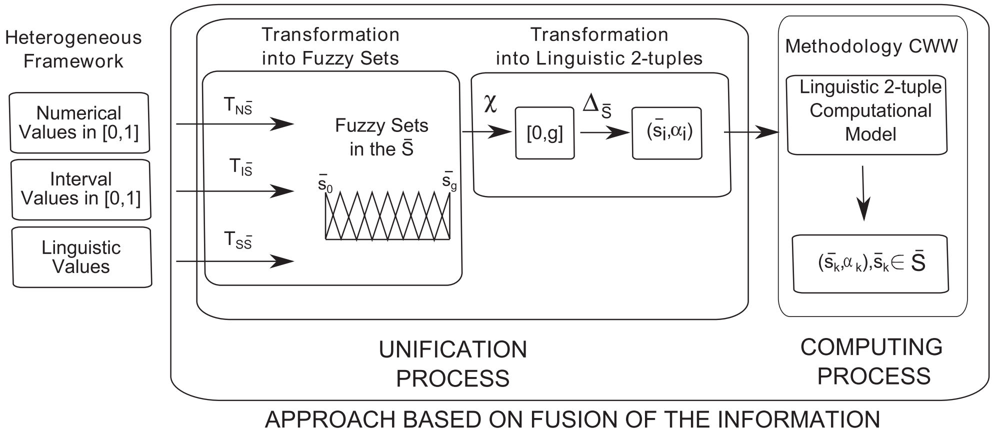

Fig. 3. Approach based on information fusion into linguistic values.

(a) Numerical domain. When $u \in [0,1]$, a numerical transformation function, $T_{N\bar{S}} : [0,\, 1] \rightarrow F(\bar{S})$, is defined by:

$$T_{N\bar{S}}(u) = \sum_{i=0}^{g} (\bar{s}_i/\gamma_i), \tag{1}$$

where $\gamma_i = \mu_{\bar{s}_i}(u) \in [0,\, 1]$ is the membership degree of u to $\bar{s}_i \in \bar{S}$.

(b) Interval domain. When $u \in P([0,1])$, an interval transformation function, $T_{I\bar{S}} : P([0,\, 1]) \rightarrow F(\bar{S})$, is defined by:

$$T_{I\bar{S}}(u) = \sum_{i=0}^{g} (\bar{s}_i/\gamma_i), \tag{2}$$

where $\gamma_i = \max_y \min\{\mu_I(y), \mu_{\bar{s}_i}(y)\},\ i = 0, \ldots, g$, and

$$\mu_I(y) = \begin{cases} 0 & \text{if } y < d, \\ 1 & \text{if } d \leqslant y \leqslant e, \\ 0 & \text{if } y > e. \end{cases} \tag{3}$$

being $y \in [0,1]$.

(c) Linguistic domain. Being $u \in S$, such that $S = \{s_j,\ j = 1, \ldots, h\}$ and $h \leqslant g$, a linguistic transformation function, $T_{S\bar{S}} : S \rightarrow F(\bar{S})$, is defined by:

$$T_{S\bar{S}}(u) = \sum_{i=0}^{g} (\bar{s}_i/\gamma_i), \tag{4}$$

where $\gamma_i = \max_y \min\{\mu_{s_j}(y), \mu_{\bar{s}_i}(y)\},\ i = 0, \ldots, g$.

2. *Transformation of fuzzy sets*, $F(\bar{S})$, *into linguistic 2-tuples in* $\bar{S}$.

The previous fuzzy sets are conducted into linguistic 2-tuples which facilitate the processes of CWW and produce interpretable results [21]. The linguistic 2-tuple representation model is based on the concept of *symbolic translation* [21] and represents the linguistic information through a 2-tuple (s, α), where $s \in S = \{s_0, \ldots, s_g\}$ is a linguistic term and α is a numerical value representation of the symbolic translation [21].

Thereby, being $\beta \in [0, g]$ the value generated by a symbolic aggregation operation, we can assign a 2-tuple (s, α) that expresses the equivalent information of that given by β.

Definition 1 [21]. Let $S = \{s_0, \ldots, s_g\}$ be a set of linguistic terms. The *2-tuple set associated with S* is defined as $\langle S \rangle = S \times [-0.5, 0.5)$. We define the function Δ_S: $[0, g] \rightarrow \langle S \rangle$ given by,

$$\Delta_S(\beta) = (s_i, \alpha), \quad \text{with} \begin{cases} i = \text{round } (\beta), \\ \alpha = \beta - i, \end{cases} \tag{5}$$

where *round* assigns to β the integer number $i \in \{0, 1, \ldots, g\}$ closest to β.

We note that Δ_S is bijective [21] and $\Delta_S^{-1} : \langle S \rangle \to [0, g]$ is defined by $\Delta_S^{-1}(s_i, \alpha) = i + \alpha$. In this way, the 2-tuples of $\langle S \rangle$ will be identified with the numerical values in the interval [0, g].

As aforementioned, fuzzy sets obtained previously, $F(\overline{S})$, are transformed into linguistic 2-tuples in the $\overline{S}$ at this stage by using the function χ defined as:

Definition 2 [22]. Given the linguistic term set $S = \{s_0, s_1, \ldots, s_g\}$, the function $\chi : \mathcal{F}(S) \to \langle S \rangle$ is defined by

$$\chi(\{\gamma_0, \gamma_1, \ldots, \gamma_g\}) = \Delta_S\left(\frac{\sum_{j=0}^{g} j\gamma_j}{\sum_{j=0}^{g}\gamma_j}\right) = (s_i, \alpha) \in S. \tag{6}$$

3.2. Computing process

The linguistic 2-tuple representation model has a linguistic computing model associated that accomplishes CWW processes in a precise way. Different aggregation operators have been proposed for linguistic 2-tuple [47,48,54]. In our proposal we will use the ordered weighted average operator, the weighted arithmetic average operator and the Choquet integral for linguistic 2-tuple.

4. A 360-degree performance appraisal model

Our aim in this paper is to present a novel integrated model for 360-degree performance appraisal based on a decision analysis scheme with a flexible evaluation framework in which reviewers can express their judgments in different domains, whose results are linguistically expressed and the evaluation model considers the interaction among the evaluated criteria, their relevance and the importance of the reviewers.

To do so, the 360-degree performance appraisal model consists of the phases shown in Fig. 4 that cover the essential phases of decision analysis [12]. The following subsections present in further detail these phases of the performance appraisal model.

4.1. Heterogeneous evaluation framework

In this phase, the evaluation framework establishes the structure of the 360-degree performance appraisal process. It is necessary to define the main features and terminology of this process in which employees are evaluated from different points of view, by using multiple expression domains.

Let us suppose there is a set of employees $X = \{x_1, \ldots, x_n\}$ to be evaluated by three collectives: a set of supervisors (executive staff) $A = \{a_1, \ldots, a_r\}$, a set of collaborators (fellows) $B = \{b_1, \ldots, b_s\}$ and a set of customers $C = \{c_1, \ldots, c_t\}$. Employees will be evaluated attending to a set of criteria $Y = \{Y_1, \ldots, Y_p\}$.

The assessments provided by the members of the collectives $a_i \in A$, $b_i \in B$ and $c_i \in C$ about the employee x_j, according to the criterion Y_k are denoted by a_j^{ik}, b_j^{ik} and c_j^{ik}, respectively. Moreover, x_j^{jk} is the assessment of x_j about himself with respect to Y_k.

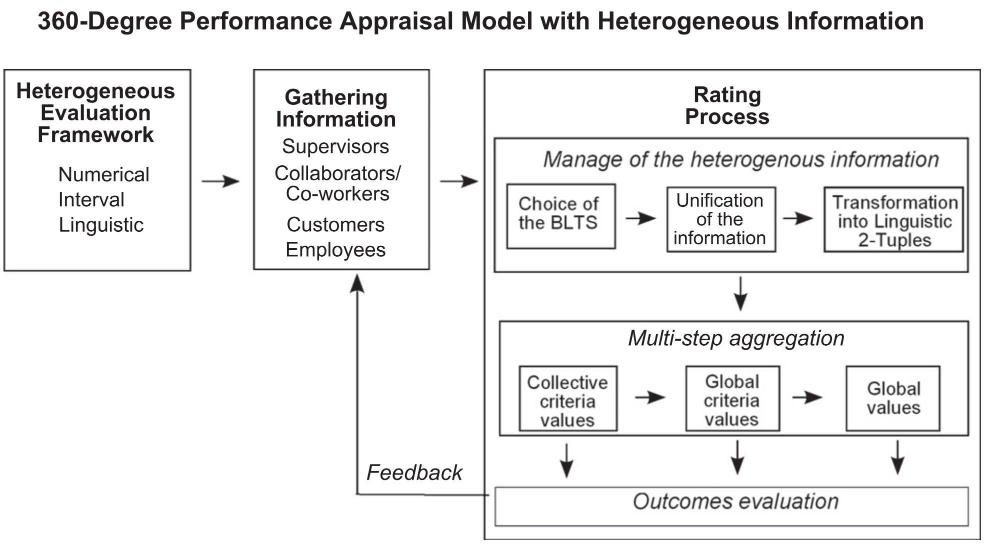

Fig. 4. A 360-degree performance appraisal model.

Therefore, we consider an heterogeneous evaluation framework in which each collective of reviewers can use different domains to assess each criterion Y^k, $k = 1,\ldots,p$, depending on either the nature of the criteria or the reviewer's background, degree of knowledge, perceptions and feelings about the evaluated employees. Our model includes in the heterogeneous evaluation framework: numerical values, interval-values, and linguistic values with different granularity, i.e., linguistic term sets with different numbers of terms.

4.2. Gathering information

Once the framework has been defined, the reviewers of the different collectives provide their judgments in a numerical, interval or linguistic domain for the evaluated employees, x_j, $j = \{1,\ldots,n\}$ and the evaluated criteria Y_k, $k = \{1,\ldots,p\}$. The opinions of each collective are provided by means of assessment vectors: $\left\{\hat{a}_j^{i1},\ldots,\hat{a}_j^{ip}\right\}$ with $i \in \{1,\ldots,r\}$ for supervisors, $\{\hat{b}_j^{i1},\ldots,\hat{b}_j^{ip}\}$ with $i \in \{1,\ldots,s\}$ for collaborators, $\{\hat{c}_j^{i1},\ldots,\hat{c}_j^{ip}\}$ with $i \in \{1,\ldots,t\}$ for customers, and finally, $\left\{\hat{x}_j^{j1},\ldots,\hat{x}_j^{jp}\right\}$ for the evaluated employee.[1]

4.3. Rating process

The aim of this process is to obtain a linguistic global assessment for each employee, easy to understand and interpretable to make right decisions by the company.

To do so, the heterogeneous information will be conducted into a linguistic domain by using the approach reviewed in Section 3. The linguistic information will be aggregated in multiple-stages to obtain intermediate and global assessments for the performance of each evaluated employee. In such an aggregation process it will be considered the weighting and relevance of the different collectives and criteria, as well as the interaction among the evaluated criteria. Eventually, the different linguistic results obtained across the aggregation process will be analyzed by the Human Resources Department.

The following subsections present in detail the rating process phases that were graphically described in Fig. 4.

4.3.1. Unification of heterogeneous information

According to the approach reviewed in Section 3, the heterogeneous information is conducted into a linguistic domain. To do so, the unification domain, $\bar{S}$, is chosen [22]. The heterogeneous information is then conducted by fuzzy sets on $\bar{S}$ according to the expression domain, by using the respective transformation functions (see Eqs. (1), (2) and (4)). In order to facilitate the understandability of the results, the fuzzy sets are transformed in $\bar{S}$ into linguistic 2-tuples, $\langle\bar{S}\rangle$, by using Eqs. (5) and (6) (see Fig. 3).

In this way, the heterogeneous information provided by the different collectives has been already unified into linguistic 2-tuples in $\bar{S}$:

- $\left\{a_j^{i1},\ldots,a_j^{ip}\right\},\ i \in \{1,\ldots,r\}$ with $a_j^{ik} = (\bar{s}_i, \alpha_i)_j^{ik} \in \langle\bar{S}\rangle$.
- $\left\{b_j^{i1},\ldots,b_j^{ip}\right\},\ i \in \{1,\ldots,s\}$ with $b_j^{ik} = (\bar{s}_i, \alpha_i)_j^{ik} \in \langle\bar{S}\rangle$.
- $\left\{c_j^{i1},\ldots,c_j^{ip}\right\},\ i \in \{1,\ldots,t\}$ with $c_j^{ik} = (\bar{s}_i, \alpha_i)_j^{ik} \in \langle\bar{S}\rangle$.
- $\left\{x_j^{j1},\ldots,x_j^{jp}\right\}$ with $x_j^{jk} = (\bar{s}_i, \alpha_i)_j^{jk} \in \langle\bar{S}\rangle$.

4.3.2. Multi-step aggregation process

The main objective of the performance appraisal process is to obtain a global assessment for each evaluated employee that summarizes her/his performance, considering the interaction among criteria and reviewers weights.

Our integrated model proposes the aggregation of the unified information into linguistic 2-tuples by means of a multi-step aggregation process [9], in which an adequate set of aggregation operators is utilized to integrate the interaction among criteria and the relevance and importance of the different collectives, according to the needs and objectives of the Human Resources Department (see Fig. 5). The intermediate and final assessments will be expressed in a linguistic domain that facilitates their interpretation and understandability.

A point worthy of mention is that usually the opinions of employees about themselves are not included in the aggregation process because can bias the result of the process. These opinions are used by companies in the rating phase with the purpose of improving their performance and synchronizing companies goals with employees goals (see Fig. 4). This part of the performance appraisal procedure is so-called *feedback* and *coaching process* [17]. Following, we present in further detail each stage of the multi-step aggregation process.

4.3.2.1. Computing collective criteria values, $v_{\_}^k(x_j)$. In this stage, we obtain for each employee an assessment for each collective and for each criterion. These assessments are computed by means of the *2-tuple OWA operator*, G^w. We suggest this

[1] We denote $\hat{}$ as the assessment in an expression domain (numerical, interval-valued or linguistic), according to the uncertainty and nature of criteria as well as the background of each reviewer.

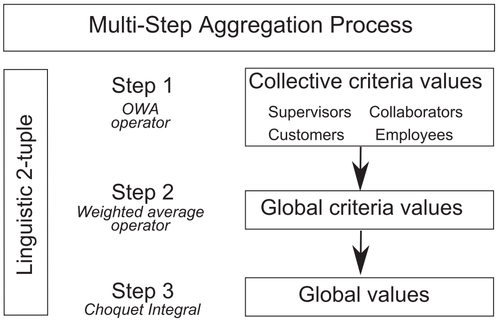

Fig. 5. Multi-step aggregation process.

aggregation operator because it is anonymous and it does not distinguish the origin of the assessments, since the weight is not associated to a particular reviewer, but to the magnitude of his/her assessment.

The 2-tuple OWA operator needs a weighting vector that can be determined by different methods based on weight generating functions. Yager [50,52] proposed the use of monotone continuous functions as *regular increasing monotone* (RIM) quantifiers [50] that facilitate to express the concept of fuzzy majority, namely: *for all*, *there exists*, *identity*, *most*, *at least half*, *as many as possible*, etc. These functions allow generate OWA weights for any number of inputs. It is important to note that each aggregation procedure, across this multi-step process, with OWA operators can use different linguistic quantifiers. In our proposal, linguistic quantifiers will be established by the Human Resources Department.

Definition 3 [21]. Let $((s_1, \alpha_1),\ldots,(s_m, \alpha_m)) \in \langle S\rangle$ be a vector of linguistic 2-tuples, and $w = (w_1,\ldots,w_m)$, $w_i \in [0,1]$ be a weighting vector such that $\sum_{i=1}^{m} w_i = 1$. The *2-tuple OWA operator associated with w* is the function G^w: $\langle S\rangle^m \to \langle S\rangle$ defined by

$$G^{\boldsymbol{w}}((s_1,\alpha_1),\ldots,(s_m,\alpha_m)) = \Delta_{\bar{S}}\left(\sum_{i=1}^{m} w_i\beta_i^*\right) = (s_l,\alpha_l) \in \langle S\rangle,$$

where β_i^* is the ith largest element of $\{\Delta_S^{-1}(s_1,\alpha_1),\ldots,\Delta_S^{-1}(s_m,\alpha_m)\}$.

Under these assumptions, the supervisors' assessment about criterion k, regarding the employee x_j, $\upsilon_A^k(x_j)$ is computed by the function $G_{A,k}^w : \langle\bar{S}\rangle^r \to \langle\bar{S}\rangle$ defined by

$$\upsilon_A^k(x_j) = G_{A,k}^w\left(a_j^{1k},\ldots,a_j^{rk}\right) \in \langle\bar{S}\rangle,$$

where $a_j^{ik} \in \langle\bar{S}\rangle$ for $i = 1\ldots r$ are linguistic 2-tuples belong to $\bar{S}$.

In the same way, it is possible to obtain the collective criteria assessments about the criterion Y_k for the others reviewers' collectives: $\upsilon_B^k(x_j)$ (collaborators), $\upsilon_C^k(x_j)$ (customers), and $\upsilon_X^k(x_j)$ (evaluated employees themselves).

4.3.2.2. Computing global criteria values, $\upsilon^k(x_j)$. In this step of the aggregation process, a global criteria assessment for each employee is computed by aggregating the previous collective assessments for each collective by means of a *2-tuple weighted average operator* to obtain a global value for each criterion and for each employee. We propose this operator to aggregate the information because it allows companies to establish different weights for each reviewers' collective, taking into account their knowledge about the evaluated criteria and their significance in the performance appraisal process.

Definition 4 [21]. Let $((s_1, \alpha_1),\ldots,(s_m, \alpha_m)) \in \langle S\rangle$ be a vector of linguistic 2-tuples, and $w = (w_1,\ldots,w_m)$,$w_i \in [0,1]$ be a weighting vector such that $\sum_{i=1}^{m} w_i = 1$. The *2-tuple weighted average operator* associated with w is the function F^w: $\langle S\rangle^m \to \langle S\rangle$ defined by

$$F^{\boldsymbol{w}}((\bar{s}_1,\alpha_1),\ldots,(\bar{s}_m,\alpha_m)) = \Delta_S\left(\sum_{i=1}^{m} w_i\Delta_S^{-1}(s_i,\alpha_i)\right) = (s_l,\alpha_l) \in \langle S\rangle.$$

The collective assessments then obtained in the previous step, $\upsilon_A^k(x_j)$, $\upsilon_B^k(x_j)$ and $\upsilon_C^k(x_j)$ for every $k \in \{1,\ldots,p\}$, are aggregated by $F_k^{\boldsymbol{w}} : \langle\bar{S}\rangle^3 \to \langle\bar{S}\rangle$, where $\boldsymbol{w} = (w_A, w_B, w_C)$ and $\sum w_- = 1$, obtaining a global value for each criterion Y_k modeled by a linguistic 2-tuple:

$$\upsilon^k(x_j) = F_k^{\boldsymbol{w}}\left(\upsilon_A^k(x_j), \upsilon_B^k(x_j), \upsilon_C^k(x_j)\right) \in \langle\bar{S}\rangle.$$

As we have previously mentioned, even though the opinion of each employee about her/himself, $\upsilon_X^k(x_j)$ can be useful for the organization, we do not take into account this information in the aggregation process.

4.3.2.3. Computing a global value, $v(x_j)$. At this stage, a global assessment for each employee regarding all criteria is computed, taking into account the *interaction among them*, $v(x_j)$. This value is obtained by aggregating the global criteria values related to each employee $x_j \in X$, by means of a *Choquet integral* [11] that considers the mutual interaction among criteria. The Choquet integral has been successfully applied to different problems [6,7,45].

To show the interaction among criteria in the problem, let us take a classical example provided (see [18]) of evaluating students with respect to three subjects (criteria): statistics, probability, and literature. Obviously, the first two criteria are related one to another since, usually, students good at statistics are also good at probability and vice versa. Thus, these two criteria present some degree of redundancy.

In performance appraisal may be common the interaction among the evaluated criteria. Thus, we propose the use of the Choquet integral which requires fuzzy measures [46] that represent the interaction among criteria. In our model, the relationship among criteria, their importance and constraints are provided by Human Resources experts in order to compute fuzzy measures by using optimization methods (see [5,26], among others).

Definition 5 [46]. Let $N = \{1,\ldots,m\}$ be a set of m criteria. A *fuzzy measure* is a set function ϕ: $2^N \to [0,1]$ that satisfies the following conditions:

- $\phi(\emptyset) = 0$, $\phi(N) = 1$
- $\phi(S) \leqslant \phi(T)$ whenever $S \subseteq T$ (ϕ is monotonic).

Considering the previous definition and due to the fact that our model manages assessments into linguistic 2-tuples in order to provide intermediate and final results easy to interpret, the linguistic 2-tuple Choquet integral will be used in this stage as aggregation operator.

Definition 6 [54]. Let $((s_1, \alpha_1),\ldots,(s_m, \alpha_m)) \in \langle S\rangle^m$ be a vector of linguistic 2-tuples, N be the set of attributes and ϕ be a fuzzy measure on [0,1], the *linguistic 2-tuple Choquet integral* is given by $M_\phi : \langle \bar{S}\rangle^m \to \langle \bar{S}\rangle$

$$M_\phi((s_1,\alpha_1),\ldots,(s_m,\alpha_m)) = \Delta_S\left(\sum_{i=1}^{n}\left[(\phi(H)_{\sigma(i)}) - (\phi(H)_{\sigma(i-1)})\right]\Delta_S^{-1}(s_i,\alpha_i)\right),$$

where $(\sigma(1),\sigma(2),\ldots,\sigma(m))$ is a permutation of $(1,2,\ldots,m)$ such that $((s_{\sigma(1)}, \alpha_{\sigma(1)}) \geqslant (s_{\sigma(2)},\alpha_{\sigma(2)}) \geqslant \ldots \geqslant (s_{\sigma(m)}, \alpha_{\sigma(m)}))$, being $x_{\sigma(i)}$ the criterion corresponding to the $(s_{\sigma(1)}, \alpha_{\sigma(1)})$ and $(H)_{\sigma(i)} = \{x_{\sigma(k)} | k \leqslant i\}$ for $i \geqslant 1$ with $(H)_{\sigma(0)} = \emptyset$.

Therefore, the last stage of the multi-step aggregation process is carried out as follows:

$$v(x_j) = M_\phi(v^1(x_j), v^2(x_j), \ldots, v^p(x_j)) \in \langle \bar{S}\rangle.$$

It is noteworthy that our integrated model provides linguistic results at all the stages. These results are close to human cognitive model making more them understandable and interpretable by the multiple members of the company as required by the Human Resources Department.

4.3.3. Rating phase: outcomes evaluation

Usually, the global assessments are used by the company in order to apply some specific policies. Furthermore, when the final assessment is not sufficient or when the Human Resources Department requires intermediate assessments, the outcomes for each employee obtained in each stage of the multi-step aggregation process are evaluated or checked.

The intermediate and final assessments, provided by the proposed model, are expressed in a linguistic domain easy to interpret, since these assessments will be used to evaluate employees' outcomes according to companies' goals: developmental uses, administrative uses, organizational maintenance and documentation (see [1,29,31,41], among others).

Moreover, if needed or required by the Human Resources Department orders and rankings of employees might be obtained by using the intermediate and final linguistic assessments depending on the necessities required.

Finally, the opinions of employees about themselves $v_X(x_j)$ are used in order to improve their performance and synchronizing companies' goals with employees' goals (feedback and coaching process, see Fig. 4) [17].

5. Case study

In this section, we show a real case study to show the usefulness and effectiveness of the proposed integrated model that can manage a heterogenous evaluation framework and provides linguistic assessments in order to be close to human cognitive model, while considering the interaction among criteria and reviewers relevances. This case study has been conducted through a software prototype that includes the proposed model to support the development of a integral evaluation process.[2]

[2] The integral evaluation software prototype can be found in http://serezade.ujaen.es:8080/mspev2.

5.1. Heterogeneous evaluation framework

We have developed our study on a well-known multinational clothing company, which each month carries out an integral evaluation process over their employees in each store. Our case study involves opinions from supervisors, collaborators/co-workers, customers and employees themselves. Specifically, the reviewers' collectives are the following:

- A set of **supervisors** that, in the case of this company, is made up of three subset:
  1. The *area manager* subset: $A^A = \{a_1^A\}$.
  2. The *direct supervisors* subset: $A^D = \{a_1^D, a_2^D, a_3^D\}$.
  3. The *non-direct supervisors* subset: $A^{ND} = \{a_1^{ND}, a_2^{ND}, a_3^{ND}\}$.

Therefore, the collective of supervisors reviewers is defined as

$$A = A^A \cup A^D \cup A^{ND} \quad \text{where } A^A \cap A^D \cap A^{ND} = \emptyset.$$

- A set of **collaborators or/and co-workers** consists of:
  1. A subset of *selling employees*: $B^S = \left\{b_1^S, b_2^S, b_3^S, b_4^S, b_5^S, b_6^S, b_7^S\right\}$.
  2. A subset of *non-selling employees*: $B^{NS} = \left\{b_1^{NS}, b_2^{NS}, b_3^{NS}, b_4^{NS}\right\}$.

Consequently, the set of collaborators/co-workers reviewers is defined as

$$B = B^S \cup B^{NS}, \quad \text{where } B^S \cap B^{NS} = \emptyset.$$

- And finally, a set of **customers**: $C = \{c_1, \ldots, c_{20}\}$. Obviously, such an amount is not the total of customers that visited the shop for a month. We have selected twenty-representative of them with the purpose of simplifying the case study.

In this company, the employee's performance is characterized by eleven criteria $Y = \{Y_1, \ldots, Y_{11}\}$, which are shown below:

- Y_1: *Productivity*. This criterion is the amount of employee's sales divides among the employee's hour worked.
- Y_2: *Level of sales*. This criterion is the employee's sales amount.
- Y_3: *Average closing time*. After the closing time, each employee has to arrange a specific shop zone. This criterion measures how much it takes employee to arrange her/his zone.
- Y_4: *Identification with the company*. Identification with the product that company sales. Think company's values. Trust and defend the company. Like fashion.
- Y_5: *Training interest*. Positive attitude to learn and improve.
- Y_6: *Work tasks*. Open truck and alarmed. Organization of stock. Replacement of products. Coordinate and shape. Neat and clean work. Serve and sell in changing room.
- Y_7: *Customers service*. Available for posting. Always say hello. Thank the purchase.
- Y_8: *Responsibility*. Achieve daily work correctly. Not leave the shop before finishing work. Do tasks that are not her/his responsibility. Assume the consequences of her/his acts. Be always on time.
- Y_9: *Initiative*. Get in before work needs. Propose ideas and solutions. Make decisions within their responsibilities. Accept supervision. Help collaborators and co-workers.
- Y_{10}: *To serve as an example*. Fulfill all the shop rules and methods. Serve as a model for co-workers and collaborators. Be positive. Look forward solutions. Constructive attitude.
- Y_{11}: *Personal image*. Dresses stylishly. Be polite. Have pleasant manners. Dress with taste.

We can note that each group of reviewers express their opinions on selling employees about each criterion according to the uncertainty and nature of such criteria and the background of each reviewer, through a specific domain: numerical (N), interval (I) or linguistic (L). Specifically in this case study, reviewers can express their linguistic assessments in four linguistic domains with different number of terms $\{S^3, S^5, S^7, S^9\}$. Each linguistic term set is symmetrically and uniformly distributed and its syntax is as follows:

$$S^3 = \{\text{Null (N)},\ \text{Medium (M)},\ \text{Perfect (P)}\},$$

$$S^5 = \{\text{Null (N)},\ \text{Low (L)},\ \text{Medium (M)},\ \text{High (H)},\ \text{Perfect (P)}\},$$

$$S^7 = \{\text{Null (N)},\ \text{VeryLow (VL)},\ \text{Low (L)},\ \text{Medium (M)},\ \text{High (H)},\ \text{VeryHigh (VH)},\ \text{Perfect (P)}\},$$

$$S^9 = \{\text{Null (N)}, \text{AlmostNull (AN)}, \text{VeryLow (VL)}, \text{Low (L)}, \text{Medium (M)}, \text{High (H)}, \text{SlightlyHigh (SH)}, \text{VeryHigh (VH)}, \text{Perfect (P)}\}.$$

All reviewers do not evaluate all the criteria, as there are collectives that do not have sufficient knowledge to evaluate certain criteria. The collective of reviewers for each criterion and the expression domain used for evaluating are shown in Table 1.

Table 1
Reviewers' collective for each criterion.

		A^A	A^D	A^{ND}	B^S	B^{NS}	C
Cost	Y_1	N+					
	Y_2	N+					
	Y_3		N+				
Benefit	Y_4	S^7	S^7	S^7	S^5	S^5	
	Y_5	S^5	S^5	S^5			
	Y_6		S^9				
	Y_7	S^3	S^3	S^3	S^3	S^3	S^7
	Y_8		S^7				
	Y_9		S^7	S^7	S^3	S^3	
	Y_{10}	S^7	S^7	S^7		S^3	
	Y_{11}	S^5	S^5	S^5	S^5	S^5	S^3

5.2. Gathering information

Once the evaluation framework has been fixed, the reviewers express their opinions about evaluated employees. In this case study, we manage a great amount of information: 7 evaluated employees, 11 criteria and 38 reviewers, being 7 supervisors, 11 collaborators and 20 customers. Due to this fact, we omit the assessments provided by the reviewers about selling employees for the set of criteria in this paper, but it can be consulted in the additional material.[3]

5.3. Rating process

According to the integrated proposed model in Section 4, we carry out the three steps of the rating process.

5.3.1. Unification heterogeneous information

The heterogenous information is unified into a basic linguistic terms set, $\langle \bar{S} \rangle$. In our case study the $\langle \bar{S} \rangle$ corresponds to the linguistic terms set with nine labels, S^9, in order to keep as much knowledge as possible. This domain is key in our case study because the global assessments will be expressed in it in order to offer results easy to interpret, following the CWW methodology.

An important aspect to consider in our case study is that criteria Y_1, Y_2 and Y_3 are cost criteria. Therefore, preferences about these criteria must be normalized according to their expression domains. Once this is done, we unify the gathered information.[4]

5.3.2. Multi-step aggregation process

This stage computes a global and intermediate assessments for each selling employee in a multi-step aggregation process that considers an adequate set of aggregation operators in order to meet the needs of performance assessment according to the interaction among criteria and reviewers weights.

5.3.2.1. Computing collective criteria values. In the first step of this process, we apply the *2-tuple OWA operator*, which requires an *OWA weighting vector*. This vector can be determined by means of different ways, in our case study, the Human Resource Department uses a non-decreasing linguistic quantifiers [49], specifically, the linguistic quantifier *Most*.[5]

In this way, collectives' assessments for each selling employee about each criterion are computed and these are shown in Table 2.

5.3.2.2. Computing global criteria values. In the second step of this process, we apply the *linguistic 2-tuple weighted average operator*, which also requires a *weighting vector*. This vector is defined by the Human Resource Department, attending to the evaluated criterion and the reviewer collective. Therefore, global criteria values obtained with the weights fixed by Human Resource Department are shown in Table 3.

[3] The additional material associated provide all data about the case study. In addition, updated information about such case study can be found at the following URL: http://sinbad2.ujaen.es/index.php/es/verpublicaciones.

[4] The gathered information, its transformation into linguistic 2-tuples in the $\langle \bar{S} \rangle$ can be consulted in the additional material.

[5] The additional material provides the weighting vectors obtained by the quantifier.

Table 2
Collectives' assessments for each selling employee about each criterion.

	Collective	x_1	x_2	x_3	x_4	x_5	x_6	x_7
Y_1	A	$(SH, .3)$	$(SH, -.5)$	$(P, .0)$	$(VH, .2)$	$(M, -.4)$	$(H, .0)$	$(N, .0)$
Y_2	A	$(VH, -.5)$	$(SH, -.5)$	$(P, .0)$	$(VH, .0)$	$(L, .0)$	$(H, -.5)$	$(N, .0)$
Y_3	A	$(P, -.2)$	$(P, -.4)$	$(M, -.2)$	$(H, .4)$	$(AN, .2)$	$(L, .0)$	$(H, -.4)$
Y_4	A	$(SH, .1)$	$(M, -.2)$	$(H, -.2)$	$(VL, .1)$	$(M, .0)$	$(H, .2)$	$(VH, -.4)$
Y_4	B	$(SH, .0)$	$(M, .3)$	$(M, .3)$	$(AN, .3)$	$(L, .0)$	$(H, -.4)$	$(VH, -.3)$
Y_5	A	$(M, .2)$	$(H, -.3)$	$(L, .1)$	$(L, -.5)$	$(AN, .4)$	$(VL, .3)$	$(SH, .3)$
Y_6	A	$(SH, -.2)$	$(VH, .0)$	$(L, -.3)$	$(L, .2)$	$(SH, .0)$	$(M, .1)$	$(VH, -.2)$
Y_7	A	$(H, .4)$	$(M, .0)$	$(M, .0)$	$(L, -.2)$	$(M, .0)$	$(M, .0)$	$(VH, -.3)$
Y_7	B	$(H, .3)$	$(M, .0)$	$(L, -.4)$	$(VL, -.3)$	$(M, .0)$	$(M, -.5)$	$(VH, -.3)$
Y_7	C	$(L, .0)$	$(AN, .3)$	$(AN, -.5)$	$(AN, .3)$	$(AN, .3)$	$(H, .1)$	$(SH, .1)$
Y_8	A	$(SH, -.5)$	$(SH, -.5)$	$(L, -.3)$	$(L, -.4)$	$(L, -.3)$	$(AN, .2)$	$(VH, .3)$
Y_9	A	$(M, 0)$	$(L, -.3)$	$(AN, .4)$	$(VL, .3)$	$(H, -.4)$	$(SH, 0)$	$(SH, 0.4)$
Y_9	B	$(M, .0)$	$(M, .3)$	$(VL, .2)$	$(AN, .3)$	$(L, -.4)$	$(AN, .3)$	$(H, .3)$
Y_{10}	A	$(M, .0)$	$(L, -.4)$	$(L, -.4)$	$(AN, .0)$	$(AN, .2)$	$(AN, .2)$	$(L, -.4)$
Y_{10}	B	$(AN, .3)$	$(M, .0)$	$(AN, .3)$	$(AN, .3)$	$(VL, .4)$	$(VL, .4)$	$(H, .1)$
Y_{11}	A	$(SH, -.3)$	$(L, .1)$	$(M, .0)$	$(SH, .3)$	$(M, .0)$	$(H, .1)$	$(VH, .1)$
Y_{11}	B	$(H, -.4)$	$(VL, .3)$	$(L, .3)$	$(M, .3)$	$(L, .0)$	$(L, .3)$	$(SH, .2)$
Y_{11}	C	$(H, -.5)$	$(M, .0)$	$(L, 0.2)$	$(M, .0)$	$(M, .0)$	$(M, .0)$	$(SH, .1)$

Table 3
Global criteria and collectives weights fixed by Human Resource Department.

	x_1	x_2	x_3	x_4	x_5	x_6	x_7
Y_1	$(SH, .3)$	$(SH, -.5)$	$(P, .0)$	$(VH, .2)$	$(M, -.4)$	$(H, .0)$	$(N, .0)$
Y_2	$(VH, -.5)$	$(SH, -.5)$	$(P, .0)$	$(VH, .0)$	$(L, .0)$	$(H, -.5)$	$(N, .0)$
Y_3	$(P, -.2)$	$(P, -.4)$	$(M, -.2)$	$(H, .4)$	$(AN, .2)$	$(L, .0)$	$(H, -.4)$
Y_4	$(SH, 0)$	$(M, 0)$	$(H, -.5)$	$(VL, -.3)$	$(M, -.5)$	$(H, -.1)$	$(VH, -.4)$
Y_5	$(M, .2)$	$(H, -.3)$	$(L, .1)$	$(L, -.5)$	$(AN, .4)$	$(VL, .3)$	$(SH, .3)$
Y_6	$(SH, -.2)$	$(VH, .0)$	$(L, -.3)$	$(L, -.2)$	$(SH, .0)$	$(M, .1)$	$(VH, -.2)$
Y_7	$(M, .3)$	$(L, -.3)$	$(VL, -.1)$	$(VL, -.2)$	$(L, -.3)$	$(H, .4)$	$(SH, 0.4)$
Y_8	$(SH, -.5)$	$(SH, -.5)$	$(L, -.3)$	$(L, -.4)$	$(L, -.3)$	$(AN, .2)$	$(VH, .3)$
Y_9	$(M, 0)$	$(L, .1)$	$(VL, -.4)$	$(VL, 0)$	$(M, .1)$	$(H, -.2)$	$(SH, .1)$
Y_{10}	$(L, -.1)$	$(L, .2)$	$(VL, .1)$	$(AN, .1)$	$(VL, -.2)$	$(VL, -.3)$	$(M, -.4)$
Y_{11}	$(H, 0{-}.1)$	$(L, .1)$	$(M, -.5)$	$(H, -.2)$	$(M, -.4)$	$(M, .1)$	$(SH, .3)$

$$
\begin{array}{ll}
Y_1 : w_A = 1 & Y_2 : w_A = 1 \\
Y_3 : w_A = 1 & Y_4 : w_A = 0.5 \quad w_B = 0.5 \\
Y_5 : w_A = 1 & Y_5 : w_A = 1 \\
Y_7 : w_A = 0.25 \quad w_B = 0.25 \quad w_C = 0.5 & Y_8 : w_A = 1 \\
Y_9 : w_A = 0.75 \quad w_B = 0.25 & Y_{10} : w_A = 0.6 \quad w_B = 0.4 \\
Y_{11} : w_A = 0.33 \quad w_B = 0.33 \;\; w_C = 0.33 &
\end{array}.
$$

5.3.2.3. Computing a global value. This last step obtains a global value for each employee considering the *interaction among criteria*. To do so, the Choquet integral for linguistic 2-tuple is used with fuzzy measures computed with the information provided by the Human Resources Department.

In this case study the Human Resources Department expresses that criteria Y_1 and Y_2 are positively correlated, since they present some degree of complementarity. In the same way to the criteria Y_6, Y_7 and Y_8. Therefore, fuzzy measures used in the Choquet integral are the following:

$$
\begin{array}{llll}
\phi(Y_1) = 0.1 & \phi(Y_2) = 0.1 & \phi(Y_1, Y2) = 0.43 & \phi(Y_3) = 0.02 \\
\phi(Y_4) = 0.02 & \phi(Y_5) = 0.02 & \phi(Y_6) = 0.1 & \phi(Y_7) = 0.1 \\
\phi(Y_8) = 0.02 & \phi(Y_6, Y_7, Y_8) = 0.45 & \phi(Y_9) = 0.02 & \phi(Y_{10}) = 0.02 \\
\phi(Y_{11}) = 0.02 & & &
\end{array}.
$$

Table 4
Assessments for each selling employee.

x_1	x_2	x_3	x_4	x_5	x_6	x_7
$(H, .4)$	$(H, -.5)$	$(H, -.2)$	$(M, .3)$	$(L, .2)$	$(M, -.44)$	$(M, -.4)$

In other case: $\phi(S \bigcup T) = max\{\phi(S) + \phi(T)\}$, $S, T \in 2^Y$, $S \bigcap T = \emptyset$.

We can see that fuzzy measures computed represent the interaction expressed by the Human Resources Department, since $\phi(Y_1 \bigcup Y_2) > \phi(Y_1) + \phi(Y_2)$ and $\phi(Y_6 \bigcup Y_7 \bigcup Y_8) > \phi(Y_6) + \phi(Y_7) + \phi(Y_8)$.

Finally, global values for each selling employees are computed, using the Choquet integral for linguistic 2-tuple, which are shown in Table 4.

In this phase of our case study, we have obtained linguistic results for each employee in each step of the multi-step aggregation process following the CWW methodology. These results are close to human cognitive model providing interpretability and understandability in natural language.

5.3.3. Rating phase: outcomes evaluation

Finally, we put in order all computed values with the purpose of identifying the best ones, using the final assessments.

In the case study, $(H, .4) = (High, .4) \in \langle \bar{S} \rangle$ is the highest global value and it corresponds to the employee x_1. Therefore, x_1 is the best selling employee for this evaluation. If a total ranking were required, this is as follows:

$$x_1 \succ x_3 \succ x_2 \succ x_4 \succ x_7 \succ x_6 \succ x_5.$$

Other analysis can be done about the obtained outcomes. So, if the Human Resources Department requires, it can obtain a order or ranking among evaluated employees, considering only one criterion. For example, the classification obtained, considering the criterion *personal image*, Y_{11}, is the following:

$$x_7 \succ x_1 \succ x_4 \succ x_6 \succ x_5 \succ x_3 \succ x_2.$$

6. Concluding remarks

Performance appraisal is a relevant process used for companies in order to make important decisions, such as promotions, salaries, and needs. In this paper, we have proposed an integrated 360-degree performance appraisal model that provides a flexible evaluation framework in which reviewers can provide their assessments within different domains, according to the uncertainty and nature of such criteria as well as the background of each reviewer. Moreover, with the aim of ensuring an effective aggregation of the information, the proposed model applies an adequate set of aggregation operators to cope with the interaction among criteria and reviewers weights, providing results close to human cognitive model by using the computing with words methodology in order to be understandable and interpretable by different members of the company. Finally, we have presented a real case study to show the usefulness and effectiveness of the integrated proposed model. Several questions remain open. Clearly, the implementation of a full operative software that includes the presented model to support the development of a integral evaluation process is one of them.

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