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Assessing suppliers in green supply chain based on a group compromise solution approach with interval-valued 2-tuple linguistic information

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Abstract *– The concept regarding green supply chain management developed as a response in order to increase public awareness from environmental stability which regularly holds both the environment and supply chain management. In the past few years, green supply chain management has become a challenging issue in advanced operations research. In a manufacturing company, selecting an appropriate supplier for their long-term growth prospects by the supply chain managers not only proceed with the business strategy but also help the company remain in a competing position. Considering multiple criteria group decision-making (MCGDM) problem in order to solve the green supplier selection (GSS) includes many unmeasurable and contradictory criteria. This research presents a new group decision approach via interval-valued 2-tuple linguistic preferences and compromises solution to appraise the GSP. The falsification and loss of information which happens formerly in the probabilistic linguistic information process are avoided. Next, a real application is provided via the introduced approach under uncertain conditions regarding the recent literature in the manufacturing industry. Finally, for validation, sensitivity and comparative analyses and a discussion on the effectiveness and benefits of the introduced method are completed and provided.*

Keywords*– Interval valued 2-Tuple information, Linguistic Preferences, Group compromise solution Model, Assessing green suppliers.*

I. INTRODUCTION

As the world grows wealthy, people become more affluent, and living standards improve. However, many reckless manufacturing companies are seeking their economic interests while neglecting social responsibility and ecological balance. The method causes a lot of environmental difficulties, for example, water and noise pollution. Authorities around the world are taking practical steps at all levels in order to prevent environmental pollution. One of the acceptable measures among many policies is green production (Sivakumar et al., 2015), which has led the manager on achieving economic growth in many ways.

Manufacturing firms need to concern the green economy in their production and operation. They must regard the production quality, waste disposal, and energy recovery. Green supply chain management (GSCM) plays an essential role in sustainable development model in the modern manufacturing industry that takes into account the environment and SCM (Mumtaz et al., 2018). The findings indicate that in GSCM operations a green supplier needs to heavily concentrate on certain factors because the most important factors that are effective in selecting green suppliers are product

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design, green packaging, energy/material saving, resource recycling, cleaner production and constant green innovation (Qin et al., 2017). In a manufacturing company not only finding and selecting an appropriate supplier is a vital decision for proceeding the company's business strategy for the supply chain managers, but also surviving in a competing environment, and guaranteeing the future of the company is also a crucial decision (Bai & Sarkis, 2010). Therefore, the study on the topic mentioned above has notable theoretical and practical importance; green supplier selection has become a new widespread problem in advanced operations management. As the literature associated with supplier evaluation is excessive, assessing supplier evaluation using the environmental dial is restricted to some extent (Noci 1997, Handfield et al., 2002, Humphreys et al., 2006, Lee et al., 2009).

Concerning the last literature, fuzzy decision approach can be a useful tool for managers' evaluations in the related studies (e.g., Dorfeshan et al., 2018, Dorfeshan & Mousavi, 2019; Mousavi, 2019; Hashemi et al., 2018; Foroozesh et al., 2017, 2018, 2019; Mousavi et al., 2019; Mohagheghi and Mousavi, 2019); for green suppliers' assessment is examined the GSCM by (Shen et al., 2013, Dou et al., 2014) presented a grey multi-criteria decision-making (MCDM) model to distinguish green supplier development programs (GSDPs) that can successfully enhance suppliers' performance. (Ghorabaee et al., 2016) extended an incorporated approach in light of weighted aggregated sum product assessment (WASPAS) technique to manage MCDM problems via interval type-2 fuzzy sets (IT2FSs) for the GSCM. Awasthi and Kannan (2016) considered the matter of appraising GSDPs, and they presented a fuzzy VIKOR-based arrangement approach.

The survey indicates that most researches focused on decision methods for the GSCM by utilizing linguistic expressions based on fuzzy sets to handle uncertainties for real applications of GSCM. Hence, an approximation method can be regarded to represent the results with the primary expression area due to the outcomes maybe not precisely coordinate by primary linguistic variables (Herrera and Martínez, 2000, Zhang, 2012, Liu et al., 2013, Zhang, 2013, Liu et al., 2014). According to (Liu et al., 2015), interval-valued 2-tuple linguistic (IV2TL), information can deal with previous limitations adequately. DEMATEL and MAIRCA methods are integrated with ANP method in a rough environment in order to assess the appropriate green suppliers in the electronics industry by (Chatterjee et al., 2018). A study is suggested to utilize the fuzzy inference system for appraising GSCM performance of paint companies as far as green criteria by (Pourjavad and Shahin, 2018). A pragmatic mix fuzzy multi-criteria decision-making approach including fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS methods is designed for measuring throughout the green performance of companies through a case study by (Uygun and Dede, 2016).

Suppliers' performances are rated in light of green practices such as environmental management and pollution control, cost, quality, and flexibility, handling the fuzzy-extended Elimination and Choice Expressing Reality procedure by (Kumar et al., 2017). A VIKOR method is developed in order to employ a group multi-criteria supplier selection under interval 2-tuple linguistic preferences are employed in three realistic examples by (You et al., 2015). Several 2-tuple linguistic integration operators on the basis of Muirhead mean are extended, which is integrated with multiple attributes group decision making (MAGDM) for choosing proper supplier from 2-tuple linguistic concept by Qin and Liu, 2016). Analytic hierarchy process (AHP) has been used under fuzzy 2-tuple to assess suppliers in segmentation model applied for the pharmaceutical supply center (PSC) of a teaching hospital by (Santos et al., 2017).

To overcome dealing with various multi-granulation issues, an extended 2-tuple interval transformation function and a new flexible interval 2-tuple ranking function are presented which is useful toward collecting and merging information and achieving the ranking results in a single-step method respectively. Normalized generalized interval 2-tuple distance is considered relying on the previous distance measures. Moreover, in order to select green suppliers, an interval 2-tuple is provided using the TODIM procedure (Liang et al., 2019).

In a supplier selection problem studied by (Lei et al., 2020), the probabilistic linguistic-MAGDM including incomplete weight information was investigated. In the proposed approach, the linguistic term sets (LTSs) are transformed into probabilistic linguistic term sets (PLTSs). For determining the weight information of the attribute, an optimization model is built based on the fundamental idea of conventional TOPSIS technique, by which the attribute weights can be decided. In the computational study, authors have presented a case study for green supplier selection to illustrate the advantages of the developed procedure.

In a research presented by (Wang et al., 2018), they have extended Bonferroni mean (BM) operator, and in order to obtain a good supplier selection they have considered the MADM methods. The MADM methods are proposed with newly defined operators. In order to prove the efficiency of the proposed methods, a utilized applicable example for green supplier selection in GSCM is investigated. In a study presented by (Wu et al., 2019), a GSCM model has been illustrated in which both environmental and SCM are considered, in this study, an integrated procedure to address MCGDM problems relying on the best-worst and (VIKOR) method in an interval type-2 fuzzy environment has been presented. A GSS example is presented to illustrate the performance of the given procedure. Liu et al. (2019) have considered a green supplier selection problem. In this research, a novel GSS procedure is proposed by combining QFD with the PBM operator in the context of IT2FSs. In order to show the applicability of the presented procedure, a bike-sharing case has been considered.

The main merits of the decision method can be that the supply chain-experts may provide their judgments with linguistic term sets and several granularities of uncertainties, using an IV2TL which could express decision-makers' opinions via a prepared linguistic term set. Therefore, the introduced decision model through IV2TL information could be more adaptable and exact to handle linguistic terms in order to manage the performance appraisement problem in the GSCM. In order to conjoin the evaluation outcomes generated by different granularities, the 2-tuple transformation function was determined without loss of information (Dou et al., 2014). Furthermore, it is important to set an interval 2-tuple transformation function (I2TTF). It is important to note that, at the same time, few articles have concentrated on the interval 2-tuple ranking function (I2TRF) performance, which is crucial in terms of decision using interval 2-tuple linguistic environment. (Zhang, 2013) provided a combination of score and accuracy function for comparing interval 2-tuples, which concentrated on the median and width of an interval 2-tuple. Nevertheless, the ranking procedure needs considering two steps under some circumstances, which is inappropriate to some extent, resulting in a new I2TRF needed to be introduced (Herrera and Martínez., 2001, Zhang, 2012).

In this paper, an evaluation method for green supplier's performance is presented with a new decision-making model by IV2TL and compromise solution ideas. For this reason, another adaptation of technique for order preference by similarity to ideal solution (TOPSIS) is introduced with respect to performance evaluation problem. A novel relative closeness coefficient which better represents the separation of candidates with the IV2TL is presented for the evaluation process of the supplier's performance in the GSCM. Then, a real application via recent literature (Shen et al., 2013) in the manufacturing company is illustrated and computed by the introduced decision model under uncertainty. IT2FSs are potent tools in order to illustrate uncertainty and solve the aforementioned type of problems. Presented IT2FSs model derives from a survey and related interval procedures and hence absolutely matches with practice and is able to manage uncertainty much efficiently.

The structure of this paper is prepared as follows. Section 2 provides preliminaries on IV2TL information, and proposed decision model is given in Section 3. In section 4, an application and numerical results are presented. Finally, conclusions are reported in Section 5.

II. PRELIMINARIES

A. Tuple linguistic variables

Initially, the 2-tuple linguistic procedure could be introduced by (Herrera and Martínez, 2000) according to the symbolic translation concepts. This representation is utilized in terms of a linguistic 2-tuple (s, α) for demonstrating the linguistic information. s in this term means set S, and α is a numerical value illustrating the symbolic translation. $(s_i, \alpha_i), s_i \in S$ may be explained as a 2-tuple linguistic variable where s_i gives the central value of the ith linguistic expression, and α_i demonstrates the separation to the central value of the ith linguistic term. According to the 2-tuple linguistic procedure (Herrera and Martínez., 2000), the scope of β is in the vicinity 0 and g, that is identified to the granularity of the linguistic term sets. Hence, β can be the result of an aggregation concerning the indices regarding a set of labels appraised in a linguistic term set S.

Definition 1. Let $S = \{s_0, s_1, \dots, s_g\}$ be a linguistic term set and $\beta \in [0,1]$ a value describing the result of a symbolic aggregation operation. At that point, the generalized translation function Δ utilize to determine the 2-tuple linguistic variable equivalent to β will be presented as (Tai and Chen, 2009):

$$\Delta: [0,1] \rightarrow S \times \left[-\frac{1}{2g}, \frac{1}{2g}\right) \tag{1}$$

$$\Delta(\beta) = (s_i, \alpha), with \begin{cases} s_i, & i = round(\beta . g) \\ \alpha = \beta - \frac{i}{g}, & \alpha \in \left[-\frac{1}{2g}, \frac{1}{2g}\right) \end{cases} \tag{2}$$

where round $(\cdot)$ can be viewed as the standard rounding operation, s_i can have the closest index label to β, and α can be the value of the symbolic translation. The interval of α can be defined with number of linguistic variables at S. For example, consider S introducing seven linguistic terms; thus, $g = 6$ and $\alpha \in [-0.083, 0.083)$. if the consequence of a symbolic aggregation operation $\beta = 0.6$, then the representation of this counting of information by means of a 2-tuple will be $\Delta(0.6) = (s_4, -0.067)$. Graphical display of the aforementioned transformation is illustrated in Figure 1.

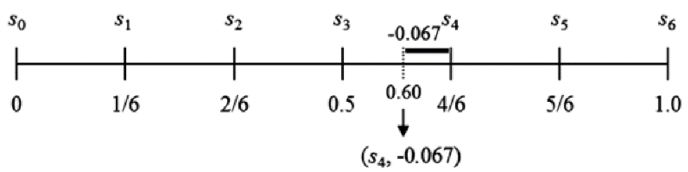

Fig. 1. Example of a symbolic translation computation

Definition 2. Allow $S = \{s_0, s_1, \dots, s_g\}$ be a linguistic term set and (s_i, α) be a 2-tuple. Consider a function Δ^{-1}, that can transform a 2-tuple linguistic variable to its equivalent numerical value $\beta \in [0,1]$. The reverse function Δ^{-1} is presented as (Tai and Chen, 2009):

$$\Delta^{-1}: S \times \left[-\frac{1}{2g}, \frac{1}{2g}\right) \rightarrow [0,1], \tag{3}$$

$$\Delta^{-1}(s_i, \alpha) = \frac{i}{g} + \alpha = \beta. \tag{4}$$

Transformation of a linguistic variable into a linguistic 2-tuple includes taking a value 0 as symbolic translation as (Herrera and Martínez, 2000):

$$s_i \in S \Rightarrow (s_i, 0) \tag{5}$$

Linguistic information comparison via 2-tuples is obtained based on an ordinary lexicographic order.

Definition 3. Let $X = \{(r_1, \alpha_1), (r_2, \alpha_2), \dots, (r_n, \alpha_n)\}$ can be a set of 2-tuples and $w = (w_1, w_2, \dots, w_n)^T$ be their associated weights, with $w_i \in [0,1]$, $i = 1,2,\dots,n$, $\sum_{i=1}^{n} w_i = 1$. The 2-tuple weighted average (TWA) may be presented as (Herrera and Martínez, 2000).

B. Interval 2-tuple linguistic variables

By definitions in Zhang (2012), an interval 2-tuple linguistic representation procedure is suggested as a generalization of the 2-tuple linguistic variable.

Definition 4. Assume $S = \{s_0, s_1, \dots, s_g\}$ as a linguistic term set. An interval 2-tuple linguistic variable includes two 2-tuples as $[(s_i, \alpha_1), (s_j, \alpha_2)]$, where $i \le j$ and $\alpha_1 \le \alpha_2$ and $s_i(s_j)$ and $\alpha_1(\alpha_2)$ describe the linguistic label of the predefined linguistic term set S and symbolic translation, respectively. The interval 2-tuple that describes the equivalent information to an interval value $[\beta_1, \beta_2](\beta_1, \beta_2 \in [0,1], \beta_1 \le \beta_2)$ is proposed by the following function follows (Zhang, 2012; Zhang, 2013):

$$\Delta[\beta_1, \beta_2] = [(s_i, \alpha_1), (s_j, \alpha_2)], \qquad with \begin{cases} s_i, & i = round(\beta_1 . g) \\ s_j, & i = round(\beta_2 . g) \\ \alpha_1 = \beta_1 - \dfrac{i}{g}, & \alpha_1 \in \left[-\dfrac{1}{2g}, \dfrac{1}{2g}\right) \\ \alpha_2 = \beta_2 - \dfrac{i}{g}, & \alpha_2 \in \left[-\dfrac{1}{2g}, \dfrac{1}{2g}\right) \end{cases} \tag{7}$$

Contrariwise, exist a function Δ^{-1}such that an interval 2-tuple can be converted into an interval value $[\beta_1, \beta_2](\beta_1, \beta_2 \in [0,1], \beta_1 \le \beta_2)$ as follows:

$$\Delta^{-1}[(s_i, \alpha_1), (s_j, \alpha_2)] = \left[\alpha_1 + \frac{i}{g}, \alpha_2 + \frac{i}{g}\right] = [\beta_1, \beta_2] \tag{8}$$

If $s_i = s_j$ and $\alpha_1 = \alpha_2$, then the interval 2-tuple linguistic term decrease to a 2-tuple linguistic term.

Definition 5. Let $\tilde{A} = \{[(r_1, \alpha_1), (t_1, \varepsilon_1)], \dots \dots, [(r_n, \alpha_n), (t_n, \varepsilon_n)]\}$ be a set of interval 2-tuples and $w = (w_1, w_2, \dots, w_n)^T$ be the related weights, with $w_i \in [0,1]$, $i = 1,2,\dots,n$, $\sum_{i=1}^{n} w_i = 1$. The interval 2-tuple weighted average (ITWA) operator will be presented as follows (Zhang, 2012; Zhang, 2013):

$$\mathrm{ITWA}([(r_1, \alpha_1), (t_1, \varepsilon_1)], \dots, [(r_n, \alpha_n), (t_n, \varepsilon_n)]) = \Delta\left[\frac{1}{n}\sum_{i=1}^{n} w_i \Delta^{-1}(r_i, \alpha_i), \frac{1}{n}\sum_{i=1}^{n} w_i \Delta^{-1}(t_i, \varepsilon_i)\right] \tag{9}$$

Definition 6. Assume a $\tilde{a} = [(r_1, \alpha_1), (t_1, \varepsilon_1)]$ and $\tilde{b} = [(r_2, \alpha_2), (t_2, \varepsilon_2)]$ as two interval 2-tuples, then

$$d(\tilde{a}, \tilde{b}) = \Delta\sqrt{\frac{1}{2}\left[\left(\Delta^{-1}(r_1, \alpha_1) - \Delta^{-1}(r_2, \alpha_2)\right)^2 + \left(\Delta^{-1}(t_1, \varepsilon_1) - \Delta^{-1}(t_2, \varepsilon_2)\right)^2\right]} \tag{10}$$

is named the normalized Euclidean distance between $\tilde{a}$ and $\tilde{b}$.

III. PROPOSED GREEN SUPPLIER'S EVALUATION APPROACH

A new decision approach is presented for evaluating green suppliers with interval 2-tuple linguistic variables. Considering an assessment problem, assume there are p members $DM_k (k = 1, 2, \dots, p)$ in supply chain-experts accountable for the assessment of *m* green suppliers candidates X_i $(i = 1, 2, \dots, m)$ in terms of *n* factors or criteria C_j $(j = 1, 2, \dots, n)$. Each supply chain expert is provided with a weight $\vartheta_k > 0$ $(k = 1, .., p)$ satisfying $\sum_{k=1}^{p} \vartheta_k = 1$ to describe his/her relative importance in the supply chain. $Y_k = \left(Y_{ij}^k\right)_{m\times n}$ can be the linguistic decision matrix of the kth supply chain decision-makers, where Y_{ij}^k is the linguistic evaluation reported by DM_k on the evaluation of X_i in terms of C_j. Assume w_j^k as the linguistic weight C_j presented by DM_k to describe its relative importance in the designation of factors in the green suppliers evaluation. Moreover, supply chain decision-makers can utilize several linguistic term sets to describe their judgments. The steps of the recommended decision procedure are presented as the following:

Step 1: Transform the linguistic decision matrix $Y_k = \left(Y_{ij}^k\right)_{m\times n}$ into an interval 2-tuple linguistic decision matrix $\tilde{R}_k = \left(\tilde{r}_{ij}^k\right)_{m\times n} = \left(\left[r_{ij}^k, 0\right], \left[t_{ij}^k, 0\right]\right)_{m\times n}$, where r_{ij}^k ; $t_{ij}^k \in S$; $S = \{s_i | \, i = 0,1,2, \dots, g\}$ and $r_{ij}^k \le t_{ij}^k$.

Regarded that DM_k illustrates the appraisements in a set of five linguistic variable, which the linguistic variable set can be presented as $S = \{s_0 = Very\ low, s_1 = Low, s_2 = , s_3 = Moderate\ High, s_4 = Very\ high\}$.

Step 2: Aggregate the supply chain decision-makers' viewpoints to establish an integrated interval 2-tuple linguistic decision matrix $\tilde{R} = \left(\tilde{r}_{ij}\right)_{m\times n}$, determining the aggregated 2-tuple linguistic weight of each risk factor (w_j, α_{wj}), where

$$\tilde{r}_{ij} = \left[(r_{ij}, \alpha_{ij}), (t_{ij}, \varepsilon_{ij})\right] = ITWA\left(\left[(r_{ij}^1, 0), (t_{ij}^1, 0)\right], \left[(r_{ij}^2, 0), (t_{ij}^2, 0)\right], \dots, \left[(r_{ij}^p, 0), (t_{ij}^p, 0)\right]\right)$$
$$= \Delta\left[\sum_{k=1}^{p} \vartheta_k \Delta^{-1}\left(r_{ij}^k, 0\right), \sum_{k=1}^{p} \vartheta_k \Delta^{-1}\left(t_{ij}^k, 0\right)\right], \qquad i = 1, \dots, m \ \ and\ j = 1, \dots, n \tag{11}$$

and,

$$(w_j, \alpha_{wj}) = ITWA\left(\left[(r_{ij}^1, 0), (t_{ij}^1, 0)\right], \left[(r_{ij}^2, 0), (t_{ij}^2, 0)\right], \dots, \left[(r_{ij}^p, 0), (t_{ij}^p, 0)\right]\right)$$
$$= \Delta\left[\sum_{k=1}^{p} \vartheta_k \Delta^{-1}\left(r_{ij}^k, 0\right), \sum_{k=1}^{p} \vartheta_k \Delta^{-1}\left(t_{ij}^k, 0\right)\right], \qquad i = 1, \dots, m \ \ and\ j = 1, \dots, n \tag{12}$$

As a result, the corresponding sequences can be generated according to the collective interval-valued 2-tuple linguistic decision matrix provided by Equation (12).

Step 3: Establish a linguistic decision matrix with collective weighted interval 2-tuple.

Following the criteria appraisement weights and the collective interval 2-tuple linguistic decision matrix $\widetilde{R'} = \left(\tilde{r}'_{ij}\right)_{m\times n}$, we have:

$$\tilde{r}'_{ij} = \left[(r'_{ij}, \alpha'_{ij}), (t'_{ij}, \varepsilon'_{ij})\right] = \left(w_j, \alpha_{wj}\right) \times \left[\left(r_{ij}, \alpha_{ij}\right), \left(t_{ij}, \varepsilon_{ij}\right)\right]$$
$$= \Delta\left[\Delta^{-1}\left(w_j, \alpha_{wj}\right).\Delta^{-1}\left(r_{ij}, \alpha_{ij}\right), \Delta^{-1}\left(w_j, \alpha_{wj}\right).\Delta^{-1}\left(t_{ij}, \varepsilon_{ij}\right)\right],$$
$$i = 1, \dots, m \ \ and\ j = 1, \dots, n \tag{13}$$

Step 4: Consider having the 2-tuple linguistic positive-ideal and negative-ideal solutions A^+ and A^- respectively, thus:

$$A^+ = [(r_1^+, \alpha_1^+), (r_2^+, \alpha_2^+), \dots, (r_n^+, \alpha_n^+)] \tag{14}$$

$$A^- = [(r_1^-, \alpha_1^-), (r_2^-, \alpha_2^-), \dots, (r_n^-, \alpha_n^-)] \tag{15}$$

where

$$(r_j^+, \alpha_j^+) = \begin{cases} \max_i\{(t_{ij}, \varepsilon_{ij})\}, & \text{for benefit criteria} \\ \min_i\{(r_{ij}, \alpha_{ij})\}, & \text{for cost criteria} \end{cases} \tag{16}$$

$$(r_j^-, \alpha_j^-) = \begin{cases} \min_i\{(r_{ij}, \alpha_{ij})\}, & \text{for benefit criteria} \\ \max_i\{(t_{ij}, \varepsilon_{ij})\}, & \text{for cost criteria} \end{cases} \tag{17}$$

Where $j = 1, \dots, n$

Step 5: Provide separation measures.

The separation measures, D_i^+ and D_i^-, regarding each green supplier's performance alternative from 2-tuple linguistic positive-ideal and negative-ideal solutions are computed according to the n −dimensional Euclidean distance of interval 2-tuples:

$$D_i^+ = \Delta \sqrt{\sum_{j=1}^{n} \left[\left(\Delta^{-1}(r'_{ij}, \alpha'_{ij}) - \Delta^{-1}(r_j^+, \alpha_j^+) \right)^2 + \left(\Delta^{-1}(t'_{ij}, \varepsilon'_{ij}) - \Delta^{-1}(r_j^-, \alpha_j^-) \right)^2 \right]}, \qquad i = 1, \dots, m \tag{18}$$

and,

$$D_i^- = \Delta \sqrt{\sum_{j=1}^{n} \left[\left(\Delta^{-1}(r'_{ij}, \alpha'_{ij}) - \Delta^{-1}(r_j^-, \alpha_j^-) \right)^2 + \left(\Delta^{-1}(t'_{ij}, \varepsilon'_{ij}) - \Delta^{-1}(r_j^-, \alpha_j^-) \right)^2 \right]}, \qquad i = 1, \dots, m \tag{19}$$

Step 6: Compute the relative closeness coefficient ξ_i using 2-tuple linguistic ideal solution.

The closeness coefficient relation concerning each alternative A_i is:

$$\xi_i = \Delta \left(\frac{\left[\Delta^{-1}(D_i^+) - \min_i\left(\Delta^{-1}(D_i^+)\right) \right]^2 + \left[\Delta^{-1}(D_i^-) - \max_i\left(\Delta^{-1}(D_i^-)\right) \right]^2}{\left| \Delta^{-1}(D_i^+) - \sum_i \frac{1}{m}\left(\Delta^{-1}(D_i^+)\right) \right| + \left| \Delta^{-1}(D_i^-) - \sum_i \frac{1}{m}\left(\Delta^{-1}(D_i^-)\right) \right|} \right), \quad i = 1, \dots, m \tag{20}$$

Step 7: Rank the alternatives related to the performance of green suppliers.

By the relative closeness coefficient to the ideal alternative, the less ξ_i, the better the green supplier's performance alternative A_i. Hence, this makes it possible for all alternatives A_i $(i = 1, 2, \dots, m)$ to be prioritized based on the ascending order of their relative closeness values.

The proposed new interval-valued 2-Tuple group decision model in the supply chain for the green suppliers' performances is represented in Figure 2.

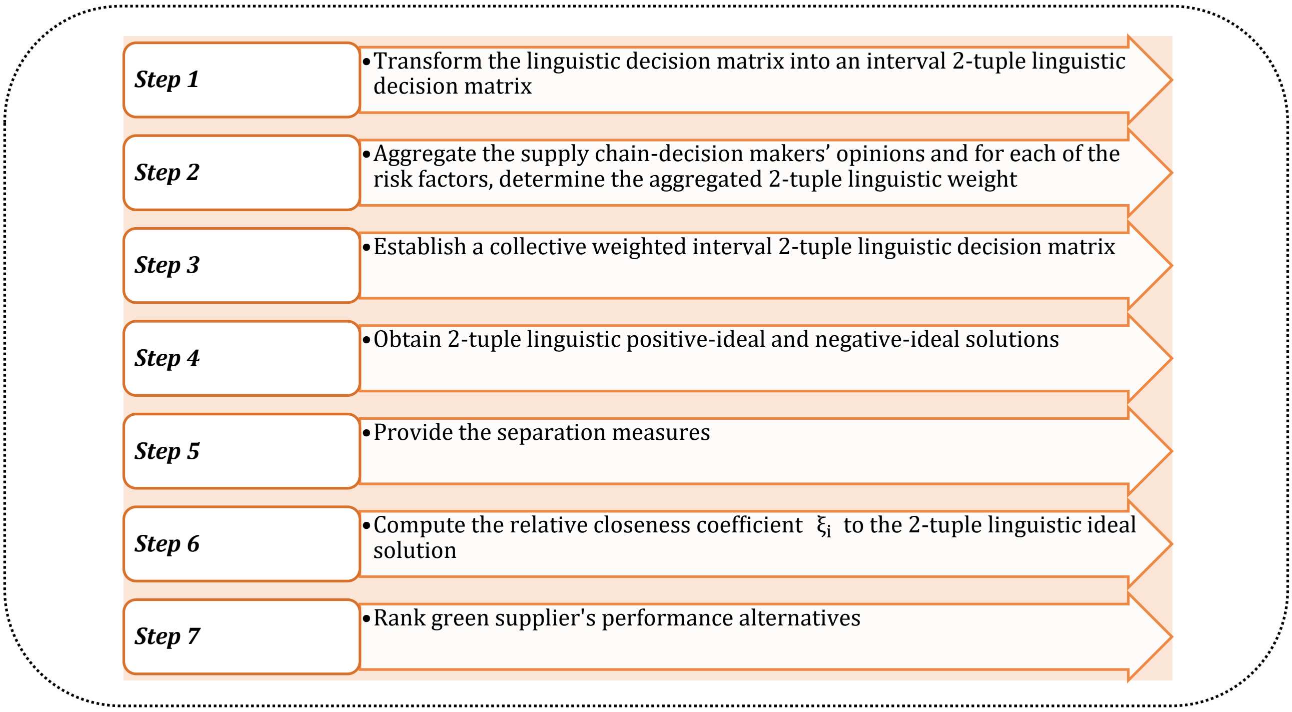

Fig. 2. Main steps of introduced interval-valued 2-Tuple group decision approach

IV. APPLICATION

Manufacturing operations have a significant effect on environmental pollution at different stages in the product life cycle, from resource extraction to manufacturing, use, reuse, recycling and disposal. There has been a weight on automobile manufacturers to enhance their supply chain environmental performance actively and to decrease environmental impacts (Olugu et al., 2011). Automobile production firms should start to actualize green practices at all phases regarding the assembling procedure in order to accomplish benefit and piece concerning the overall industry targets by bringing down their natural effects and expanding their biological effectiveness. These are some critical changes needed, because usually, several automobile components are outsourced to suppliers, and selecting suppliers as indicated by their environmental criteria will enhance the organization's natural execution. The proposed decision approach comprises three stages, including the determination of assessment criteria, the choice of best providers utilizing proposed criteria, and leading an affectability examination to specify the impacts regarding the weights of criteria on decision making.

Criteria or factors for choosing and evaluating green suppliers (Shen et al., 2013; Ghorabaee et al., 2016; Awasthi and Kannan, 2016; Wang et al., 2018, Luthra et al., 2017):

- C_1: Pollution production
- C_2: Resource consumption
- C_3: Eco-design
- C_4: Green image
- C_5: Environmental management scheme
- C_6: The commitment of GSCM from managers
- C_7: Environmentally friendly technology use
- C_8: Environmentally friendly materials use
- C_9: Staff environmental practice

Three supply chain-experts apply various linguistic term sets to evaluate the potential green supplier's performance alternatives in terms of the nine evaluation factors. Specifically, DM_1 describes the evaluations in the set of five labels, A; DM_2 describes the evaluations in the set of seven labels, B; DM_3 describes the evaluations in the set of nine labels, C. Also, the relative importance of the evaluation factors is determined using the experts with a set of five linguistic terms, D. These linguistic term sets are presented as the following:

$$A = \{a_0 = very\ low\ (VL), a_1 = low\ (L), a_2 = moderately\ low(ML), a_3 = moderate(M)\ , a_4 = moderately\ high\ (MH), a_5 = high(H), and\ a_6 = very\ high\ (VH)\}$$

$$B = \{b_0 = very\ low\ (VL), b_1 = low\ (L), b_2 = moderate(M), b_3 = high\ (H), and\ b_4 = very\ high\ (VH)\}$$

$$C = \{c_0 = extremely\ low(EL), c_1 = very\ low\ (VL), c_2 = low\ (L), c_3 = moderately\ low(ML), c_4 = moderate(M)\ , c_5 = moderately\ high\ (MH), c_6 = high(H), c_7 = very\ high(VH), and\ c_8 = extreme\ high\ (EH)\}$$

$$D = \{d_0 = very\ low\ (VL), d_1 = low\ (L), d_2 = medium\ low(ML), d_3 = medium(M)\ , d_4 = medium\ high\ (MH), d_5 = high(H), and\ d_6 = very\ high\ (VH)\}$$

A. Computational Results

According to the steps regarding the proposed decision model, in order to evaluate green supplier's performance, the interval-valued 2-Tuple linguistic preferences have been used. The linguistic green supplier performance evaluation and the linguistics used for representing the criteria weights are illustrated in Tables 1 and 2, respectively.

As shown in Table 3, the performances are aggregated in the decision matrix; the weight of each criterion has been taken into account. Furthermore, the distances from positive and negative ideal solutions are calculated and reported in the second and third columns of Table 4. Moreover, computational outcomes and rankings of the mentioned new evaluation model are illustrated in this table. The third green supplier performance alternative is selected as the best one. The results have been confirmed and compared with the conventional fuzzy TOPSIS method.

Table 1. Linguistic green supplier performance evaluation

Criteria	*Supplier X_1*			*Supplier X_2*			*Supplier X_3*		
	DM_1	DM_2	DM_3	DM_1	DM_2	DM_3	DM_1	DM_2	DM_3
C_1	M	M	ML	H	M	VH,EH	MH	M	H
C_2	M,MH	VL,L	M	H	L,M	H	MH	VL,L	MH
C_3	MH	M	ML,MH	M	M	MH	H	L,M	H
C_4	M	VL	ML	MH	VL,L	M		L,M	ML
C_5	MH	M	M	VH	H	MH	MH,H	M	MH
C_6		VL	ML	M	VL,L	MH	ML	VL	M
C_7	ML	VL,L	M	MH,H	VH	H,VH	MH	H	MH
C_8	ML	M	ML	M		MH	H	M	M
C_9	M	VL,L	ML	H	VH	H	MH	H	MH,EH

Table 2. Linguistic for criteria weights

Criteria	*Decision makers*		
	DM_1	DM_2	DM_3
C_1	VH	VH	H
C_2	MH	H	H
C_3	H	H	VH
C_4	MH	M	M
C_5	M	MH	H
C_6	M	M	M
C_7	M	M	MH
C_8	H	MH	MH
C_9	MH	M	M

Table 3. Aggregated interval 2-tuple decision matrix and aggregated weights of criteria

Criteria	*Supplier* X_1	*Supplier* X_2	*Supplier* X_3	*Weight*
C_1	Δ[0.458, 0.458]	Δ[0.736, 0.778]	Δ[0.639, 0.639]	Δ[0.944]
C_2	Δ[0.333, 0.472]	Δ[0.611, 0.694]	Δ[0.431, 0.514]	Δ[0.778]
C_3	Δ[0.514, 0.597]	Δ[0.542, 0.542]	Δ[0.611, 0.694]	Δ[0.889]
C_4	Δ[0.292, 0.292]	Δ[0.389, 0.472]	Δ[0.208, 0.625]	Δ[0.556]
C_5	Δ[0.556, 0.556]	Δ[0.794, 0.792]	Δ[0.597, 0.653]	Δ[0.667]
C_6	Δ[0.125, 0.458]	Δ[0.375, 0.458]	Δ[0.278, 0.278]	Δ[0.500]
C_7	Δ[0.278, 0.361]	Δ[0.806, 0.903]	Δ[0.681, 0.681]	Δ[0.556]
C_8	Δ[0.403, 0.403]	Δ[0.375, 0.708]	Δ[0.611, 0.611]	Δ[0.722]
C_9	Δ[0.292, 0.375]	Δ[0.861, 0.861]	Δ[0.681, 0.806]	Δ[0.556]

Table 4. Distance from positive and negative ideal solutions

Green Suppliers candidates	D_i^+	D_i^-	ξ_i	*Ranking by proposed method*	*Ranking by Conventional Fuzzy TOPSIS*
X_1	Δ[0.820]	Δ[0.577]	Δ[0.542]	3	3
X_2	Δ[0.640]	Δ[0.772]	Δ[0.242]	2	2
X_3	Δ[0.485]	Δ[0.697]	Δ[0.031]	1	1

B. Discussion of results and comparisons

In this subsection, a sensitivity analysis is discussed by conducting the weight's effect on green supplier performance to further study for evaluating and selecting a problem on the final ranking. The results are accounted for Tables 5 and 6, respectively. In this evaluation, each weight regarding green supplier performance criteria was replaced intentionally with another expert's weight. Furthermore, the main fundamental demonstrates the initial results of the green suppliers' performances which relates to what this paper expects. Most rankings have remained with restricted changes.

An affectability investigation covering the effect concerning the weights regarding nine green supplier performance criteria is directed to review further for the assessment and determination issue on the last positioning. The consequences of this affectability investigation are given in Tables 5 and 6, separately. The assessment can trade each weight of nine green supplier performance criteria with another weight. It relates to what this paper expects. Most rankings have remained with minor changes.

Table 5. Changes on weights of nine green supplier performance criteria

Conditions	$\Delta^{-1}(w_1, \alpha_{w1})$	$\Delta^{-1}(w_2, \alpha_{w2})$	$\Delta^{-1}(w_3, \alpha_{w3})$	$\Delta^{-1}(w_4, \alpha_{w4})$	$\Delta^{-1}(w_5, \alpha_{w5})$	$\Delta^{-1}(w_6, \alpha_{w6})$	$\Delta^{-1}(w_7, \alpha_{w7})$	$\Delta^{-1}(w_8, \alpha_{w8})$	$\Delta^{-1}(w_9, \alpha_{w9})$
Main	0.944	0.778	0.889	0.556	0.667	0.500	0.556	0.722	0.556
1	0.778	0.944	0.889	0.556	0.667	0.500	0.556	0.722	0.556
2	0.889	0.778	0.778	0.556	0.667	0.500	0.556	0.722	0.556
3	0.556	0.778	0.889	0.778	0.667	0.500	0.556	0.722	0.556
4	0.667	0.778	0.889	0.556	0.778	0.500	0.556	0.722	0.556
5	0.500	0.778	0.889	0.556	0.667	0.778	0.556	0.722	0.556
6	0.556	0.778	0.889	0.556	0.667	0.500	0.778	0.722	0.556
7	0.722	0.778	0.889	0.556	0.667	0.500	0.556	0.778	0.556
8	0.556	0.778	0.889	0.556	0.667	0.500	0.556	0.722	0.778
9	0.944	0.889	0.778	0.556	0.667	0.500	0.556	0.722	0.556
10	0.944	0.556	0.889	0.778	0.667	0.500	0.556	0.722	0.556
11	0.944	0.667	0.889	0.556	0.778	0.500	0.556	0.722	0.556
12	0.944	0.500	0.889	0.556	0.667	0.778	0.556	0.722	0.556
13	0.944	0.556	0.889	0.556	0.667	0.500	0.778	0.722	0.556
14	0.944	0.722	0.889	0.556	0.667	0.500	0.556	0.778	0.556
15	0.944	0.556	0.889	0.556	0.667	0.500	0.556	0.722	0.778
16	0.944	0.778	0.556	0.889	0.667	0.500	0.556	0.722	0.556
17	0.944	0.778	0.667	0.556	0.889	0.500	0.556	0.722	0.556
18	0.944	0.778	0.500	0.556	0.667	0.889	0.556	0.722	0.556
19	0.944	0.778	0.556	0.556	0.667	0.500	0.889	0.722	0.556
20	0.944	0.778	0.722	0.556	0.667	0.500	0.556	0.889	0.556
21	0.944	0.778	0.556	0.556	0.667	0.500	0.556	0.722	0.889

Continue Table 5. Changes on weights of nine green supplier performance criteria

Conditions	$\Delta^{-1}(w_1, \alpha_{w1})$	$\Delta^{-1}(w_2, \alpha_{w2})$	$\Delta^{-1}(w_3, \alpha_{w3})$	$\Delta^{-1}(w_4, \alpha_{w4})$	$\Delta^{-1}(w_5, \alpha_{w5})$	$\Delta^{-1}(w_6, \alpha_{w6})$	$\Delta^{-1}(w_7, \alpha_{w7})$	$\Delta^{-1}(w_8, \alpha_{w8})$	$\Delta^{-1}(w_9, \alpha_{w9})$
22	0.944	0.778	0.889	0.667	0.556	0.500	0.556	0.722	0.556
23	0.944	0.778	0.889	0.500	0.667	0.556	0.556	0.722	0.556
24	0.944	0.778	0.889	0.556	0.667	0.500	0.556	0.722	0.556
25	0.944	0.778	0.889	0.722	0.667	0.500	0.556	0.556	0.556
26	0.944	0.778	0.889	0.556	0.667	0.500	0.556	0.722	0.556
27	0.944	0.778	0.889	0.556	0.500	0.667	0.556	0.722	0.556
28	0.944	0.778	0.889	0.556	0.556	0.500	0.667	0.722	0.556
29	0.944	0.778	0.889	0.556	0.722	0.500	0.556	0.667	0.556
30	0.944	0.778	0.889	0.556	0.556	0.500	0.556	0.722	0.667
31	0.944	0.778	0.889	0.556	0.667	0.556	0.500	0.722	0.556
32	0.944	0.778	0.889	0.556	0.667	0.722	0.556	0.500	0.556
33	0.944	0.778	0.889	0.556	0.667	0.556	0.556	0.722	0.500
34	0.944	0.778	0.889	0.556	0.667	0.500	0.722	0.556	0.556
35	0.944	0.778	0.889	0.556	0.667	0.500	0.556	0.722	0.556
36	0.944	0.778	0.889	0.556	0.667	0.500	0.556	0.556	0.722

Table 6. Sensitivity analysis on final ranking for weights of nine criteria

Conditions	X_1	X_2	X_3
Main	Δ[0.542]	Δ[0.242]	Δ[0.031]
1	Δ[0.555]	Δ[0.307]	Δ[0.020]
2	Δ[0.546]	Δ[0.170]	Δ[0.039]
3	Δ[0.576]	Δ[0.027]	Δ[0.026]
4	Δ[0.593]	Δ[0.067]	Δ[0.049]
5	Δ[0.613]	Δ[0.028]	Δ[0.079]
6	Δ[0.759]	Δ[0.021]	Δ[0.090]
7	Δ[0.589]	Δ[0.114]	Δ[0.035]
8	Δ[0.755]	Δ[0.034]	Δ[0.060]
9	Δ[0.537]	Δ[0.347]	Δ[0.026]
10	Δ[0.521]	Δ[0.044]	Δ[0.035]
11	Δ[0.552]	Δ[0.113]	Δ[0.055]

Continue Table 6. Sensitivity analysis on final ranking for weights of nine criteria

Conditions	X_1	X_2	X_3
12	Δ[0.560]	Δ[0.042]	Δ[0.111]
13	Δ[0.702]	Δ[0.032]	Δ[0.111]
14	Δ[0.557]	Δ[0.200]	Δ[0.035]
15	Δ[0.697]	Δ[0.048]	Δ[0.126]
16	Δ[0.477]	Δ[0.058]	Δ[0.023]
17	Δ[0.545]	Δ[0.112]	Δ[0.074]
18	Δ[0.539]	Δ[0.075]	Δ[0.106]
19	Δ[0.757]	Δ[0.034]	Δ[0.143]
20	Δ[0.577]	Δ[0.253]	Δ[0.034]
21	Δ[0.750]	Δ[0.062]	Δ[0.082]
22	Δ[0.518]	Δ[0.226]	Δ[0.019]
23	Δ[0.552]	Δ[0.251]	Δ[0.040]
24	Δ[0.542]	Δ[0.242]	Δ[0.031]
25	Δ[0.480]	Δ[0.123]	Δ[0.025]
26	Δ[0.542]	Δ[0.242]	Δ[0.031]
27	Δ[0.541]	Δ[0.247]	Δ[0.035]
28	Δ[0.602]	Δ[0.164]	Δ[0.044]
29	Δ[0.532]	Δ[0.200]	Δ[0.038]
30	Δ[0.599]	Δ[0.195]	Δ[0.034]
31	Δ[0.516]	Δ[0.303]	Δ[0.027]
32	Δ[0.505]	Δ[0.121]	Δ[0.065]
33	Δ[0.518]	Δ[0.276]	Δ[0.032]
34	Δ[0.611]	Δ[0.082]	Δ[0.076]
35	Δ[0.542]	Δ[0.242]	Δ[0.031]
36	Δ[0.607]	Δ[0.109]	Δ[0.053]

Unlike the previous studies, the comprehensive approach has some benefits that make it reliable and appropriate for the MCGDM. In Figure 3, the advantages of the presented approach are discussed in detail.

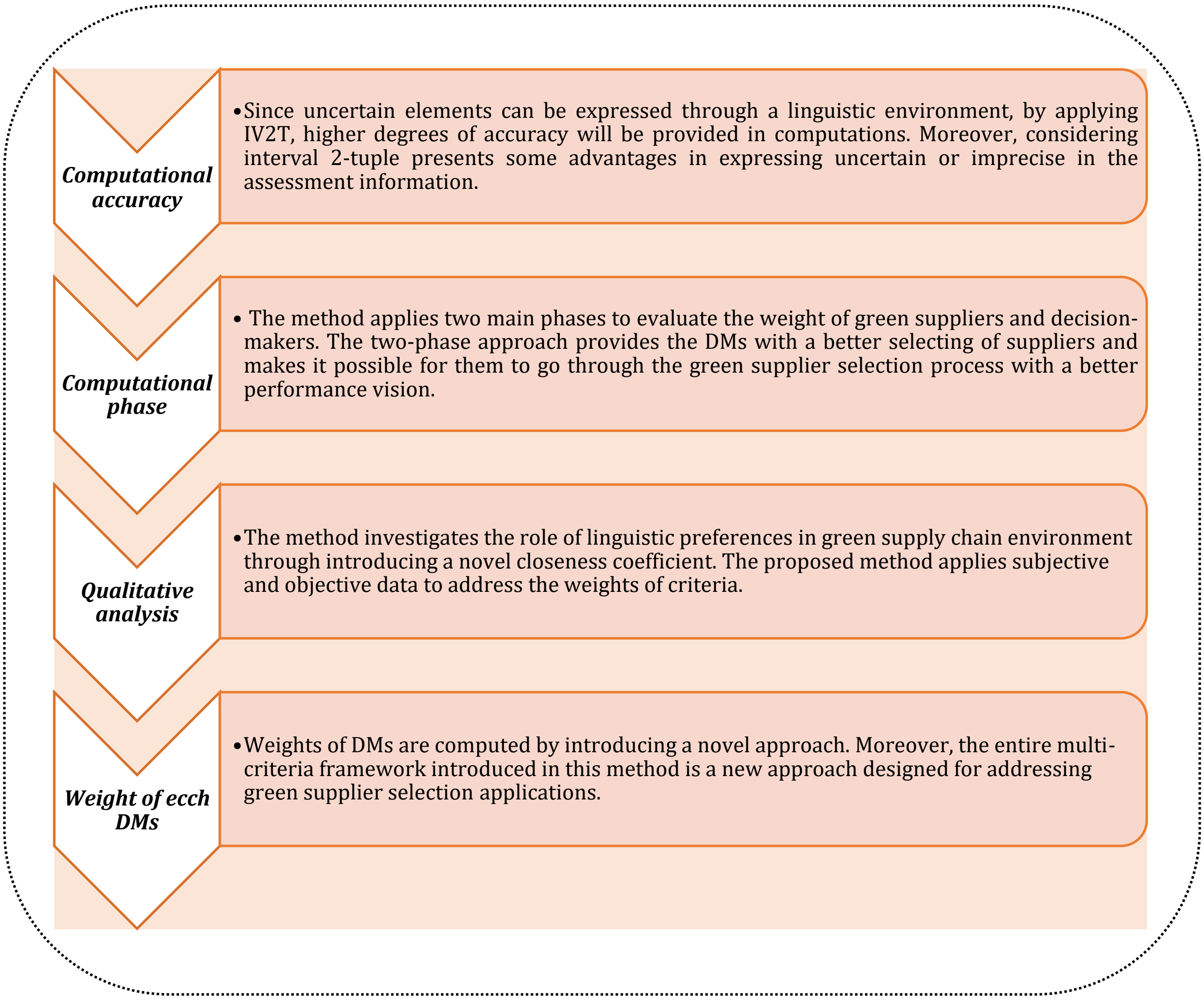

Fig. 3. A concise review of the advantages regarding the presented method

V. CONCLUSION

Increasing the performance of suppliers in the environmental aspect is significant for the green supply chain management. Supplier performances are enhanced by associations putting resources into different green supplier development plans. Making suitable program for green suppliers' development is frequently a challenging choice because of the absence of related information, restricted quantitative data, a particular setting of the association, and changing supplier foundations. This article presents a new decision model based on interval-valued 2-Tuple linguistic preferences and compromise solution for assessing green supplier's performance. For this purpose, a new decision-making process following an interval-valued 2-Tuple linguistic information environment was introduced based on a new version of the procedure concerning the preference order similar to ideal solution (TOPSIS) method. A new ranking index with interval-valued 2-tuple linguistic was provided for the evaluation process regarding green supplier's performance. In addition, a case study from the recent literature in the manufacturing business was solved by the recommended decision model under uncertainty. The third green supplier performance alternative was selected as the best one. The results have been confirmed and compared with the conventional fuzzy TOPSIS method. The model, as mentioned earlier, with concerns to both economically and environmentally essential criteria, presents a systematic procedure for supply chain managers to evaluate suppliers. The suggested model benefits from the compromise solution, which partially satisfied everyone involved. Moreover, it presents more compatible weights for the criteria. Consequently, it is much more possible for managers to make more logical and compatible decisions. Another advantage of this research is that the recommended model applies to different firms active in Iran's automotive business without significant adjustments. That is because the case study of this article presents significant automobile production firms in Iran with a wide variety of components, and the assessment criteria are collected by a comprehensive literature survey and by experts' consensus.

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