Volume XXII, Issue (x) (2026) 299-308

International May Conference on Strategic Management

DOI: 10.5937/IMCSM26299D *Research Article*

GIBSU-HISA: AN ENHANCED INFLUENCE ANALYSIS METHOD FOR GROUP DECISION-MAKING UNDER UNCERTAINTY

Gregor Dolinar, Petra Grošelj*

University of Ljubljana, Biotechnical Faculty, Slovenia

Abstract: Methods for analyzing interdependencies among system components are essential for understanding complex decision problems. The Heterogeneous Influence and Strength Attenuation (HISA) method represents a significant advancement over traditional approaches such as DEMATEL and WINGS by incorporating heterogeneous influence, negative relationships, and attenuation effects. However, HISA assumes crisp aggregation of expert judgments, which may obscure the diversity of opinions in group decision-making contexts. To address this limitation, this paper proposes a novel Group Interval-Based HISA method Balancing Satisfaction and Uncertainty (GIBSU-HISA) that integrates the principles of the GIBSU-DEMATEL framework into the HISA model. The proposed approach uses interval-based aggregation of expert assessments and determines the optimal interval width by balancing expert satisfaction and uncertainty. This enables a more realistic representation of divergent opinions while maintaining analytical robustness. The effectiveness of the method is demonstrated through a case study on smart home systems, where the results of GIBSU-HISA are compared with those of the original HISA. The findings show that the proposed method preserves the overall causal structure while providing more reliable and informative rankings of factors. Consequently, GIBSU-HISA enhances decision support in complex group decision-making environments under uncertainty.

Keywords: Group Interval-Based method Balancing Satisfaction and Uncertainty (GIBSU), method considering heterogeneous influence and strength attenuation (HISA), interval judgments, expert satisfaction, uncertainty.

1. INTRODUCTION

Methods for analyzing interdependencies among system components are essential for understanding complex decision problems, where factors influence each other rather than act independently. Among these methods, the Decision-Making Trial and Evaluation Laboratory (DEMATEL) (Gabus & Fontela, 1973) is widely recognized as an effective tool for identifying cause–effect relationships and visualizing the structure of complex systems. By using influence

* *Corresponding author: petra.groselj@bf.uni-lj.si*

Gregor Dolinar, ORCID: 0000-0001-9106-3995
Petra Grošelj, ORCID: 0000-0001-9363-9783

matrices and deriving total relationships, DEMATEL enables decision makers to distinguish between cause and effect factors and identify key elements within the system.

Despite its advantages, DEMATEL has several limitations. It assumes only positive influences, neglects the initial strength of factors, and does not consider attenuation effects during influence propagation. To address some of these shortcomings, the Weighted Influence Non-linear Gauge System (WINGS) (Michnik, 2013) was proposed, incorporating the strength of factors However, WINGS still omits important aspects such as attenuation effects and heterogeneous importance of connections. More recently, the method considering the Heterogeneous Influence and Strength Attenuation (HISA) (Wang et al., 2022) has been introduced as a further advancement. HISA considers both positive and negative influences, integrates attenuation effects in influence propagation, and accounts for the heterogeneous importance of factors, for example through PageRank-based mechanisms. These improvements enable a more realistic and accurate representation of complex systems and enhance the identification of critical factors. The original study by Wang et al. (2022) applied HISA to a smart home system, demonstrating its ability to identify critical factors and capture both positive and negative relationships more accurately than traditional methods. Building on this, recent research has extended HISA to uncertain environments, resulting in the grey HISA model (Hsu et al., 2024; Huang et al., 2026), Z-HISA (Chang & Pai, 2025), and hybrid models integrating other multi-criteria decision-making methods (Yang et al., 2025).

While these methods provide powerful tools for structural analysis of interdependent systems, they are primarily developed for single decision makers or assume straightforward aggregation of expert opinions. In real-world applications, however, decision-making is increasingly performed in groups, where multiple experts contribute their knowledge, experience, and perspectives. Group decision-making enhances the robustness and credibility of results, but also introduces significant challenges related to aggregating diverse and often conflicting individual assessments. Traditional approaches, such as arithmetic averaging, may oversimplify the diversity of opinions and create an artificial sense of certainty, failing to adequately represent disagreement among experts. Therefore, an important research gap remains in integrating group decision-making aspects, particularly uncertainty and expert satisfaction, into influence-based methods such as HISA. While recent developments like Group Interval-Based DEMATEL method Balancing Satisfaction and Uncertainty (GIBSU-DEMATEL) (Dolinar & Grošelj, 2026) explicitly address the trade-off between uncertainty and satisfaction through interval-based aggregation and optimization, similar concepts have not yet been incorporated into more advanced interdependency models, such as HISA. This gap limits the applicability of HISA in group decision contexts where divergent expert opinions and uncertainty play a crucial role.

The aim of this paper is to develop a novel GIBSU-HISA method by adapting the principles of GIBSU-DEMATEL to the HISA framework. The proposed approach enables the analysis of interdependent systems while explicitly accounting for uncertainty and expert satisfaction in group decision-making. The effectiveness of the method is demonstrated through a case study comparing the results of classical HISA and the proposed GIBSU-HISA. In this way, the paper contributes to bridging the gap between advanced influence-based methods and the modern requirements of group decision-making under uncertainty.

2. OVERVIEW OF THE HISA

HISA is a method used to assess the importance of interrelated factors within a complex system. While similar to DEMATEL, it incorporates features that allow a more realistic representation of real-life problems.

Let n be the number of factors, and K the number of experts. Each expert provides a direct influence matrix $A^{(k)} = \left(a_{ij}^{(k)}\right)_{n\times n}$, $1 \le k \le K$. For each pair $1 \le i, j \le n,\ i \ne j$, $a_{ij}^{(k)}$ represents the influence of i-th factor on j-th factor as assessed by the k-th expert, while the diagonal elements $a_{ii}^{(k)}$ denote i-th factor's importance for the system, again as viewed by the k-th expert. The values are taken from the set $\{-4,\ -3,\ -2,\ -1,\ 0,1,\ 2,\ 3,\ 4\}$, where 0 indicates no influence (or importance) and 4 represents very high influence (or importance). The negative values indicate that the influence of factor i on factor j is negative. Matrices $A^{(k)}$ are the input of the HISA algorithm. The output is obtained in the following steps.

Step 1: Group matrix

The group matrix $A = (a_{ij})_{n\times n}$ is obtained from matrices $A^{(k)}$ by calculating average of each component, i.e. $a_{ij} = \frac{1}{K}\sum_{k=1}^{K} a_{ij}^{(k)}$. Matrix A is then normalized to get matrix

$$D = \frac{A}{s}, \text{where } s = \max\left\{\max_{1\le i\le n}\sum_{j=1}^{n}\left|a_{ij}\right|, \max_{1\le j\le n}\sum_{j=1}^{n}\left|a_{ij}\right| + 10^{-5}\right\}. \quad (1)$$

Step 2: Total influence matrix

Indirect influences are calculated as powers of D. One of the features of HISA is the possibility to weaken the strengths of indirect influences the further apart two factors are, by introducing the attenuation parameter $0 < \alpha \le 1$. Instead of calculating powers of D, powers of αD are calculated. The matrix of total influences T is then calculated as

$$T = \left(t_{ij}(\alpha)\right)_{n\times n} = \sum_{m=1}^{\infty}(\alpha D)^m = \alpha D(I - \alpha D)^{-1} \quad (2)$$

Step 3: Total individual influences

To assess the importance of each factor, a PageRank algorithm is adapted to account for possible negative values. Define $O(i,\alpha) = \sum_{i=1}^{n}\left|t_{ji}(\alpha)\right|$ and $I(i,\alpha) = \sum_{i=1}^{n}\left|t_{ij}(\alpha)\right|$. The amount of influence that factors exert, denoted by $OPR(i,\alpha)$ is obtained by solving the following system of linear equations:

$$OPR(i,\alpha) = 1 - d + d\sum_{j=1}^{n}\frac{t_{ij}(\alpha)}{I(j,\alpha)}OPR(j,\alpha), \quad 1 \le i \le n, \quad (3)$$

where $0 < d \le 1$ is a damping parameter. Similarly, we obtain the amount of influence that factors receive as the solution of the following system of linear equations:

$$IPR(i,\alpha) = 1 - d + d\sum_{j=1}^{n}\frac{t_{ij}(\alpha)}{O(j,\alpha)}IPR(j,\alpha), \quad 1 \le i \le n. \quad (4)$$

Step 4: Prominence and relation

Prominence $P(i,\alpha)$ and relation $R(i,\alpha)$ of i-th factor are then calculated as $P(i,\alpha) = \left|OPR(i,\alpha)\right| + \left|IPR(i,\alpha)\right|$ and $R(i,\alpha) = \left|OPR(i,\alpha)\right| - \left|IPR(i,\alpha)\right|$. Factors with a positive relation belong to the causal group. They mainly exert influence. Factors with a negative relation belong to the effect group. They mainly receive influence. Ranks of factors are

assigned according to prominence values, from the factor with the biggest R to the factor with the smallest R.

3. GIBSU HISA

In the original HISA method, the aggregated matrix A is represented by crisp values. However, relying only on the arithmetic mean for aggregation does not adequately capture the diversity of experts and their individual assessments. This approach may obscure disagreements and create an artificial sense of consensus. To ensure the results more accurately reflect this diversity, it is preferable to use interval-valued representations rather than crisp numbers when aggregating experts' judgments.

When using interval-valued representations, two conflicting issues must be considered. On one hand, the intervals should not be too narrow, as they need to include as many individual assessments as possible to ensure a high level of expert satisfaction with the aggregated matrix. On the other hand, wide intervals increase the uncertainty of the calculated results. Therefore, determining the optimal interval width is a trade-off between these two objectives. To address this issue, we use the method developed by Dolinar and Grošelj (2026) and adapt it to the HISA framework. The procedure is outlined step by step below.

Step 1: Group matrix

Let $A^{(k)} = \left(a_{ij}^{(k)}\right)_{n\times n}$ be the direct-influence matrices for $1 \le k \le K$. Calculate the means $a_{ij}^{M} = \frac{1}{K}\sum_{k=1}^{K} a_{ij}^{(k)}$ and standard deviations $\sigma_{ij} = \sqrt{\frac{1}{K}\sum_{k=1}^{K}\left(a_{ij}^{(k)} - a_{ij}^{M}\right)^2}$. The group matrix is an interval matrix

$$A = ([a_{ij}^{\ell}, a_{ij}^{u}])_{n\times n}, \text{ where } a_{ij}^{\ell} = a_{ij}^{M} - \lambda\sigma_{ij} \text{ and } a_{ij}^{u} = a_{ij}^{M} + \lambda\sigma_{ij} \text{ for some } 0 < \lambda \le 1. \quad (5)$$

Step 2: Optimizing parameter λ

Step 2.1: Experts' satisfaction

An expert is considered satisfied with the group matrix if their assessment lies within the aggregated interval, i.e., $a_{ij}^{(k)} \in \left[a_{ij}^{\ell}, a_{ij}^{u}\right]$. If $a_{ij}^{(k)} \notin \left[a_{ij}^{\ell}, a_{ij}^{u}\right]$, their satisfaction decreases as the distance of $a_{ij}^{(k)}$ from $\left[a_{ij}^{\ell}, a_{ij}^{u}\right]$ increases, reaching 0 at a certain distance. In our application, we assume that the decrease in satisfaction is quadratic and that it reaches 0 at a distance of 1.

Let $d_{ij}^{(k)}(\lambda)$ be the distance between $a_{ij}^{(k)}$ and $\left[a_{ij}^{\ell}, a_{ij}^{u}\right]$, and

$$c_{ij}^{(k)}(\lambda) = \begin{cases} 0, & \text{if } d_{ij}^{(k)}(\lambda) > 1 \\ (1 - d_{ij}^{(k)}(\lambda))^2, & \text{if } 0 < d_{ij}^{(k)}(\lambda) \le 1. \\ 1, & \text{if } d_{ij}^{(k)}(\lambda) = 0 \end{cases} \quad (6)$$

Single expert's satisfaction is calculated as $s_{ij}^{(k)}(\lambda) = \frac{1}{n^2}\sum_{i=1}^{n} c_{ij}^{(k)}(\lambda)$, and total expert satisfaction is $S(\lambda) = \frac{1}{K}\sum_{k=1}^{K} s_{ij}^{(k)}(\lambda)$.

Step 2.2: Uncertainty of aggregated intervals

The uncertainty of the group matrix is measured by the indeterminacy index $U(\lambda)=\frac{2\lambda}{n^2}\sum_{i,j=1}^{n}\sigma_{ij}$. Note that the maximum value of the standard deviation σ_{ij}, when using a -4 to 4 scale, is 4. Therefore, the value of $U(\lambda)$ is at most 8.

Step 2.3: Objective function

The objective function is defined as $f(\lambda)=\beta S(\lambda)+(1-\beta)\psi(U(\lambda))$. The parameter $0\le\beta\le 1$ serves as a relative weight assigned to satisfaction and uncertainty. In our application we set $\beta=0.5$, which means we consider satisfaction and uncertainty equally important. Both $S(\lambda)$ and $U(\lambda)$ are increasing functions. However, it is beneficial for our goal that uncertainty is as small as possible, and since we want to maximize the objective function $f(\lambda)$, we must reverse the monotonicity of $U(\lambda)$ by applying a decreasing function ψ. We define

$$\psi(U(\lambda))=\begin{cases}-\frac{U(\lambda)}{4}+1, & \text{if } 0\le U(\lambda)\le 4\\ 0, & \text{if } 4<U(\lambda)\le 8\end{cases}. \qquad (7)$$

Values of $U(\lambda)$ greater than 4 are considered unacceptable; therefore, $\psi\left(U(\lambda)\right)=0$ for these values. Finally, we find λ, with $0<\lambda\le 1$, such that the objective function $f(\lambda)$ reaches its maximum.

Step 3: Total influence matrix

Once we have obtained the optimal value of λ, and thus the group interval matrix A, we calculate

$$s=\max\left\{\max_{1\le i\le n}\sum_{j=1}^{n}\left|a_{ij}^{u}\right|,\max_{1\le j\le n}\sum_{i=1}^{n}\left|a_{ij}^{u}\right|+10^{-5}\right\}. \qquad (8)$$

Next, we create the normalized matrix $D=\left(\left[d_{ij}^{\ell},d_{ij}^{u}\right]\right)_{n\times n}$ with $d_{ij}^{\ell}=a_{ij}^{\ell}/s$ and $d_{ij}^{u}=a_{ij}^{u}/s$. Define $D^{\ell}=\left(d_{ij}^{\ell}\right)_{n\times n}$ and $D^{u}=\left(d_{ij}^{u}\right)_{n\times n}$. The total influence matrix is matrix $T=\left(\left[t_{ij}^{\ell},t_{ij}^{u}\right]\right)_{n\times n}$, where

$$T^{\ell}=\left(t_{ij}^{\ell}(\alpha)\right)_{n\times n}=\sum_{i=1}^{\infty}(\alpha D^{\ell})^{i}=\alpha D^{\ell}(I-\alpha D^{\ell})^{-1},\ \text{and}\ T^{u}=\left(t_{ij}^{u}(\alpha)\right)_{n\times n}=\alpha D^{u}(I-\alpha D^{u})^{-1}. \qquad (9)$$

Step 4: Prominence and relation

We calculate $I^{\ell}(j,\alpha)=\sum_{i=1}^{n}\left|t_{ij}^{\ell}(\alpha)\right|$, $I^{u}(j,\alpha)=\sum_{i=1}^{n}\left|t_{ij}^{u}(\alpha)\right|$, $O^{\ell}(i,\alpha)=\sum_{j=1}^{n}\left|t_{ij}^{\ell}(\alpha)\right|$ and $O^{u}(i,\alpha)=\sum_{j=1}^{n}\left|t_{ij}^{u}(\alpha)\right|$. The values IPR^{ℓ} are obtained as solutions of the system of linear equations

$$IPR^{\ell}(i,\alpha)=1-d+d\sum_{j=1}^{n}\frac{t_{ij}^{\ell}(\alpha)}{O^{\ell}(j,\alpha)}IPR^{\ell}(j,\alpha),\quad 1\le i\le n. \qquad (10)$$

Similarly, the values IPR^{u} are solutions of the system of linear equations

$$IPR^u(i,\alpha) = 1 - d + d\sum_{j=1}^{n} \frac{t_{ij}^u(\alpha)}{O^u(j,\alpha)} IPR^u(j,\alpha), \quad 1 \le i \le n. \qquad (11)$$

Additionally, the values OPR^ℓ are solutions of the system of linear equations

$$OPR^\ell(i,\alpha) = 1 - d + d\sum_{j=1}^{n} \frac{t_{ij}^\ell(\alpha)}{I^\ell(j,\alpha)} OPR^\ell(j,\alpha), \quad 1 \le i \le n. \qquad (12)$$

and the values OPR^u are solutions of the system of linear equations

$$OPR^u(i,\alpha) = 1 - d + d\sum_{j=1}^{n} \frac{t_{ij}^u(\alpha)}{I^u(j,\alpha)} OPR^u(j,\alpha), \quad 1 \le i \le n. \qquad (13)$$

Finally, we calculate prominence $P_i = \left(|OPR^\ell + OPR^u| + |IPR^\ell + IPR^u|\right)/2$ and relation $R_i = \left(|OPR^\ell + OPR^u| - |IPR^\ell + IPR^u|\right)/2$.

4. CASE STUDY

HISA was originally introduced in Wang et al. (2022) in a case study involving 14 factors SF1 – SF14 affecting smart home systems, evaluated by five experts. The same data was used to demonstrate the applicability of the proposed GIBSU-HISA method. Parameters were set to $\alpha = 1$ and $d = 0.85$.

The optimization procedure produced an optimal value of $\lambda = 0.8164$. This results in the following interval group matrix *A*. For clarity, the matrix is presented as two separate matrices: the lower bounds (Table 1) and the upper bounds (Table 2), while Table 3 shows the corresponding crisp group matrix *A* from the original case study. The resulting interval group matrix achieved a relatively high average expert satisfaction of $S(\lambda) = 0.7315$. Meanwhile, the indeterminacy index $U(\lambda) = 1.1021$, which measures uncertainty, indicates that the average width of interval judgments is slightly above 1. These values result in an overall objective function value of $f(\lambda) = 0.7280$, demonstrating a balanced trade-off between expert satisfaction and uncertainty.

Table 1. Lower bounds of interval group matrix *A* for GIBSU HISA

4	1.6	1.75	2.95	1.4	1.2	2	4	4	4	3.2	4	-2.89	-0.13
0	2.2	1.75	2.59	2.42	2.87	2.87	0.19	-0.05	0.25	-2.13	1.12	-3.52	0
0	-0.13	2	0.95	0.62	0.11	0.97	-0.05	0	-0.13	1.27	-0.13	-2.89	0
-0.13	-0.25	-0.25	3.47	0	-0.25	-0.13	0.77	-0.13	-0.25	-0.78	-0.25	-3.25	0
0	0.4	0.19	0	1.87	0.48	0	0	0	-0.02	-1.52	0	1.4	0
0	0.19	-0.25	-0.13	-0.25	2.48	0	0	-0.25	-0.13	-0.53	-0.03	-2.15	0
0	-0.05	0	0.48	0	0	2.48	1.47	-0.13	0	-1	-0.05	1.59	0
-0.13	-0.15	0	2.48	-0.25	-0.13	0	2.19	0.42	0	-3.25	0.57	-2.13	0
-0.03	0.48	0.59	1.42	0.59	0.77	0.77	2.59	2.47	0.62	-2.62	1.74	-2.6	-0.13
-0.25	1.59	0.95	3	0.77	2	1.59	0.57	2.42	1.95	-4	3.47	-1.62	0
-1.11	-2.13	-0.8	2.48	-1	-1	-1.41	-3.43	-2.88	-3.81	3.47	-3	-1.41	-1.58
0.4	1.25	0.95	1.11	0.47	0.47	0.85	1.25	1.25	1.11	-3.05	2.87	0.25	0
-1.52	-2.23	-1.6	-1	-2.88	-2	0.48	-2.05	-1.81	-0.8	0	-1.13	3	-0.53
0	-0.38	0	0	0	0	0.11	0.77	1.12	-0.13	0.19	1.4	0	3

Table 4 compares the results obtained using the original HISA and the proposed GIBSU-HISA method, including influence exerted (IPR), influence received (OPR), prominence (P), relation (R), and the resulting rankings of factors based on prominence values. Both methods identified the same causal and effect groups. Specifically, factors SF1, SF2, SF9, SF10, SF11, SF12, SF13, and SF14 are classified as causal factors, while SF3, SF4, SF5, SF6, SF7, and SF8 belong to the effect group (Figures 1 and 2). This consistency confirms the robustness of the proposed method.

Table 2. Upper bounds of interval group matrix *A* for GIBSU HISA

4	4	3.05	4	3	2	2.8	4	4	4	4	4	-1.11	0.53
0	3	3.05	3.81	4	3.53	3.53	1.41	1.25	2.15	-1.47	3.28	-2.48	0
0	0.53	3.6	2.25	2.58	1.89	3.03	1.25	0	0.53	2.73	0.53	-1.11	0
0.53	1.05	1.05	4	0	1.05	0.53	2.43	0.53	1.05	2.38	1.05	-1.95	0
0	2	1.41	0	2.53	1.52	0	0	0	2.82	-0.48	1.6	3	0
0	1.41	1.05	0.53	1.05	3.52	0	0	1.05	0.53	0.13	2.03	-0.25	0
0	1.25	2.4	1.52	0	0	3.52	2.13	0.53	0.8	-0.2	1.25	2.81	0
0.53	1.75	1.6	3.52	1.05	0.53	2.4	3.41	2.38	0	-1.95	2.23	-1.47	0
2.03	1.52	1.81	3.38	1.81	2.43	2.43	3.81	3.13	2.58	-0.18	4	-1	0.53
1.05	2.81	2.25	3	2.43	2	2.81	2.23	4	3.25	-2.4	4	0.82	0
1.51	-1.47	0	3.52	-0.2	-0.2	-0.19	-1.77	-0.72	-2.59	4	-1.4	-0.19	0.38
2	3.15	2.25	2.89	1.13	1.13	2.75	3.15	3.15	2.89	-1.75	3.53	2.15	0
-0.48	-0.57	0	-0.2	-0.72	-0.4	1.52	-0.75	-0.59	0	0	-0.47	3	0.13
0.8	1.58	1.6	1.6	0.8	0.8	1.89	2.43	3.28	0.53	1.41	3	0	3.8

Table 3. Crisp group matrix *A* for original HISA

	SF1	SF2	SF3	SF4	SF5	SF6	SF7	SF8	SF9	SF10	SF11	SF12	SF13	SF14
SF1	4	2.8	2.4	3.6	2.2	1.6	2.4	4	4	4	3.6	4	-2.0	0.2
SF2	0	2.6	2.4	3.2	3.4	3.2	3.2	0.8	0.6	1.2	-1.8	2.2	-3.0	0
SF3	0	0.2	2.8	1.6	1.6	1	2	0.6	0	0.2	2	0.2	-2.0	0
SF4	0.2	0.4	0.4	3.8	0	0.4	0.2	1.6	0.2	0.4	0.8	0.4	-2.6	0
SF5	0	1.2	0.8	0	2.2	1	0	0	0	1.4	-1.0	0.8	2.2	0
SF6	0	0.8	0.4	0.2	0.4	3	0	0	0.4	0.2	-0.2	1	-1.2	0
SF7	0	0.6	1.2	1	0	0	3	1.8	0.2	0.4	-0.6	0.6	2.2	0
SF8	0.2	0.8	0.8	3	0.4	0.2	1.2	2.8	1.4	0	-2.6	1.4	-1.8	0
SF9	1	1	1.2	2.4	1.2	1.6	1.6	3.2	2.8	1.6	-1.4	3	-1.8	0.2
SF10	0.4	2.2	1.6	3	1.6	2	2.2	1.4	3.4	2.6	-3.2	3.8	-0.4	0
SF11	0.2	-1.8	-0.4	3	-0.6	-0.6	-0.8	-2.6	-1.8	-3.2	3.8	-2.2	-0.8	-0.6
SF12	1.2	2.2	1.6	2	0 .8	0.8	1.8	2.2	2.2	2	-2.4	3.2	1.2	0
SF13	-1	-1.4	-0.8	-0.6	-1.8	-1.2	1	-1.4	-1.2	-0.4	0	-0.8	3	-0.2
SF14	0.4	0.6	0.8	0.8	0.4	0.4	1	1.6	2.2	0.2	0.8	2.2	0	3.4

Despite this general agreement, several differences in factor rankings are observed. For example, SF9 and SF10 switch the third and fourth positions and minor ranking changes are also evident for factors SF2, SF6, SF7, SF8, and SF14. These variations highlight the ability of GIBSU-HISA to incorporate the diversity of expert opinions through interval-valued judgments, resulting in rankings that more accurately reflect group consensus.

To further assess the quality and robustness of the results obtained by different methods, total deviation degree (TDD) is employed, which compares the prominence values obtained by HISA and GIBSU-HISA. The TDD of the *i*-th factor is defined as $TDD_i = \frac{P_{\max} - P_i}{P_{\max}}$, where $P_{\max} = \max\{P_i | \ i = 1,...,n\}$. The TDD of a method is then defined as $TDD = \sum_{i=1}^{n} TDD_i$. Higher TDD values indicate greater differentiation among factors and, consequently, more robust and informative results. The findings show that the TDD of HISA is 5.0931, while the TDD of GIBSU-HISA is 5.6531, indicating that the proposed method provides more robust outcomes.

A key advantage of GIBSU-HISA is its explicit consideration of uncertainty and expert satisfaction. Unlike the original HISA, which relies on arithmetic averaging and may obscure disagreement among experts, GIBSU-HISA preserves this variability by using optimized interval aggregation. The resulting interval group matrix, obtained with the optimal value $\lambda = 0.8164$, achieves a relatively high level of average expert satisfaction, $S(\lambda) = 0.7315$, while maintaining a moderate level of uncertainty $U(\lambda) = 1.1021$. These values indicate a well-balanced trade-off between inclusiveness of expert opinions and precision of the results.

Consequently, GIBSU-HISA offers enhanced support for group decision-making in complex and uncertain environments while preserving the interpretability and analytical strengths of the original HISA framework.

Table 4. Results for GIBSU HISA and HISA: the amount of influence that factors exert (IPR) and receive (OPR), prominence (P) and relation (R) values, and ranking of factors based on prominence values

Factors	GIBSU HISA					HISA				
	IPR_i	OPR_i	P_i	Rank	R_i	IPR_i	OPR_i	P_i	Rank	R_i
SF1	0.273	1.409	1.682	1	1.136	0.263	1.398	1.661	1	1.135
SF2	0.481	0.650	1.130	5	0.169	0.536	0.671	1.206	6	0.135
SF3	0.524	0.317	0.841	11	-0.207	0.581	0.276	0.857	11	−0.305
SF4	0.741	0.351	1.093	8	-0.390	0.809	0.338	1.147	8	−0.472
SF5	0.479	0.312	0.791	12	-0.167	0.506	0.310	0.816	12	−0.196
SF6	0.549	0.316	0.865	10	-0.233	0.589	0.308	0.897	9	−0.281
SF7	0.575	0.291	0.866	9	-0.285	0.603	0.279	0.883	10	−0.324
SF8	0.645	0.474	1.119	6	-0.172	0.666	0.509	1.175	7	−0.157
SF9	0.471	0.789	1.259	3	0.318	0.483	0.835	1.318	4	0.352
SF10	0.427	0.808	1.235	4	0.380	0.462	0.865	1.327	3	0.403
SF11	-0.093	-0.279	0.372	13	0.186	−0.065	−0.385	0.450	13	0.320
SF12	0.602	0.749	1.351	2	0.147	0.648	0.800	1.448	2	0.153
SF13	-0.083	-0.245	0.328	14	0.163	−0.129	−0.268	0.397	14	0.139
SF14	0.240	0.873	1.113	7	0.633	0.188	1.026	1.214	5	0.838

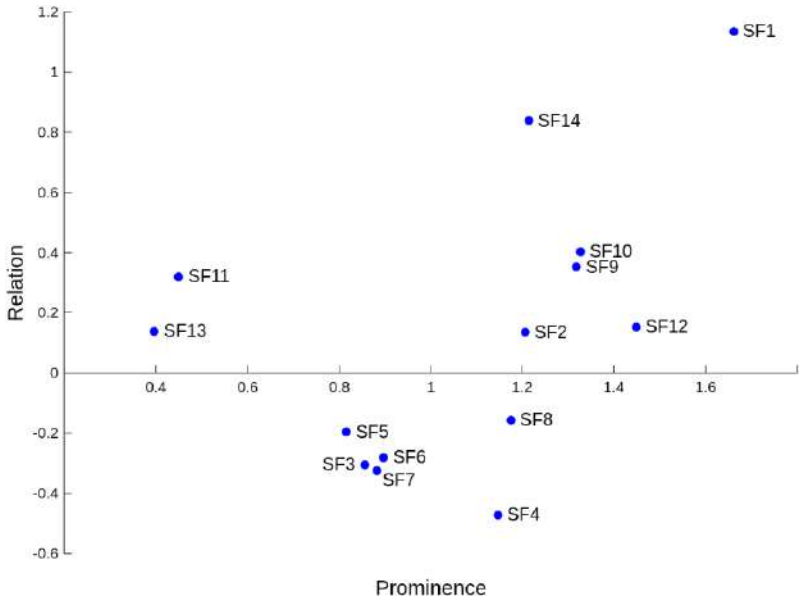


Figure 1. The causal diagram for 14 factors, derived by HISA

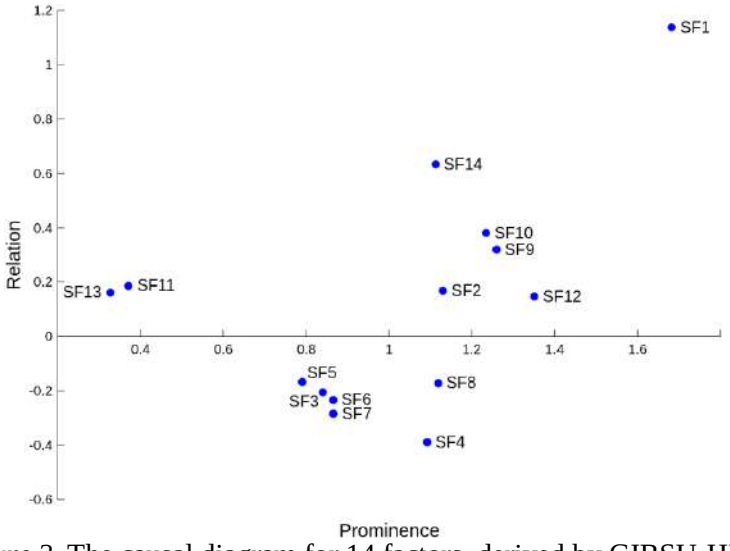


Figure 2. The causal diagram for 14 factors, derived by GIBSU-HISA

5. CONCLUSIONS

This paper presents the GIBSU-HISA method, a novel extension of the HISA technique for group decision-making under uncertainty. By incorporating interval-based aggregation of expert judgments and optimizing the balance between expert satisfaction and uncertainty, the proposed approach offers a more realistic representation of diverse expert opinions.

The comparative case study shows that GIBSU-HISA preserves the fundamental causal structure identified by the original HISA method while providing additional insights into the variability of expert assessments. Although the classification of factors into cause and effect groups remains unchanged, several differences in factor rankings were observed, reflecting a more nuanced and representative depiction of group consensus. The method also achieves a well-balanced trade-off between inclusiveness and precision, as indicated by the relatively high level of expert satisfaction and moderate uncertainty obtained for the optimal parameter value.

Despite its advantages, the proposed approach has certain limitations. Specifically, the specification of the expert satisfaction S and uncertainty U functions, including their parameter

settings, was based on reasonable assumptions rather than empirical validation. Future research should explore alternative parametrizations and functional shapes, as well as apply the method to diverse case studies to further assess its generalizability.

From a practical perspective, GIBSU-HISA provides decision makers with richer and more reliable information, supporting the identification of critical factors and more informed strategic planning. Future work may also examine its integration with other uncertainty modeling approaches, such as fuzzy or probabilistic frameworks.

ACKNOWLEDGMENT

Funding: This study was supported by the Slovenian Research Agency, Research Programs P4-0059.

REFERENCES

Chang, C.-C., & Pai, C.-J. (2025). Non-profit fundraising activities in a war environment: An exploration of hindrance factors using a modified Z-HISA hybrid model. *Journal of Business Research, 189*, 115209. https://doi.org/10.1016/j.jbusres.2025.115209

Dolinar, G., & Grošelj, P. (2026). GIBSU-DEMATEL: Enhancing group decision-making by integrating expert satisfaction and uncertainty in interval judgments. *Expert Systems with Applications*, *308*, 131141. https://doi.org/10.1016/j.eswa.2026.131141

Gabus, A., & Fontela, E. (1973). Perceptions of the world problematique: Communication procedure, communicating with those bearing collective responsibility. In *Battelle Geneva Research Centre, Geneva, Switzerland*.

Hsu, W.-C. J., Lo, H.-W., Lin, S.-W., & Zheng, Y.-T. (2024). Interaction measurement of success factors in the telemedicine development: Using a grey heterogeneous influence and strength attenuation technique. *Technology in Society*, *77*, 102596. https://doi.org/10.1016/j.techsoc.2024.102596

Huang, S.-C., Siao, Z., Gul, M., & Lo, H.-W. (2026). Exploring success factors in enterprise digital transformation in the electronics manufacturing sector: Using a modified grey HISA technique. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, *20*(2), 617–637. https://doi.org/10.1007/s12008-025-02423-2

Michnik, J. (2013). Weighted Influence Non-linear Gauge System (WINGS) – An analysis method for the systems of interrelated components. *European Journal of Operational Research*, *228*(3), 536–544. https://doi.org/10.1016/j.ejor.2013.02.007

Wang, Q., Jia, G., & Song, W. (2022). Identifying critical factors in systems with interrelated components: A method considering heterogeneous influence and strength attenuation. *European Journal of Operational Research*, *303*(1), 456–470. https://doi.org/10.1016/j.ejor.2022.02.012

Yang, C.-C., Lo, H.-W., Tang, K.-Y., & Lin, C.-W. (2025). A sustainability indicator framework for the funeral sector: Identification, interrelationship analysis, and performance assessment. *Environmental and Sustainability Indicators*, *28*, 100889. https://doi.org/10.1016/j.indic.2025.100889