33RD CONGRESS
OF THE INTERNATIONAL COUNCIL
OF THE AERONAUTICAL SCIENCES
STOCKHOLM, SWEDEN, 4-9 SEPTEMBER, 2022

ICAS 2022 SWEDEN

HUMAN-MACHINE FUNCTION ALLOCATION METHOD FOR SINGLE PILOT OPERATION USING HESITANT FUZZY 2-TUPLE LINGUISTIC INFORMATION

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Abstract

Single pilot operation(SPO) is the key technology for the next generation operation of the future commercial aircraft. It consists of single pilot in the cockpit, advanced onboard automation and ground airline operator. In order to make the overall system efficient, safe, reliable and economic, human-machine function allocation for single-pilot operation should comprehensively consider various factors. Thus, the human-machine function allocation can be viewed as a typical multiple attribute group decision making (MAGDM) problem under uncertainty and ambiguity. To this end, this paper introduces a human-machine function allocation method based on hesitant fuzzy 2-tuple linguistic information. Firstly, the prioritized weighted hesitant fuzzy 2-tuple linguistic Bonferroni mean (PWHF2TLBM) operator is defined. Then the human-machine function allocation method is proposed, where the evaluations of experts are presented in the form of hesitant fuzzy 2-tuple linguistic information, and the PWHF2TLBM operator is used to aggregate the evaluations of different attributes. Finally, an illustrative example is provided to demonstrate the practicality of this method.

Keywords: single pilot operation; human-machine function allocation, hesitant fuzzy set; 2-tuple linguistic information, Fuzzy 2-tuple linguistic Bonferroni mean (HF2TLBM) operator, prioritized weighted hesitant Fuzzy 2-tuple linguistic Bonferroni mean (PWHF2TLBM) operator

1. Introduction

With the development of automation and integration of large civil aircraft operation system, the minimum required number of flight crews has reduced from five in the 1950s to two nowadays [1], Meanwhile, the cost associated with pilots (salaries, benefits, training, etc.) has become a significant fraction of the airlines operating cost, and the shortage of experienced pilots has been unable to meet the rapid development of aviation market demand [2].

In order to reduce the high cost of pilots and the safety risks caused by different perceptions and inconsistent operations of two pilots, single-pilot operation (SPO) has been viewed by Federal Aviation Administration (FAA), aircraft manufacturers and airlines as the key technology for the next generation operation of the future commercial aircraft [3]. National Aeronautics and Space Administration (NASA) put forward the concept and operation architecture of single pilot operation system, and constructed the cooperative mode of single pilot in the cockpit, advanced onboard automation and ground airline operator, which laid the foundation for the development of single pilot operation technology [4]. Other researchers have proposed several different roles of ground operators [1] and estimated the required number of ground operators [5], which made the SPO closer to reality.

The key of single pilot operation technology is the human-machine function allocation between single pilot in the cockpit, advanced onboard automation and ground airline operator. Appropriate human-machine function allocation benefits the complement between single pilot in the cockpit, advanced onboard automation and ground airlines operator, and makes the single pilot operation system more effective and reliable.

In order to make the overall system efficient, safe, reliable and economic, human-machine function allocation for single-pilot operation should comprehensively consider various factors, which include functional requirements, workload of pilot, reliability of automation and cost of the system. Therefore, it can be viewed as a typical multiple attribute group decision making (MAGDM) problem, and many decision-making methods such as intuitionistic 2-tuple information, interval 2-tuple information, and evidence theory could be applied to handle this problem.

For human-machine function allocation problems, Ref. [6] proposed a method based on fuzzy analytic hierarchy process (FAHP), Ref. [7] combined the uncertain extended weighted arithmetic averaging (UEWAA) method and uncertain linguistic hybrid aggregation (ULHA) operators for function allocation. Ref. [8] integrated the interval 2-tuple linguistic (I2TL) information into humam-machine function allocation. For other MAGDM problems, Ref. [9] proposed a multiple attribute group decision-making (MAGDM) based on the plant growth simulation algorithm (PGSA) and interval 2-tuple weighted average operators. Ref. [10] proposed a method based on improved evidence theory and 2-tuple linguistic. The 2-tuple linguistic has shown its feasibility and flexibility to solve the MAGDM problems.

However, due to the complexity and uncertainty of cockpit function allocation process and the ambiguity of human thinking, when ergonomic experts are facing some objective and subjective limitations, they wouldn't be able to accurately measure the decision attribute, and they may only give fuzzy linguistic values of evaluation factors of function allocation, and sometimes even the linguistic value itself may be uncertain.

Because of this, several methods based on hesitant fuzzy linguistic information have been proposed. Ref. [11] proposed a MAGDM method based on hesitant 2-tuple linguistic information and TOPSIS method. Ref. [13] defined the expectation and variance of hesitant fuzzy 2-tuple linguistic set, and consequently proposed a decision-making method. Ref. [14] proposed a method based on distance measure of hesitant fuzzy 2-tuple linguistic set and entropy weight. Ref. [15] developed a method based on Hesitant Fuzzy McLaurin Symmetric Mean (HFMSM) algorithm and Archimedean norm.

For MAGDM problem, considering the interrelationship between variables is also important, and Bonferroni mean operator has an advantage of capturing this. Ref. [16] introduced 2-tuple linguistic Bonferroni averaging (2TLBA) operator, and weighted 2TLBA operator. At the principle of this, Ref. [17] defined a concept of hesitant Bonferroni element and a hesitant fuzzy Bonferroni mean operator. Ref. [18] proposed a prioritized weighted hesitant 2-tuple linguistic Bonferroni mean operator.

Focus on the problem of function allocation for single pilot operation, this paper introduced a novel pilot-automation-ground-operator function allocation method using the hesitant fuzzy 2-tuple linguistic information. Firstly, the notion of hesitant fuzzy 2-tuple sets is introduced, hesitant fuzzy 2-tuple linguistic Bonferroni mean (HF2TLBM) operator. Then, the prioritized weighted hesitant fuzzy 2-tuple linguistic Bonferroni mean (PWHF2TLBM) operator is defined. Next the human-machine function allocation method for single pilot operation based on hesitant fuzzy 2-tuple linguistic information is proposed. Finally, an example is presented to illustrate the effectiveness of the proposed method.

2. Preliminaries

Definition 1 [18]: Let $S^T = \{s_i \mid i = 0,1,\dots T\}$ be a collection of linguistic terms whose granularity is $T+1$, $H = \{(s_i, a_i) \mid i = 1,2,\dots c\}, c = card(H)$ be some 2-tuple linguistic terms in S^T, and c is the cardinality of H (In this paper, If not specified, function $card(\bullet)$ means the cardinality of the set in the parenthesis), then we call H a Hesitant Fuzzy 2-tuple Linguistic Set (HF2TS) with a granularity of $T+1$.

Definition 2 [18]: Let $H = \{(s_i, a_i) \mid i = 1,2,\dots c\}, c = card(H)$ be a HF2TS. Then the expectation value $S(H)$ and variance value $V(H)$ of H can be calculated as follows.

$$S(H)=\frac{1}{c}\sum_{k=1}^{c}\Delta^{-1}(s_k,a_k) \tag{1}$$

$$V(H)=\frac{1}{c}\left(\sum_{k=1}^{c}|\Delta^{-1}(s_k,a_k)-E(H)|^2\right)^{1/2} \tag{2}$$

where $\Delta^{-1}(s_k,a_k)=s_k+a_k=\beta_k$, β_k is the precise value of 2-tuple (s_k,a_k), we also have an operator $\Delta(\cdot)$ which means $\Delta(\beta_k)=(s_k,a_k)$, with $s_k=round(\beta_k)$ and $a_k=\beta_k-s_k, a_k\in[-0.5,0.5)$.

Let H^1 and H^2 be two HF2TSs, we can compare H^1 and H^2 by the following rules:

(1) If $E(H^1)<E(H^2)$, then $H^1<H^2$

(2) If $E(H^1)>E(H^2)$, then $H^1>H^2$

(3) If $E(H^1)=E(H^2)$, then: $\begin{cases} H^1<H^2, & if \quad V(H^1)>V(H^2) \\ H^1>H^2, & if \quad V(H^1)<V(H^2) \\ H^1=H^2, & if \quad V(H^1)=V(H^2) \end{cases}$

Definition 3: For n HF2TSs $\left\{H^1,H^2,\cdots,H^n\right\}$, the hesitant fuzzy 2-tuple weighted average (HF2TWA) operator is defined as:

$$HF2TWA(H^1,H^2,...,H^n)=\left\{\Delta\left(\sum_{i=1}^{n}w_i\cdot\Delta^{-1}(x_z^i)\right)\middle| x_z^i\in H^i, i=1,2...n, z=1,2,...,c_i\right\} \tag{3}$$

where $c_i=card\left(H^i\right)$ is the cardinality of H^i. $0\le w_1,w_2...w_n\le 1$, $\sum_{i=1}^{n}w_i=1$, and x_i^z is the zth value of linguistic set H^i.

Definition 4 [18]: For any $p,q\ge 0$, with $p+q>0$, let $\left\{d_1,d_2...d_n\right\}$ be a collection of n real numbers with $d_i\ge 0$, where d_i is a precise value. Then the Bonferroni mean (BM) operator is defined as:

$$BM^{p,q}(d_1,d_2,...,d_n)=\left(\frac{1}{n(n-1)}\sum_{i=1}^{n}\sum_{\substack{j=1\\ j\ne i}}^{n}d_i^p d_j^q\right)^{\frac{1}{p+q}} \tag{4}$$

Definition 5 [18]**:** Let $C=\{C_1,C_2...C_n\}$ be a set of n criteria with prioritization relationship $C_1>C_2...>C_n$ and $x_i=\left\{C_{i1},C_{i2},\cdots,C_{in}\right\}$ be the ith object defined on C, where C_{ij} represents the performance of the ith object regarding C_j. Then the prioritized weighted average (PWA) operator is defined as follows.

$$PWA(C_{ij})=\sum_{j=1}^{n}w_i C_{ij} \tag{5}$$

where $C_{ij}\in[0,1]$, and w_i is obtained by:

$$w_j=T_j/\sum_{j=1}^{n}T_j \tag{6}$$

where $T_1 = 1$ and $T_j = \prod_{l=1}^{j-1} C_{il} \, (j = 2,3...n)$.

3. Proposed human-machine function allocation method

Based on the hesitant fuzzy linguistic 2-tuple linguistic information, a novel human-machine function allocation method for single pilot operation is proposed, where the HF2TWA operator and the PWHF2TLBM operator are adopted. The main steps of the proposed method are summarized as follows:

3.1 Prioritized Weighted Hesitant Fuzzy 2-tuple Linguistic Bonferroni Mean operator

Definition 6: Let $H^1, H^2, ..., H^n$ be n HF2TSs. $H^i = \left\{ x_z^i \mid x_z^i = \left(s_z^i, a_z^i\right), z = 1,2,...,c_i \right\}$, $c_i = card(H^i)$. $w = \left[w_1, w_2, ..., w_n\right]$ is the weight vector obtained by (6) with prioritization relationship $H^{y_1} > H^{y_2} > ... > H^{y_n}$, in which $y_1, y_2, ..., y_n$ is a rearrangement of $1,2,...,n$. Then we define the prioritized weighted hesitant fuzzy 2-tuple linguistic Bonferroni mean (PWHF2TLBM) operator as follows.

$$
\begin{aligned}
&H' = PWHF2TLBM^{p,q}(H^1, H^2, ..., H^n) = \\
&\left\{ x_{z'} \left| x_{z'} = \Delta^{-1}\left(\left(\frac{1}{n(n-1)} \sum_{i=1}^{n} \sum_{\substack{j=1 \\ j \neq i}}^{n} \left(w_i \cdot \Delta^{-1}\left(x_{z_i}^i\right)\right)^p \cdot \left(w_j \cdot \Delta^{-1}\left(x_{z_j}^j\right)\right)^q \right)^{\frac{1}{p+q}} \right), z' = 1,2,...,c \right. \right\}
\end{aligned}
\tag{7}
$$

where $c = card\left(H'\right)$, and $c = \prod_{i=1}^{n} c_i$.

3.2 Human-machine function allocation method using the hesitant fuzzy 2-tuple linguistic information

Based on the hesitant fuzzy linguistic 2-tuple linguistic information, a novel human-machine function allocation method for single pilot operation is proposed, where the HF2TWA operator and the PWHF2TLBM operator are adopted. The main steps of the proposed method are summarized as follows:

Step 1: For the human-machine function allocation problem of single pilot operation, assume that $A = \left\{a_1, a_2, ..., a_i, ..., a_m\right\}$ is the allocation scheme set, $G = \left\{g_1, g_2, ..., g_j, ..., g_n\right\}$ and $D = \left\{d_1, d_2, ..., d_k, ..., d_t\right\}$ are correspondingly attributes set and decision-makers set. The weighted vector of decision-makers is $\lambda = \left[\lambda_1, \lambda_2, ..., \lambda_k, ..., \lambda_t\right]$, and the prioritization relationship of the attributes is $g_{j_1} > g_{j_2} > ... > g_{j_z} > ... > g_{j_n}$ in which $j_1, j_2, ..., j_z, ..., j_n$ is a rearrangement of $1,2,...,n$. Decision maker d_k provides the value $H_k^{ij} = \{h_{k1}^{ij}, h_{k2}^{ij}, ..., h_{kc_k^{ij}}^{ij}\}$ using hesitant fuzzy 2-tuple linguistic information for attribute $g_j \in G$ of the scheme $a_i \in A$, and then the evaluation matrix $R_k = \left(H_k^{ij}\right)_{m \times n}$ is obtained.

Step 2: Apply the HF2TLWA operator on the evaluation matrices R_k, $k = 1,2,...,t$ of different experts, and the comprehensive evaluation matrix $\hat{R} = \left(\hat{H}^{ij}\right)_{m \times n}$, $\hat{H}^{ij} = \left\{\hat{h}_1^{ij}, \hat{h}_2^{ij}, ..., \hat{h}_{\hat{c}_{ij}}^{ij}\right\}$, $\hat{c}_{ij} = card(\hat{H}^{ij})$ of decision-makers $d_1, d_2, ..., d_k, ..., d_t$ is obtained as:

$$\hat{H}^{ij} = \left\{ \Delta\left(\sum_{k=1}^{t} \left(\lambda_k \cdot \Delta^{-1}\left(h_{kl_k^{ij}}^{ij} \right) \right) \right) \middle| h_{kl_k^{ij}}^{ij} \in H_k^{ij}, l_k^{ij} = 1,2,\ldots,c_k^{ij}, c_k^{ij} = card(H_k^{ij}) \right\} \tag{8}$$

where $\lambda = [\lambda_1, \lambda_2, \ldots, \lambda_k, \ldots, \lambda_t]$ is the HF2TLWA operator's weight vector, with $\sum_{k=1}^{t} \lambda_k = 1$.

Step 3: Calculate the weight matrix $W' = \left(w_{j_z}^i\right)_{n\times m}$ of attributes $g_{j_1}, g_{j_2}, \ldots, g_{j_z}, \ldots, g_{j_n}$ under scheme $a_1, a_2, \ldots, a_i, \ldots, a_m$ using the prioritized aggregation operator as:

$$T_{j_z}^i = \begin{cases} 1, & j_z = 1 \\ \prod_{z=1}^{j_z-1} S\left(\hat{H}^{ij_z}\right), & j_z = 2,3,\ldots,n \end{cases} \tag{9}$$

$$w_{j_z}^i = T_{j_z}^i \,/\, \sum_{z=1}^{j_z} T_{j_z}^i \tag{10}$$

Rearrange the rows of the matrix $W' = \left(w_{j_z}^i\right)_{n\times m}$ and obtain the weight matrix $W = \left(w_j^i\right)_{n\times m}$ $j = 1,2,\ldots,n, i = 1,2,\ldots,m$ of attributes $g_1, g_2, \ldots, g_j, \ldots, g_n$.

Step 4: Apply the HF2TLBM operator on the evaluation matrix $\hat{R}$, and the collective group comprehensive assessed matrix $\hat{\hat{R}} = \left\{\hat{\hat{H}}^i\right\}_m$, $\hat{\hat{H}}^i = \left\{\hat{\hat{h}}_1^i, \hat{\hat{h}}_2^i, \ldots, \hat{\hat{h}}_{\hat{\hat{c}}^i}^i\right\}$ is obtained as:

$$\hat{\hat{H}}^i = \left\{ \Delta\left(\left(\frac{1}{n(n-1)} \cdot \sum_{j_1=1}^{n} \sum_{\substack{j_2=1 \\ j_2 \neq j_1}}^{n} \left(w_{j_1}^i \cdot \Delta^{-1}\left(\hat{h}_{\hat{l}^{ij_1}}^{ij_1}\right) \right)^p \cdot \left(w_{j_2}^i \cdot \Delta^{-1}\left(\hat{h}_{\hat{l}^{ij_2}}^{ij_2}\right) \right)^q \right)^{\frac{1}{p+q}} \right) \middle| \hat{h}_{\hat{l}^{ij_1}}^{ij_1} \in \hat{H}^{ij_1}, \hat{h}_{\hat{l}^{ij_2}}^{ij_2} \in \hat{H}^{ij_2} \right\} \tag{11}$$

where $\hat{l}^{ij_1} = 1,2,\ldots,\hat{c}^{ij_1}, \hat{l}^{ij_2} = 1,2,\ldots,\hat{c}^{ij_2}, \hat{c}^{ij_1} = card(\hat{H}^{ij_1}), \hat{c}^{ij_2} = card(\hat{H}^{ij_2}), j_1, j_2 = 1,2,\ldots,n$, and $w_{j_1}^i, w_{j_2}^i \in \left[w_1^i, w_2^i, \ldots, w_j^i, \ldots, w_n^i\right]$ is the weight of attribute g_{j_1}, g_{j_2} under scheme $a_i \in A$.

Step 5: Apply the expectation function and the variance function to group comprehensive assessed matrix $\hat{\hat{H}}^i, i = 1,2,\ldots,m$, and obtain the expectation vector $S = \left[\hat{\hat{H}}^1, \hat{\hat{H}}^2, \ldots, \hat{\hat{H}}^m\right]$ and the variance vector $V = \left[\hat{\hat{H}}^1, \hat{\hat{H}}^2, \ldots, \hat{\hat{H}}^m\right]$ of the schemes. Then different schemes could be ranked according to their quantitative value.

4. An illustrative example

In order to demonstrate the effectiveness and feasibility of the proposed method, an illustrate example the ground proximity warning system (GPWS) of the aircraft cockpit is presented.

Let D_1, D_2 and D_3 be the three decision-makers, and $\lambda = [0.4615,\ 0.3077,\ 0.2308]$ be their associated weights. The linguistic term set used by the DMs is shown as follows:

$$S^5 = \{s_0^5 = very\ bad,\ s_1^5 = bad,\ s_2^5 = normal,\ s_3^5 = good,\ s_4^5 = very\ good\}$$

Suppose $A = \{a_1, a_2, a_3\}$ is the function allocation schemes set, and the meaning of these schemes is summarized in Table 1:

Table 1: Schemes of function allocation for SPO.

No.	*scheme*
a_1	Pilot is responsible for GPW mission, and the rest 2 as backup
a_2	Automation is responsible for GPW mission, and the rest 2 as backup
a_3	Ground operator is responsible for GPW mission, and the rest 2 as backup

Suppose $G=\{g_1,g_2,g_3,g_4,g_5\}$ is the attributes set, whose elements correspond to five evaluation criteria: g_1 -reliability, g_2 -decision-making risk, g_3 -mental workload, g_4 -situation awareness, g_5 -system cost. The prioritized relationship of these attributes is $g_1 > g_2 > g_3 > g_4 > g_5$.

The decision-makers provide their hesitant fuzzy 2-tuple linguistic evaluation matrix R_k $(k=1,2,3)$ of $a_i(i=1,2,3)$ on the attribute $g_j(j=1,2,3,4,5)$ as Tables 2-4.

Table 2: Evaluation matrix R_1 of decision-maker d_1

	g_1	g_2	g_3	g_4	g_5
a_1	$\{(s_3^5,0.35),(s_4^5,0)\}$	$\{(s_0^5,0.25)\}$	$\{(s_2^5,0.11),(s_3^5,0.01)\}$	$\{(s_2^5,-0.11)\}$	$\{(s_2^5,0.01)\}$
a_2	$\{(s_0^5,0.3),(s_1^5,0.1)\}$	$\{(s_3^5,0.2)\}$	$\{(s_1^5,0.03),(s_2^5,0)\}$	$\{(s_2^5,0.12),(s_4^5,-0.21)\}$	$\{(s_2^5,0),(s_3^5,0.19)\}$
a_3	$\{(s_0^5,0.4),(s_1^5,0.12),(s_2^5,0.02)\}$	$\{(s_2^5,0.32)\}$	$\{(s_0^5,0),(s_2^5,0)\}$	$\{(s_1^5,0.07)\}$	$\{(s_1^5,0.3)\}$

Table 3: Evaluation matrix R_2 of decision-maker d_2

	g_1	g_2	g_3	g_4	g_5
a_1	$\{(s_4^5,-0.12)\}$	$\{(s_0^5,0.02),(s_0^5,0.11)\}$	$\{(s_3^5,0.02)\}$	$\{(s_2^5,0.2)\}$	$\{(s_2^5,0.03)\}$
a_2	$\{(s_1^5,-0.05)\}$	$\{(s_4^5,-0.02)\}$	$\{(s_2^5,0.24)\}$	$\{(s_3^5,0.05)\}$	$\{(s_3^5,0.23)\}$
a_3	$\{(s_2^5,0.3)\}$	$\{(s_1^5,0),(s_2^5,0.32)\}$	$\{(s_1^5,0.21)\}$	$\{(s_0^5,0.33)\}$	$\{(s_1^5,0.2)\}$

Table 4: Evaluation matrix R_3 of decision-maker d_3

	g_1	g_2	g_3	g_4	g_5
a_1	$\{(s_4^5,-0.08)\}$	$\{(s_1^5,0.2)\}$	$\{(s_4^5,0)\}$	$\{(s_2^5,0.13)\}$	$\{(s_2^5,0.01)\}$
a_2	$\{(s_0^5,0.23)\}$	$\{(s_4^5,-0.3)\}$	$\{(s_3^5,0.21)\}$	$\{(s_4^5,0)\}$	$\{(s_1^5,0),(s_3^5,0.39)\}$
a_3	$\{(s_1^5,0.06)\}$	$\{(s_2^5,0.14)\}$	$\{(s_2^5,0.23)\}$	$\{(s_1^5,0.04)\}$	$\{(s_0^5,0.47)\}$

Then the evaluation of different decision-makers on the same attribute could be aggregated to obtain a comprehensive evaluation matrix $\hat{R}=\left(\hat{H}^{ij}\right)_{3\times 5}$ by using the HF2TLWA operator, and the HF2TL weighted array of each decision-maker is $\lambda=[0.4615,0.3077,0.2308]$. Thus, the comprehensive evaluation matrix $\hat{R}$ of decision-makers is obtained, as shown in Table 5.

Table 5: Comprehensive evaluation matrix $\hat{R}$

	g_1	g_2	g_3	g_4	g_5
a_1	$\{(s_4^5,-0.36),(s_4^5,-0.06)\}$	$\{(s_0^5,0.4),(s_0^5,0.43)\}$	$\{(s_3^5,-0.17),(s_3^5,0.24)\}$	$\{(s_2^5,-0.01)\}$	$\{(s_2^5,0.02)\}$
a_2	$\{(s_0^5,0.48),(s_1^5,-0.15)\}$	$\{(s_4^5,-0.45)\}$	$\{(s_2^5,-0.09),(s_2^5,0.35)\}$	$\{(s_3^5,-0.16),(s_4^5,-0.39)\}$	$\{(s_2^5,0.15),(s_3^5,-0.3),(s_3^5,-0.3),(s_3^5,0.25)\}$
a_3	$\{(s_1^5,0.14),(s_1^5,0.47),(s_2^5,-0.12)\}$	$\{(s_2^5,-0.13),(s_2^5,0.28)\}$	$\{(s_1^5,-0.11),(s_2^5,-0.19)\}$	$\{(s_1^5,-0.16)\}$	$\{(s_1^5,0.08)\}$

Calculate the weight matrix $W=\left(w_j^i\right)_{5\times 3}$ of attributes $g_j(j=1,2,3,4,5)$ under each scheme $a_i(i=1,2,3)$ using Eqs. (9)-(10) with the prioritized relationship of attributes $g_1 > g_2 > g_3 > g_4 > g_5$, and the weight matrix is obtained as:

$$W=\begin{bmatrix} 0.05 & 0.04 & 0.08 \\ 0.18 & 0.03 & 0.11 \\ 0.08 & 0.09 & 0.23 \\ 0.23 & 0.2 & 0.32 \\ 0.46 & 0.64 & 0.26 \end{bmatrix}$$

Then we can obtain the collective group comprehensive assessed matrix $\hat{\hat{R}}=\left\{\hat{\hat{H}}^i\right\}_3$ using Eq. (11), by applying the expectation function and the variance function on each $\hat{\hat{H}}^i, i=1,2,3$, we can have the expectation vector $S=\left[0.3436,0.5231,0.2353\right]$ and the variance vector $V=\left[0.0015,0.0058,0.0033\right]$ of the three schemes a_1,a_2,a_3.

Compare the expectation value and the variance value, the ranking order of the three different schemes is obtained as: $a_2 > a_1 > a_3$, that is to say, a_2 is the best function allocation scheme.

5. Conclusions

Single-pilot operation represents a viable concept for commercial aircraft as the potential benefits in crew member reduction. A function allocation method based on hesitant fuzzy 2-tuple linguistic set, prioritized weighted aggregation and the Bonferroni mean for SPO is proposed in this paper. By using hesitant fuzzy 2-tuple linguistic information, the proposed method can handle the ambiguity and uncertainty in human-machine allocation of single pilot operation and avoid loss of information and deviation of decisions.

In summary, the proposed method provides a more reasonable and reliable method for human-machine function allocation of single-pilot operation, and provides references for the design of the human-machine interface and formulation of single-pilot operation procedures for commercial airliners.

6. Acknowledgment

This work is partially supported by the National Natural Science Foundation of China (Nos. 61903305, 62073267), the Aeronautical Science Foundation of China (No. 201905053001), and the Research Funds of Interdisciplinary Subject, NWPU.

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8. Copyright Statement

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