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Intuitionistic Fuzzy VIKOR Method for Facility Location Selection Problem

S.S. Alkafaas
Instructor,
Production Engineering and Mechanical Design Department, Faculty of Engineering, Menoufia University, Shebin El Kom, Egypt.

M. Fattouh
Professor,
Production Engineering and Mechanical Design Department, Faculty of Engineering, Menoufia University, Shebin El Kom, Egypt.

R. Masoud
Associate Professor,
Basic Engineering Sciences Department, Faculty of Engineering, Menoufia University, Shebin El Kom, Egypt.

O. Nada
Lecture,
Production Engineering and Mechanical Design Department, Faculty of Engineering, Menoufia University, Shebin El Kom, Egypt.

***Abstract*: The selection of a facility location, which is a kind of multi-criteria decision-making (MCDM) problem, should be considered strategically. The purpose of this paper is to demonstrate and validate the application of the intuitionistic fuzzy VIKOR (IF-VIKOR) method to solve one problem of real-time location selection of facilities, in which the criteria values are described in exact (crisp) values form. Firstly, the decision matrix is fuzzified and then transformed into an intuitionistic fuzzy decision matrix. The criteria weights are determined using the Intuitionistic fuzzy entropy weight method. Euclidean distance measure is used in this work. The ranking performance of IF-VIKOR is discussed and compared with the other conventional MCDM methods obtained by past researchers to assess the impact of the IF- VIKOR method.**

It is observed that the ranking largely remains unchanged in almost all the applied methods and the first two top alternatives exactly match with those as obtained by the past researchers. There exists a high Spearman's rank correlation coefficient value between IF-VIKOR method and other conventional methods. The comparative analysis, therefore, confirms that no matter the changes made to the MCDM method and weights of the criteria (crisp and/or IF set).

Keywords: Facility Location Selection Problem; MCDM; IF-VIKOR

I. INTRODUCTION

Facility location selection is the determination of a geographic site for a firm's operations. The facility location decision contains organizations looking to locate, relocate, or develop their operations. The facility location decision process includes the identification, analysis, evaluation, and selection of alternatives, [1]. Selecting a plant location is a very significant decision for firms because they are costly and difficult to inverse, and they need a long term guarantee. And also position decisions have an influence on operating costs and profits. For instance, an unfortunate choice of location might result in unnecessary transportation costs, a shortage of qualified labor, loss of competitive advantage, inadequate supplies of raw materials, or some similar condition that would be disadvantageous to operations.

There are four famous conventional approaches are usually used in the facility location selection; factor rating system, break-even analysis, enters of gravity method, and transportation method as in [2].

Facility location selection is a typical multi-criteria decision making (MCDM) problem. Past researchers have already applied different conventional MCDM techniques to deal with the facility location selection problems. Reference [3] presented a survey about multiple criteria facility location problems. Reference [4] presented a TOPSIS methodology to find the supportive centers in military logistic systems. Reference [5] considered a facility location selection problem consisting of six alternative facility locations and five different criteria. Reference [6] applied different crisp decision-making techniques. SAW, weighted product method (WPM), AHP, graph theory and matrix approach (GTMA), TOPSIS and modified TOPSIS methods to deal with the facility location selection problem considered as in [5]. Reference [7] applied PROMETHEE II method to deal with the same problem.

However, a key drawback of the most conventional MCDM approaches is the need for accurate measurement of the performance values and criteria weights. The most conventional MCDM approaches for facility location problems tend to be less effective in dealing with the imprecise or vague nature of the linguistic assessment. In real life, the evaluation data of plant location suitability for various subjective criteria, and the weights of the criteria are usually expressed in linguistic terms. And also, to efficiently resolve the ambiguity frequently arising in available information and do more justice to the essential fuzziness in human judgment and preference, the fuzzy set theory has been used to establish an ill-defined multiple criteria decision-making problems.

Reference [8] developed a fuzzy SAW for solving facility location selection problems. Reference [9] applied a fuzzy TOPSIS method-based approach to solve the solid waste transshipment site selection problem. Reference [10] focused on the applications of fuzzy AHP and fuzzy TOPSIS methods for solving facility location selection problems. Reference [11] presented a Z-PROMETHEE with Z-numbers as a new

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representation of vague information for a facility location selection problem.

The literature review above indicates that the majority of the previous studies evaluated and selected facility locations under a crisp and fuzzy environment. However, the fuzzy set theory cannot be used to completely tackle vague and imprecise data given by decision-makers. The IF set theory has been used to establish an ill-defined facility location selection problem. Reference [12] proposed the IF TOPSIS method for dealing with imprecise information on the facility location selection problem.

Given the strengths and wide applications of the VIKOR method and IFSs, this paper attempts to bridge the gap in the literature by developing an intuitionistic fuzzy VIKOR method for solving facility location selection problems.

The primary contributions of this study are summarized as follows: (1) to deal with the uncertainty and vagueness in facility location selection problems. performance ratings of alternatives are taken as crisp values denoted by IF numbers; (2) IF- entropy weight method is proposed to define criteria weights in solving the selection problems; and (3) to identify the most appropriate location, an extended VIKOR method is used for the ranking of the considered alternatives. Furthermore, one empirical example of facility location selection is provided to illustrate the applicability and effectiveness of the IF- VIKOR method.

The remainder of this paper is organized as follows. Section 2 reviews some basic concepts of IFSs. In Section 3, one application example is demonstrated to highlight the applicability of the IF VIKOR method. In Section 4, a comparative analysis is conducted. The final section summarizes the main work of this paper with a discussion of implications for future research.

II. PRELIMINARIES

A. *Intuitionistic Fuzzy Set (IFS)*

An intuitionistic fuzzy set A in the universe of discourse X is defined as follows [13] :

$$A = \{ \langle x, \mu A (x) , \nu A (x) \rangle | x \in X\} \quad (1)$$

Where $\mu A (x)$, $\nu A (x)$: $X \rightarrow [0,1]$ respectively represent the membership and non-membership functions on condition that $0 \le \mu A (x) + \nu A (x) \le 1$. Additionally, IFS introduces a third construct $\pi A (x)$, the intuitionistic fuzzy index which expresses whether or not x belongs to A.

$$\pi A = 1 - \mu A (x) - \nu A (x) \quad (2)$$

The intuitionistic index in (2) measures the hesitancy degree of element x in A where it becomes obvious that $0 \le (x) \le 1$ for each $x \in X$. A small value of $\pi A (x)$ implies that information about x is more certain. On the other hand, a higher value of the hesitancy degree $\pi A(x)$ means the information that x holds is more uncertain. An intuitionistic fuzzy set can therefore fully be defined as:

$$A = \{ \langle x, \mu A (x), \nu A (x), \pi A (x) \rangle | x \in X \}$$

Where $\mu A \in [0,1]$; $\nu A \in [0,1]$; $\pi A \in [0,1]$

πA is also frequently referred to as the degree of hesitancy of x to A. It expresses the degree of uncertainty in the assessment as to whether x is, or is not, a member of IFS.

B. *Construct IF Set from Crisp set*

In this step, IFS can be created by the following sub steps:

- Define the universe of discourse for the crisp set by taking their real numerical values.
- Construct the proper fuzzy sets for each crisp criterion. The process of transforming a crisp value to a fuzzified grade of membership is known as fuzzification. The membership function formation includes graphical representations in the form of different shapes and equations and can be implemented and used. In this work, the vector normalization is used as a membership function.

$$P_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (3)$$

- Apply the method [14] to construct IFS from FS obtained in Step 2.

C. *Intuitionistic Fuzzy Entropy (IFE)*

Different from the traditional entropy method, IFE focuses on the credibility of the input data to determine criteria weights. It measures the extent of separation of the IFSs from fuzzy sets rather than from ordinary sets as in the traditional entropy method. Several widely used IFE are proposed. Reference [15] derived an entropy value for IFSs and the intuitionistic fuzzy entropy weight as in [16]. The entropy value for each criterion can be calculated as:

$$E_J = -\frac{1}{m \ ln2} \sum_{i}^{m} [\mu_{ij} ln \mu_{ij} + \nu_{ij} ln \nu_{ij} - (1 - \pi_{ij}) ln \, (1 - \pi_{ij}) - \pi_{ij} ln2]. \quad j = 1.2 \ldots\ldots n \quad (4)$$

The objective weights of criteria can be evaluated as follows:

$$W_j = \frac{1 - E_j}{\sum_{j=1}^{n}(1 - E_j)} \ . \quad j = 1.2 \ldots\ldots n \quad (5)$$

where n is the number of criteria

2.3. Distance Measure Between IFSs

Let A and B be two IFSs in the universe of discourse X, where $A = \{\langle x\ i, (xi), \nu_{A(xi)} \rangle \mid$ and $B = \{\langle x\ i, uB(xi), \nu_{B(xi)} \rangle \mid xi \in X\}$. Several widely used distance measures are proposed. Reference [17] proposed Euclidean distance as (6):

$$d_E(A.B) = \sqrt{\frac{1}{2}\sum_{i=1}^{n}\left[(\mu_A(x_i) - \mu_B(x_i))^2 + (\nu_A(x_i) - \nu_B(x_i))^2 + (\pi_A(x_i) - \pi_B(x_i))^2\right]} \quad (6)$$

III. IF-VIKOR METHOD FOR MADM

As per, Reference [18], [19] initially proposed VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje), which means multi-criteria optimization and compromise solution. This method focuses on ranking and selecting from a set of alternatives, and determines compromise solutions for a problem with conflicting criteria, which can help the decision-makers to reach a final decision. Here, the compromise solution is a feasible solution that is the closest to the ideal, and a compromise means an agreement established by mutual concessions. It introduces the multi-criteria ranking index based on the particular measure of ‘closeness” to the ‘‘ideal”.

$$S_i = \sum_{j=1}^{n} w_j \left(\frac{d(x_j^+ . x_{ij})}{d(x_j^+ . x_j^-)} \right) \tag{8}$$

$$R_i = max_j w_j \left(\frac{d(x_j^+ . x_{ij})}{d(x_j^+ . x_j^-)} \right) \tag{9}$$

$$Q_i = \gamma \frac{(S_i - S^*)}{(S_i - S^*)} + (1 - \gamma) \frac{(R_i - R^*)}{(R_i - R^*)} \tag{10}$$

Where S^- = max$i$ S_i, S^* = min$i$ Si, R^- = maxiR_i, S^* = min$i$ R_i . γ is the coefficient of decision mechanism. The compromise solution can be elected by majority (γ > 0.5), consensus (γ = 0.5), or veto (γ < 0.5).

Step 5: Rank the alternatives and derive the compromise solution.

Sort S_i,R_i , and Q_i in ascending order and generate three ranking lists S, R, and Qsuch that the lower the value the better the alternative. Then, the alternative a′ that ranks the best in Q (minimum value) and fulfills the following two conditions simultaneously would be the compromise solution.

- Condition 1 (acceptable advantage). One has Q(a″) −Q(a′) ⩾ DQ where a″ is the alternative which is ranked second by Q and DQ $= \frac{1}{(m-1)}$
- Condition 2 (acceptable stability). The alternative a′ should also be the best ranked by Si and Ri.

If one of the conditions in Step 5 is not satisfied, propose a set of compromise solutions which include:

- Alternatives a′ and a″ if only Condition 2 is not satisfied, or
- Alternatives a′, a″, a(n) if only Condition 1 is not satisfied; the closeness of the alternative a(n) ranked nth by Q is determined by

Q(a(n)) −Q(a′) < DQ for the maximum.

IV. CASE STUDY ILLUSTRATION

Reference [4] considered a facility location (plant location) selection problem consisting of six alternatives (locations) and five different criteria. The five different criteria are cost of land (C_1), cost of energy (C_2), cost of raw materials (C_3), the cost of transportation (C_4) and the cost of labor (C_5). All these criteria are non-beneficial where smaller values are desirable. In this work, the Bhattacharya dataset of facility location selection problem is considered as the case study. This MCDM problem is listed in Table (1).

Table (1): Quantitative information of Bhattacharya of facility location selection problem

Location	C1	C2	C3	C4	C5
A1	3,300,000	2.5	142	6	214
A2	2,500,000	3.1	179	5.8	175
A3	5,200,000	3.6	138	7.8	325
A4	2,500,000	2.8	195	8.4	252
A5	2,000,000	3.2	167	6.3	155
A6	5,700,000	3.7	142	6	214

A. *Case Study Solution*

Reference [5] has been solved herein to exhibit the application potential of IF - VIKOR.

Since the weights of attributes and IF DM are completely unknown, the best alternative would be selected with the information given above. In the following, the IF-VIKOR method is applied to solve this problem. The operation process is given below.

Phase 1: It is necessary to construct the IF decision matrix and determine the IF entropy weight of each criterion before applying the IF – VIKOR.

Step 1: Constructing the IF Decision Matrix

Firstly, it is necessary to construct the IF decision matrix from a crisp decision matrix Table (1).

Intuitionistic fuzzy decision matrix can be created as the following:

Crisp numerical values of each criterion C_j are fuzzified by using vector normalization as the membership function of the fuzzy set. The following fuzzy data values of C_j are obtained and listed in Table (2).

Table (2): Fuzzy decision matrix.

Location	C1	C2	C3	C4	C5
A1	0.3540	0.3468	0.3445	0.3645	0.3939
A2	0.2682	0.4300	0.4342	0.3523	0.3221
A3	0.5578	0.4993	0.3348	0.4738	0.5982
A4	0.2682	0.3884	0.4731	0.5103	0.4638
A5	0.2145	0.4438	0.4051	0.3827	0.2853
A6	0.6114	0.5132	0.4391	0.3341	0.2945

II Apply the method as in [14] as applied by [26] to construct IFSs from FSs obtained in Step 1.

The IF decision matrix is constructed as showing in Table (3)

Table .3: Intuitionistic Fuzzy Decision Matrix.

Loction	**C_1**	**C_2**	**C_3**
A_1	(0.3075.0.5613.0.1312)	(0.2850.0.5370.0.1780)	(0.2899.0.5517.0.1584)
A_2	(0.2330.0.6359.0.1312)	(0.3535.0.4686.0.1780)	(0.3655.0.4762.0.1584)
A_3	(0.4846.0.3842.0.1312)	(0.4105.0.4116.0.1780)	(0.2818.0.5599.0.1584)
A_4	(0.2330.0.6359.0.1312)	(0.3193.0.5028.0.1780)	(0.3981.0.4435.0.1584)
A_5	(0.1864.0.6825.0.1312)	(0.3649.0.4572.0.1780)	(0.3410.0.5007.0.1584)
A_6	(0.5312.0.3376.0.1312)	(0.4219.0.4002.0.1780)	(0.3696.0.4721.0.1584)

Loction	**C_4**	**C_5**
A_1	(0.3023.0.5272.0.1705)	(0.3267.0.5027.0.1707)
A_2	(0.2923.0.5372.0.1705)	(0.2671.0.5622.0.1707)
A_3	(0.3930.0.4365.0.1705)	(0.4961.0.3332.0.1707)
A_4	(0.4233.0.4062.0.1705)	(0.3847.0.4447.0.1707)
A_5	(0.3175.0.5120.0.1705)	(0.2366.0.5927.0.1707)
A_6	(0.2771.0.5524.0.1705)	(0.2442.0.5851.0.1707)

Step 2: Determine the IF Entropy Weight of each Criterion

Based on the objective weighting method, the IFE value of each criterion is obtained by (4) and the objective criteria weights are calculated based on (5). Therefore, the weight vector is

$$W = (0.4174.0.0748.0.1204.0.1410.0.2464)^T$$

Phase 2: Applying the IF-VIKOR

Step 1. Determine the Best and Worst Value for all criteria

The best value and the worst value for all criteria can be determined by using (7) and the IF decision matrix Table (3) as the following:

$$X_j^+ = \{(0.1864.0.6825.0.1312).(0.2850.0.5370.0.1780).$$
$$(0.2818.0.5599.0.1584).(0.2771.0.5524.0.1705).(0.2366.0.5927.0.1707)\}$$

$$X_j^- = \{(0.5312.0.3376.0.1312).(0.4219.0.4002.0.1780).(0.3981.0.4435.0.1584).$$
$$(0.4233.0.4062.0.1705).(0.4961.0.3332.0.1707)\}$$

Step 2. Compute the values Si, Ri, and Qi.

Table (4): Utility value for each criterion S_{ij} and group utility value S_i for all alternatives.

Location	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_i
A1	0.1467	0.0000	0.0085	0.0243	0.0855	0.2649
A2	0.0564	0.0374	0.0866	0.0146	0.0290	0.2240
A3	0.3610	0.0686	0.0000	0.1118	0.2464	0.7878
A4	0.0564	0.0187	0.1204	0.1410	0.1406	0.4771
A5	0.0000	0.0436	0.0613	0.0389	0.0000	0.1438
A6	0.4174	0.0748	0.0908	0.0000	0.0072	0.5903

The group utility value for alternative A1 in Table 5 is calculated by using (8) as follows:

$$S_1 = 0.1467 + 0 + 0.0085 + 0.0243 + 0.0855 = 0.2649$$

The same calculation steps can be performed to obtain the group utility value S_i for each alternative as given in Table (4). The individual regret value R_1 for alternative A_1 in Table (5) is calculated by using (9) as follows:

$$R_1 = max_j(d_{ij}) = 0.1467$$

The individual regret value R_i for each alternative are presented in Table 5.

Without loss of generality, let γ = 0.5. By using (10) the value of Qi for each alternative can be obtained. The compromise value Q_i for each alternative are listed in Table (5)

Table (5) Compromise Value Qi for each Alternative

Location	Si	Ri	Qi
A1	0.2649	0.1 467	0.2139------- 3 a″
A2	0.2240	0.0866	0.0979 ------- 2 a″
A3	0.7878	0.3610	0.9208 6
A4	0.4771	0.1410	0.3707 4
A5	0.1438	0.0613	0.0000 ------- 1 a'
A6	0.5903	0.4174	0 8467 5

where, a', a″, and a″ are the top three alternatives in Qi.

Step 3. Rank the Alternatives and Derive the Compromise Solution.

From the Table (5), It can be clearly identified that the ranking result based on the measure Q is: $A_5 < A_2 < A_1 < A_4 < A_6 < A_3$ reaching the conclusion .

That A_5 (minimum Q value) is the best choice and A_3 is the worst choice (maximum Q value) for the selection problem.

The ranking result based on the measure Q obtained from Table (5), has been checked for acceptability conditions. To validate the ranking results based on the measure Q, the two already explained conditions required to be satisfied:

- Condition 1 (acceptable advantage). One has

Q (a″) − Q (a′) ⩾ DQ. Not Satisfied

- Condition 2 (acceptable stability). The alternative A_1should also, be the best ranked by Si and Ri.

Alternative A_1 is the best ranked by S and R. Satisfied

If one of the above conditions is not satisfied, then a set of compromise solutions is proposed.

The condition 1 (acceptable advantage) is not satisfied; then alternatives a′, a″, and a″ are considered as compromise solutions; a(n) is determined by the relation

Q(a(n)) −Q(a′) < DQ for maximum n (the positions of these alternatives are ‘‘in closeness”).

It can be clearly identified that the ranking result based on the measure Q $A_5 = A_2 < A_1 < A_4 < A_6 < A_3$ and the alternatives A_5 and A_2 are only compromised solutions.

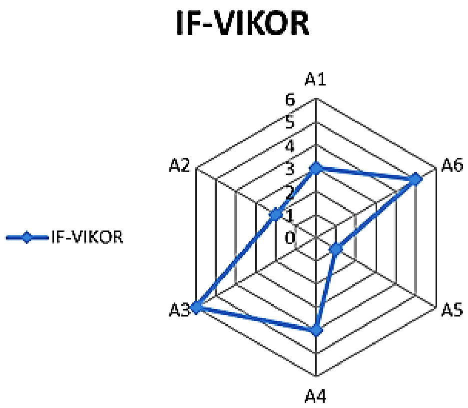

Fig. 1. Ranking of alternatives.

V. COMPARATIVE ANALYSIS

References [6] & [7] have already applied different crisp decision-making techniques to deal with the facility location selection problem considered by [5].

The results obtained by [6] & [7], and the IF MCDM methods considered in this work are listed in Table (6) and Figure. 2.

The results show that the ranking remains unchanged in almost all the methods applied by [6] except in the TOPSIS method where alternative A3 outranks alternative A6 as compared to the other methods as in [6].

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The ranking order thus obtained through the exploration of the IF-VIKOR approach has been compared. It is observed that the two top-ranked alternatives A5and A2 exactly match with those as obtained as in [6-7].

Table (6) Comparative Review of Obtained Results [6] & [7] and the IF MCDM approach.

CRISP-MCDM								*IF-MCDM*
Rao							*Athawale*	*Present Work*
location	*WPM*	*GTMA*	*SAW*	*AHP*	*TOPSIS*	*M.TOPSIS*	*METHEEII*	*IF VIKOR*
A1	3	3	3	3	3	3	3	3
A2	2	2	2	2	2	2	2	2
A3	6	6	6	6	5	6	4	6
A4	4	4	4	4	4	4	5	4
A5	1	1	1	1	1	1	1	1
A6	5	5	5	5	6	5	6	5

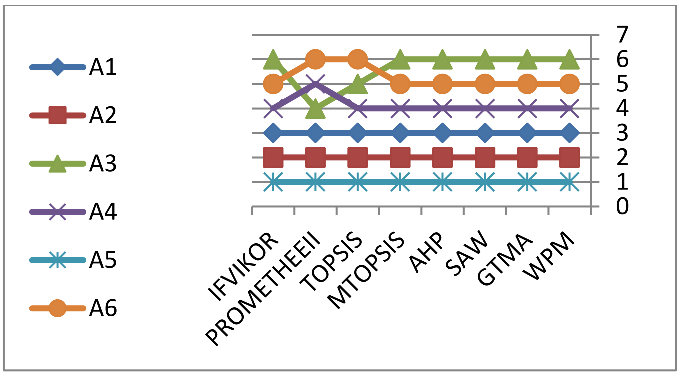

Fig.2.Plot of Comparative analysis of Obtained Results [6] & [7] and the IF MCDM approaches.

It can be seen that ranking largely remains unchanged especially among the first 2 ideal alternatives. The comparative analysis, therefore, confirms that no matter the changes made to the MCDM methods (crisp and/or IF) and weights of the criteria (traditional and/or IF), alternatives A5 and A2 remain the best alternatives in the selection of facility locations, but it is reflecting on the ranking order of alternatives.

Table (7) shows the Spearman's rank correlation coefficient values when the rankings of the alternative facility locations as obtained using IF-VIKOR and other MCDM methods as in [6] & [7]. It is observed that the Spearman's rank correlation coefficient value ranges from 0.83 to 1. There exists a high Spearman's rank correlation coefficient value between IF-VIKOR and SAW, WPM, AHP, GTMA, and M TOPSIS methods which suggests that these two MCDM methods are similar regarding their ranking perform.

The ranking performance of the IF-VIKOR method with respect to other MCDM methods are observed to be quite satisfactory which asserts the justification that the same can also be applied to other strategic decision-making problems.

Table .7. the Spearman's rank correlation coefficient values

	WPM	**GTMA**	**SAW**	**AHP**	**MTOPSIS**	**TOPSIS**	**METHEEII**	**IF TOPSIS**	**IF GRA**
IF-VIKOR	1	1	1	1	1	0.94	0.83	0.94	0.94

VI. CONCLUSIONS

Since the VIKOR method is an effective MCDM method to reach a compromise solution, and IFSs are an effective tool to depict fuzziness and non-specificity in assessment information, this paper combines them to deal with those facility location selection problems in which the importance of criteria are given and described in exact (crisp) values form. To illustrate the feasibility and effectiveness of the proposed IF-VIKOR, [5] facility location selection problem is considered in this work and the obtained result is compared with the other conventional MCDM methods obtained by past researchers.

It is observed that the ranking largely remains unchanged in almost all the applied methods and the first two top alternatives exactly match with those as obtained by the past researchers. There exists a high Spearman's rank correlation coefficient value between IF- VIKOR method and other conventional methods. The comparative analysis, therefore, confirms that no matter the changes made to the MCDM method and weights of the criteria (crisp and/or IF set). Also, the proposed IF-VIKOR method is a general method, which can be used for other areas of decision-making problems.

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