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Article

A Hybrid Intuitionistic Fuzzy Group Decision Framework and Its Application in Urban Rail Transit System Selection

Bing Yan [1], Yuan Rong [2], Liying Yu [2] and Yuting Huang [2,*]

[1] School of Urban Railway Transportation, Shanghai University of Engineering Science, Shanghai 201620, China; bingyan@sues.edu.cn
[2] School of Management, Shanghai University, Shanghai 200444, China; ry1995@shu.edu.cn (Y.R.); yuliying@shu.edu.cn (L.Y.)
* Correspondence: huangyuting1018@shu.edu.cn

Abstract: The selection of an urban rail transit system from the perspective of green and low carbon can not only promote the construction of an urban rail transit system but also have a positive impact on urban green development. Considering the uncertainty caused by different conflict criteria and the fuzziness of decision-making experts' cognition in the selection process of a rail transit system, this paper proposes a hybrid intuitionistic fuzzy MCGDM framework to determine the priority of a rail transit system. To begin with, the weights of experts are determined based on the improved similarity method. Secondly, the subjective weight and objective weight of the criterion are calculated, respectively, according to the DEMATEL and CRITIC methods, and the comprehensive weight is calculated by the linear integration method. Thirdly, considering the regret degree and risk preference of experts, the COPRAS method based on regret theory is propounded to determine the prioritization of urban rail transit system ranking. Finally, urban rail transit system selection of City N is selected for the case study to illustrate the feasibility and effectiveness of the developed method. The results show that a metro system (P_1) is the most suitable urban rail transit system for the construction of city N, followed by a municipal railway system (P_7). Sensitivity analysis is conducted to illustrate the stability and robustness of the designed decision framework. Comparative analysis is also utilized to validate the efficacy, feasibility and practicability of the propounded methodology.

Keywords: urban rail transit; intuitionistic fuzzy set; regret theory; DEMATEL; CRITIC; COPRAS

MSC: 90B50; 94D05

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1. Introduction

At present, environmental problems, such as acid rain, air pollution and global warming, are prominent. One of the important reasons for this series of environmental problems is the emission of a large number of greenhouse gases caused by urban traffic operation. Severe environmental problems affect the ecological balance and human health [1]. The large-scale increase in the number of cars stems from the deepening degree of urbanization. The process of urbanization is accelerating, the construction of urban infrastructure is gradually improving and many cities have successfully entered the automotive era with the progress of society and economic development. However, although the popularity of cars has greatly facilitated people's lives, a series of problems, such as vehicle exhaust pollution and traffic congestion, need to be paid attention to. Urban environmental problems caused by automobile operation restrict the green development of the city. As the center of population, economy and transportation, it is particularly important to realize urban sustainable development.

Green travel can save energy, alleviate traffic congestion, reduce environmental pollution and promote sustainable urban development. An urban public transport system plays an important role in promoting urban sustainable development [2]. As one of the most effective green and low-carbon transportation modes, urban public transport is an important part of green travel. It is mainly composed of buses and urban rail transit. Buses can meet the daily travel of the public in small cities, but buses are far from meeting the daily travel of the public in medium and large cities with a large population density, wide range of activities and large passenger flow. Therefore, in order to alleviate the traffic pressure in urban areas, the construction of an urban rail transit system has become the focus of attention. As the backbone of urban public transport, urban rail transit has the characteristics of being fast, convenient, efficient, safe and comfortable [3]. With the development of the economy and the progress of science and technology, urban rail transit has developed rapidly, but, in this process, its green standard has been formulated relatively late and a perfect development system has not been formed, resulting in a series of problems regarding that the existing urban rail transit does not adapt to the green development in terms of environment, resources and equipment allocation. Hence, it is particularly important to select the urban rail system from the perspective of green and low-carbon transportation.

Since the problem of urban rail transit system selection involves multiple criteria and different types of urban rail transit systems, it requires the joint discussion of experts in various fields to make decisions. Therefore, the problem of urban rail transit system selection can be regarded as an MCGDM problem. In addition, limited by the complexity of the decision-making environment and the inherent uncertainty of practical problems, a traditional deterministic decision is difficult to solve such complex and uncertain decision problems. As an effective tool to describe uncertainty, IFS [4] are proposed to use membership degree, non-membership degree and hesitation degree to express uncertain information more comprehensively by expanding fuzzy set theory. In terms of information measurement, Das et al. [5] studied the relationship between intuitionistic fuzzy information measurement and its similarity measurement, distance measurement and knowledge measurement based on the intuitionistic fuzzy framework. Mishra et al. [6] proposed a series of similarity measures and entropy measures based on the cosine function and logarithmic function under an intuitionistic fuzzy environment. In terms of decision methods, Ecer and Pamucar [7] proposed a method to rank insurance companies according to Marcos under an intuitionistic fuzzy environment. Schitea et al. [8] proposed a MCDM method based on IFS to select the best location for the summary location of hydrogen mobility in Romania. Mishra et al. [9] developed a fuzzy decision method for ranking and evaluating low-carbon sustainable suppliers by combining IFS and distance-based combined evaluation. As for the intuitionistic fuzzy preference relationship, Zhang et al. [10] studied the distance-based consistency measure in group-decision-making with an intuitionistic multiplication preference relationship and proposed some new distance measures between intuitionistic multiplication sets. Meng et al. [11] studied group-decision-making with heterogeneous intuitionistic fuzzy preference relations, including intuitionistic fuzzy preference relations, multiplicative intuitionistic fuzzy preference relations, etc.

Considering that the dimensions of different criteria are different, and there are differences, conflicts and mutual influences between criteria, the DEMATEL [12] method developed by the Geneva center of Battelle Geneva Research Centre can represent the causal logical relationship between criteria, which can visualize the structure of a complex causal relationship with the help of a matrix or graph. In the DEMATEL method, by calculating the cause degree and centrality of each criterion according to the relative importance of each criterion provided by experts, that is, the influence degree and influence degree of each criterion on other criteria, the subjective weight of each standard can then be determined according to the cause degree and centrality. This structured approach helps to analyze the interdependencies between criteria. The DEMATEL method is widely used.

Many researchers use the DEMATEL method for criterion evaluation or factor analysis. For example, Topgul et al. [13] used the IF-DEMATEL method to evaluate the green degree of four stages of incoming logistics in plant logistics, outgoing logistics and reverse logistics in the supply chain. Roostaie et al. [14] used the DEMATEL method to analyze the factors affecting the sustainability of buildings. Tseng et al. [15] and Liu et al. [16], respectively, analyzed the obstacles to the adoption of renewable energy and China's sustainable food consumption and production by using the DEMATEL method under the triangular fuzzy environment. In addition, DEMATEL can also be used to determine the subjective weight of criteria in MCDM problems, then evaluate the alternatives in combination with different evaluation methods and, finally, select the optimal alternative. For example, Hosseini et al. [17] and Li et al. [18], respectively, used the DEMATEL and VIKOR methods to evaluate solutions for ecotourism centers during the COVID-19 pandemic and select for a machine tool under the triangular fuzzy environment. Fang et al. [19] used the DEMATEL and TOPSIS methods to evaluate the energy investment risk and safety management system.

Experts have bounded rationality in the reality decision analysis procedure [20], and the psychological preference of experts will affect the decision-making results, so it is necessary to consider the psychological behavior of experts. As an important branch of behavioral decision-making theory, the regret theory proposed by Lomes and Suggen [21] and Bell [22] describes the regret avoidance behavior of decision-makers in the decision process through the regret–rejoice function and the risk preference coefficient of decision-makers. For the application of regret theory, many researchers combine regret theory with decision methods to put forward a group decision framework [23,24]. In other respects, Zhang et al. [25] developed a case retrieval method based on regret theory. Liu and Cheng [26] combined the likelihood-based MABAC method with regret theory to establish a new MCGDM method. Liang and Wang [20] developed an extended scoring method of gain and loss of advantage based on regret theory and the interval evidence reasoning method. Huang and Zhan [27] proposed a three-way decision-making method based on regret theory. Liu et al. [28] proposed a new method combining regret theory and the evaluation method based on average solution distance.

In the past few decades, researchers have proposed many new methods to deal with MCDM problems in real life, such as TOPSIS, VIKOR, MABAC, COPRAS and so on. COPRAS is an MCDM method proposed by Zavadskas et al. [29] in 1994. This method can effectively evaluate the scheme step by step in combination with the importance and effectiveness of the evaluation criteria to obtain the best scheme. It has the characteristics of wide application range and good evaluation effect [30]. The COPRAS method is also widely used. For example, Büyüközkan and Göçer [31] combine AHP and COPRAS to select the best digital supply chain partner. Balali et al. [32] used ANP and COPRAS to rank the effective risks of human resource threats in natural gas supply projects. Mishra et al. [33] and Alipour et al. [34] proposed the combination of SWARA and COPRAS for the sustainability evaluation of the bioenergy production process and the selection of fuel cell and hydrogen component suppliers, respectively. Yuan et al. [35] and Narayanamoorty et al. [36], respectively, used DEMATEL and COPRAS to evaluate and select the third-party logistics suppliers and the best alternative fuel, but both of them only used the subjective weight determination method to determine the attribute weight. In addition, although the methodological framework proposed by many scholars takes into account the regret theory, there are, however, no studies combining regret theory with the COPRAS method to provide decision support for the selection of an urban rail transit system.

Based on the above analysis, the motivations of this study are as follows:

(1) The selection of an urban rail transit system plays an important role in the sustainable development of the city, but now there is no unified standard for the selection of an urban rail transit system, and the construction of urban rail transit involves many

aspects. Therefore, it is necessary to determine the corresponding evaluation criteria to select the appropriate type of urban rail transit system.

(2) In the MCGDM problem, the weight of the criterion is a very important part. In the existing decision-making models, most studies only consider the subjective or objective weight model, and the criterion weight determination method is single, which is difficult to comprehensively consider the subjective and objective importance of the criterion so as to affect the final decision-making results. Therefore, it is necessary to establish the comprehensive weight of a criterion determination model considering the subjective and objective influence to obtain more reasonable and credible decision-making results.

(3) Through literature analysis, it is found that the intuitionistic fuzzy group decision methods in the existing research rarely consider the interaction between criteria in the decision-making process, and most decision-making methods determine the optimal alternatives based on the traditional utility theory, ignoring the psychological behavior of experts in the decision process.

According to the above research motivation, the main contributions of this study are outlined as follows:

(1) Determine evaluation criteria of an urban rail transit system. In order to solve the problem that the existing urban rail transit system selection lacks unified standards, this study establishes the urban rail transit system selection evaluation criteria from four aspects: characteristics, technology, economy and environment.

(2) Build a comprehensive weight determination model of criteria. In order to determine the criterion weight more reasonably, based on the intuitionistic fuzzy environment, the objective weight and subjective weight of the criterion are calculated, respectively, according to DEMATEL and CRITIC, and then the comprehensive weight of the criterion is calculated by the linear integration method and a new comprehensive weight determination model of the criterion is built.

(3) Develop a hybrid intuitionistic fuzzy group decision framework. Based on the proposed intuitionistic fuzzy distance measurement method, the comprehensive weight of the criterion determination model and COPRAS method combined with regret theory, a hybrid group-decision-making framework for urban rail transit system selection is established. Meanwhile, taking city N as an example, the effectiveness and rationality of the method framework proposed in this study are verified.

The rest of this study is organized as follows: the second section is the introduction of preliminaries, including IFS and regret theory. The third section first introduces the proposed intuitionistic fuzzy distance measurement model, and then introduces the detailed steps of the hybrid intuitionistic fuzzy group decision framework proposed in this study. The fourth section is the application of practical cases and the corresponding sensitivity analysis and comparative analysis and the fifth section provides the conclusions of this study.

2. Preliminaries

This section briefly introduces the background knowledge needed in this paper, including IFS theory and regret theory.

2.1. Intuitionistic Fuzzy Sets

The following introduces the basic concepts and related theories of IFS.

Definition 1 ([4]). *Let X be a non-empty set, and then*

$$\tilde{A}=\left\{\left(x,\mu_{\tilde{A}}(x),\gamma_{\tilde{A}}(x)\right)\mid x\in X\right\} \tag{1}$$

is called intuitionistic fuzzy set on X. *Where* $\mu_{\tilde{A}}(x): X \to [0,1]$ *and* $\gamma_{\tilde{A}}(x): X \to [0,1]$ *represent the membership degree and non-membership degree of the subset* $\tilde{A}$ *of element* x *in* X, *respectively, and hold true for all* $x \in X, 0 \le \mu_{\tilde{A}}(x) + \gamma_{\tilde{A}}(x) \le 1$ *on* $\tilde{A}$. $\pi_{\tilde{A}}(x) = 1 - \mu_{\tilde{A}}(x) - \gamma_{\tilde{A}}(x)$, $0 \le \pi_{\tilde{A}}(x) \le 1$ *represents the hesitation degree or uncertainty degree that element* x *in* X *belongs to* $\tilde{A}$. *The ordinal number pair* $(\mu_{\tilde{A}}(x),\ \gamma_{\tilde{A}}(x))$ *composed of membership degree* $\mu_{\tilde{A}}(x)$ *and non-membership degree* $\gamma_{\tilde{A}}(x)$ *are IFNs.*

Definition 2 ([4]). *Let* $\tilde{\alpha} = (\mu_{\tilde{\alpha}}, \gamma_{\tilde{\alpha}})$ *and* $\tilde{\beta} = (\mu_{\tilde{\beta}}, \gamma_{\tilde{\beta}})$ *be two IFN, the operational laws of IFNs are:*

(1) $\tilde{\alpha} \oplus \tilde{\beta} = (x; \mu_{\tilde{\alpha}} + \mu_{\tilde{\beta}} - \mu_{\tilde{\alpha}}\mu_{\tilde{\beta}}, \gamma_{\tilde{\alpha}}\gamma_{\tilde{\beta}})$;

(2) $\tilde{\alpha} \otimes \tilde{\beta} = (x; \mu_{\tilde{\alpha}}\mu_{\tilde{\beta}}, \gamma_{\tilde{\alpha}} + \gamma_{\tilde{\beta}} - \gamma_{\tilde{\alpha}}\gamma_{\tilde{\beta}})$;

(3) $\tilde{\alpha} \wedge \tilde{\beta} = (x; \min(\mu_{\tilde{\alpha}}, \mu_{\tilde{\beta}}), \max(\gamma_{\tilde{\alpha}}, \gamma_{\tilde{\beta}}))$;

(4) $\tilde{\alpha} \vee \tilde{\beta} = (x; \max(\mu_{\tilde{\alpha}}, \mu_{\tilde{\beta}}), \min(\gamma_{\tilde{\alpha}}, \gamma_{\tilde{\beta}}))$;

(5) $\lambda\tilde{\alpha} = \left(x; 1 - (1 - \mu_{\tilde{\alpha}})^{\lambda}, (\gamma_{\tilde{\alpha}})^{\lambda}\right), \lambda > 0$;

(6) $\tilde{\alpha}^{\lambda} = \left(x; (\mu_{\tilde{\alpha}})^{\lambda}, 1 - (1 - \gamma_{\tilde{\alpha}})^{\lambda}\right), \lambda > 0$.

Definition 3. *The score function* S *and accuracy function* H *of IFN* $\tilde{\alpha} = (\mu_{\tilde{\alpha}}, \gamma_{\tilde{\alpha}})$ *are defined as* $S(\tilde{\alpha}) = \mu_{\alpha} - \gamma_{\alpha}$ *and* $H(\tilde{\alpha}) = \mu_{\alpha} + \gamma_{\alpha}$; *however, when the membership degree is equal to the non-membership degree, the score function cannot be directly used to compare intuitionistic fuzzy numbers. So, Zeng et al.* [37] *proposed a novel score function as below:*

$$S(\tilde{\alpha}) = \mu_{\tilde{\alpha}} - \gamma_{\tilde{\alpha}} - \pi_{\tilde{\alpha}} \times \frac{\log_2(1 + \pi_{\tilde{\alpha}})}{100}, S(\tilde{\alpha}) \in [-1, 1]. \tag{2}$$

Definition 4. *Let* $\tilde{\alpha} = (\mu_{\tilde{\alpha}}, \gamma_{\tilde{\alpha}})$ *and* $\tilde{\beta} = (\mu_{\tilde{\beta}}, \gamma_{\tilde{\beta}})$ *be two IFNs; the order relations between them are defined as follows:*

(1) *If* $S(\tilde{\alpha}) > S(\tilde{\beta})$, *then* $\tilde{\alpha}$ *is better than* $\tilde{\beta}$, *written as* $\tilde{\alpha} \succ \tilde{\beta}$.

(2) *If* $S(\tilde{\alpha}) = S(\tilde{\beta})$, then

  (i) *If* $H(\tilde{\alpha}) > H(\tilde{\beta})$, *then* $\tilde{\alpha}$ *is better than* $\tilde{\beta}$, *written as* $\tilde{\alpha} \succ \tilde{\beta}$;

  (ii) *If* $H(\tilde{\alpha}) = H(\tilde{\beta})$, *then* $\tilde{\alpha}$ *is equal to* $\tilde{\beta}$, *written as* $\tilde{\alpha} = \tilde{\beta}$.

Definition 5 ([38]). *Let* $\tilde{\alpha}_j = \left(\mu_{\tilde{\alpha}_j}, \gamma_{\tilde{\alpha}_j}\right)(j = 1, 2, \cdots, n)$ *be a set of IFNs; the intuitionistic fuzzy weighted aggregation operator is defined as:*

$$IFWA_{\omega}(\widetilde{\alpha_1},\widetilde{\alpha_2},\cdots,\widetilde{\alpha_n})=\left(1-\prod_{j=1}^{n}\left(1-\mu_{\widetilde{\alpha_j}}\right)^{\omega_j},\prod_{j=1}^{n}\left(\gamma_{\widetilde{\alpha_j}}\right)^{\omega_j}\right). \tag{3}$$

where ω_j *is the weight of* $\widetilde{\alpha_j}=\left(\mu_{\widetilde{\alpha_j}},\gamma_{\widetilde{\alpha_j}}\right), j=1,2,\cdots,n$, $\omega_j\in[0,1]$ *and* $\sum_{j=1}^{n}\omega_j=1$.

2.2. Regret Theory

The main idea of regret theory is to compare the results obtained by the selected alternative with the possible results obtained by other alternatives and then characterize the degree of rejoice and regret of decision experts and select the optimal alternative that they will not regret.

Definition 6 ([39]). *Let* y_1 *and* y_2 *be the evaluation values of alternatives* P_1 *and* P_2*, and then the perceived utility value of experts on alternative* P_1 *is*

$$u(y_1,y_2)=v(y_1)+R\left(v(y_1)-v(y_2)\right). \tag{4}$$

where $v(\bullet)$ *is a monotonically increasing concave utility function satisfying* $v'(\bullet)>0$ *and* $v''(\bullet)<0$. $R(\bullet)$ *is a monotonically increasing concave regret–rejoice function satisfying* $R(0)=0$, $R'(\bullet)>0$ *and* $R''(\bullet)<0$. $\Delta v=v(x_1)-v(x_2)$ *represents the utility increment of alternatives* P_1 *and* P_1. $R(\Delta v)>0$ *means that the decision-maker is willing to choose option* P_1 *and abandon option* P_2*; otherwise, he will regret.*

3. A Hybrid Intuitionistic Fuzzy Group Decision Framework

This part introduces the proposed hybrid intuitionistic fuzzy group decision framework. Firstly, a new intuitionistic fuzzy distance measure is proposed, then the MCGDM problem studied in this paper is described and, finally, the detailed steps of the decision framework are given.

3.1. A Novel Intuitionistic Fuzzy Distance Measure

In this paper, IFS are used to deal with the fuzziness and uncertainty of decision information. In the process of decision-making, intuitionistic fuzzy distance needs to be used many times. In order to better measure intuitionistic fuzzy distance and reduce the lack of information, a novel intuitionistic fuzzy distance measurement method needs to be proposed.

Definition 7. *Let* $\widetilde{\alpha}=\left\{\widetilde{\alpha}_j \mid j=1,2,\cdots,n\right\}$ *and* $\widetilde{\beta}=\left\{\widetilde{\beta}_j \mid j=1,2,\cdots,n\right\}$ *be two intuitionistic fuzzy number vectors, where* $\widetilde{\alpha_j}=(\mu_{\widetilde{\alpha_j}},\gamma_{\widetilde{\alpha_j}})$, $\widetilde{\beta_j}=(\mu_{\widetilde{\beta_j}},\gamma_{\widetilde{\beta_j}})$*. The new generalized intuitionistic fuzzy distance measure is defined as follows:*

$$D^{\sigma}\left(\widetilde{\alpha},\widetilde{\beta}\right)=\left(\frac{1}{3n}\sum_{j=1}^{n}\left(\left|\widetilde{\mu}_j^{\widetilde{\alpha}}-\widetilde{\mu}_j^{\widetilde{\beta}}\right|^{\sigma}+\left|\widetilde{\gamma}_j^{\widetilde{\alpha}}-\widetilde{\gamma}_j^{\widetilde{\beta}}\right|^{\sigma}+\left|\widetilde{\pi}_j^{\widetilde{\alpha}}-\widetilde{\pi}_j^{\widetilde{\beta}}\right|^{\sigma}+\left|\frac{1}{2}\left(S\left(\widetilde{\alpha_j}\right)-S\left(\widetilde{\beta_j}\right)\right)\right|^{\sigma}\right)\right)^{\frac{1}{\sigma}}. \tag{5}$$

Theorem 1. *Let* $\widetilde{\alpha}=\left\{\widetilde{\alpha}_j \mid j=1,2,\cdots,n\right\}$, $\widetilde{\beta}=\left\{\widetilde{\beta}_j \mid j=1,2,\cdots,n\right\}$ *and* $\widetilde{\chi}=\left\{\widetilde{\chi}_j \mid j=1,2,\cdots,n\right\}$ *be three intuitionistic fuzzy number vectors, and then* $D^{\sigma}\left(\widetilde{\alpha},\widetilde{\beta}\right)$ *is the intuitionistic fuzzy distance measure.*

(1) $0\le D^{\sigma}\left(\widetilde{\alpha},\widetilde{\beta}\right)\le 1$;

(2) $D^{\sigma}\left(\widetilde{\alpha},\widetilde{\beta}\right)=0$ if and only if $\widetilde{\alpha}=\widetilde{\beta}$;

(3) $D^{\sigma}\left(\widetilde{\alpha},\widetilde{\beta}\right)=D^{\sigma}\left(\widetilde{\beta},\widetilde{\alpha}\right)$,

(4) If $\widetilde{\alpha}\subseteq\widetilde{\beta}\subseteq\widetilde{\chi}$, then $D^{\sigma}\left(\widetilde{\alpha},\widetilde{\beta}\right)\le D^{\sigma}\left(\widetilde{\alpha},\widetilde{\chi}\right)$, $D^{\sigma}\left(\widetilde{\beta},\widetilde{\chi}\right)\le D^{\sigma}\left(\widetilde{\alpha},\widetilde{\chi}\right)$.

(2) and (3) can be proved directly; only (1) and (4) are proved here.

(1) Since $0\le \widetilde{\mu}_j^{\widetilde{\alpha}},\widetilde{\mu}_j^{\widetilde{\beta}}\le 1$, $0\le \widetilde{\gamma}_j^{\widetilde{\alpha}},\widetilde{\gamma}_j^{\widetilde{\beta}}\le 1$, then

$$0\le\left|\widetilde{\mu}_j^{\widetilde{\alpha}}-\widetilde{\mu}_j^{\widetilde{\beta}}\right|\le 1,\ 0\le\left|\widetilde{\gamma}_j^{\widetilde{\alpha}}-\widetilde{\gamma}_j^{\widetilde{\beta}}\right|\le 1,\ \left|\widetilde{\pi}_j^{\widetilde{\alpha}}-\widetilde{\pi}_j^{\widetilde{\beta}}\right|\to 0,$$

$$0\le\left|\frac{1}{2}\left(S\left(\widetilde{\alpha}_j\right)-S\left(\widetilde{\beta}_j\right)\right)\right|\le 1.$$

Hence, $0\le\left(\left|\widetilde{\mu}_j^{\widetilde{\alpha}}-\widetilde{\mu}_j^{\widetilde{\beta}}\right|^{\sigma}+\left|\widetilde{\gamma}_j^{\widetilde{\alpha}}-\widetilde{\gamma}_j^{\widetilde{\beta}}\right|^{\sigma}+\left|\widetilde{\pi}_j^{\widetilde{\alpha}}-\widetilde{\pi}_j^{\widetilde{\beta}}\right|^{\sigma}+\left|\frac{1}{2}\left(S\left(\widetilde{\alpha}_j\right)-S\left(\widetilde{\beta}_j\right)\right)\right|^{\sigma}\right)\le 3$,

for $\sigma\ge 1$, i.e.,

$$0\le\frac{1}{3n}\sum_{j=1}^{n}\left(\left|\widetilde{\mu}_j^{\widetilde{\alpha}}-\widetilde{\mu}_j^{\widetilde{\beta}}\right|^{\sigma}+\left|\widetilde{\gamma}_j^{\widetilde{\alpha}}-\widetilde{\gamma}_j^{\widetilde{\beta}}\right|^{\sigma}+\left|\widetilde{\pi}_j^{\widetilde{\alpha}}-\widetilde{\pi}_j^{\widetilde{\beta}}\right|^{\sigma}+\left|\frac{1}{2}\left(S\left(\widetilde{\alpha}_j\right)-S\left(\widetilde{\beta}_j\right)\right)\right|^{\sigma}\right)\le 1,$$

$$0\le\left(\frac{1}{3n}\sum_{j=1}^{n}\left(\left|\widetilde{\mu}_j^{\widetilde{\alpha}}-\widetilde{\mu}_j^{\widetilde{\beta}}\right|^{\sigma}+\left|\widetilde{\gamma}_j^{\widetilde{\alpha}}-\widetilde{\gamma}_j^{\widetilde{\beta}}\right|^{\sigma}+\left|\widetilde{\pi}_j^{\widetilde{\alpha}}-\widetilde{\pi}_j^{\widetilde{\beta}}\right|^{\sigma}+\left|\frac{1}{2}\left(S\left(\widetilde{\alpha}_j\right)-S\left(\widetilde{\beta}_j\right)\right)\right|^{\sigma}\right)\right)^{\frac{1}{\sigma}}\le 1.$$

(4) Since $\widetilde{\alpha}\subseteq\widetilde{\beta}\subseteq\widetilde{\chi}$, then $\widetilde{\mu}_j^{\widetilde{\alpha}}\le\widetilde{\mu}_j^{\widetilde{\beta}}\le\widetilde{\mu}_j^{\widetilde{\chi}}$, $\widetilde{\gamma}_j^{\widetilde{\alpha}}\le\widetilde{\gamma}_j^{\widetilde{\beta}}\le\widetilde{\gamma}_j^{\widetilde{\chi}}$, $S\left(\widetilde{\alpha}_j\right)\ge S\left(\widetilde{\beta}_j\right)\ge S\left(\widetilde{\chi}_j\right)$ for all $x_j\in X$. Then, we have

$$\left|\widetilde{\mu}_j^{\widetilde{\alpha}}-\widetilde{\mu}_j^{\widetilde{\beta}}\right|^{\sigma}\le\left|\widetilde{\mu}_j^{\widetilde{\alpha}}-\widetilde{\mu}_j^{\widetilde{\chi}}\right|^{\sigma},\left|\widetilde{\mu}_j^{\widetilde{\beta}}-\widetilde{\mu}_j^{\widetilde{\chi}}\right|^{\sigma}\le\left|\widetilde{\mu}_j^{\widetilde{\alpha}}-\widetilde{\mu}_j^{\widetilde{\chi}}\right|^{\sigma};$$

$$\left|\widetilde{\gamma}_j^{\widetilde{\alpha}}-\widetilde{\gamma}_j^{\widetilde{\beta}}\right|^{\sigma}\le\left|\widetilde{\gamma}_j^{\widetilde{\alpha}}-\widetilde{\gamma}_j^{\widetilde{\chi}}\right|^{\sigma},\left|\widetilde{\gamma}_j^{\widetilde{\beta}}-\widetilde{\gamma}_j^{\widetilde{\chi}}\right|^{\sigma}\le\left|\widetilde{\gamma}_j^{\widetilde{\alpha}}-\widetilde{\gamma}_j^{\widetilde{\chi}}\right|^{\sigma};$$

$$\left|\frac{1}{2}\left(S\left(\widetilde{\alpha}_j\right)-S\left(\widetilde{\beta}_j\right)\right)\right|^{\sigma}\le\left|\frac{1}{2}\left(S\left(\widetilde{\alpha}_j\right)-S\left(\widetilde{\chi}_j\right)\right)\right|^{\sigma}\le,\left|\frac{1}{2}\left(S\left(\widetilde{\beta}_j\right)-S\chi\right)\right|^{\sigma}\le\left|\frac{1}{2}\left(S\left(\widetilde{\alpha}_j\right)-S\left(\widetilde{\chi}_j\right)\right)\right|^{\sigma}.$$

Thus,

$$\left(\left|\tilde{\mu}_j^{\tilde{\alpha}}-\tilde{\mu}_j^{\tilde{\beta}}\right|^\sigma+\left|\tilde{\gamma}_j^{\tilde{\alpha}}-\tilde{\gamma}_j^{\tilde{\beta}}\right|^\sigma+\left|\tilde{\pi}_j^{\tilde{\alpha}}-\tilde{\pi}_j^{\tilde{\beta}}\right|^\sigma+\left|\frac{1}{2}\left(S\left(\widetilde{\alpha_j}\right)-S\left(\widetilde{\beta_j}\right)\right)\right|^\sigma\right)\leq$$
$$\left(\left|\tilde{\mu}_j^{\tilde{\alpha}}-\tilde{\mu}_j^{\tilde{\chi}}\right|^\sigma+\left|\tilde{\gamma}_j^{\tilde{\alpha}}-\tilde{\gamma}_j^{\tilde{\chi}}\right|^\sigma+\left|\tilde{\pi}_j^{\tilde{\alpha}}-\tilde{\pi}_j^{\tilde{\chi}}\right|^\sigma+\left|\frac{1}{2}\left(S\left(\widetilde{\alpha_j}\right)-S\left(\widetilde{\chi_j}\right)\right)\right|^\sigma\right)$$

$$\left(\left|\tilde{\mu}_j^{\tilde{\beta}}-\tilde{\mu}_j^{\tilde{\chi}}\right|^\sigma+\left|\tilde{\gamma}_j^{\tilde{\beta}}-\tilde{\gamma}_j^{\tilde{\chi}}\right|^\sigma+\left|\tilde{\pi}_j^{\tilde{\beta}}-\tilde{\pi}_j^{\tilde{\chi}}\right|^\sigma+\left|\frac{1}{2}\left(S\left(\widetilde{\beta_j}\right)-S\left(\widetilde{\chi_j}\right)\right)\right|^\sigma\right)\leq$$
$$\left(\left|\tilde{\mu}_j^{\tilde{\alpha}}-\tilde{\mu}_j^{\tilde{\chi}}\right|^\sigma+\left|\tilde{\gamma}_j^{\tilde{\alpha}}-\tilde{\gamma}_j^{\tilde{\chi}}\right|^\sigma+\left|\tilde{\pi}_j^{\tilde{\alpha}}-\tilde{\pi}_j^{\tilde{\chi}}\right|^\sigma+\left|\frac{1}{2}\left(S\left(\widetilde{\alpha_j}\right)-S\left(\widetilde{\chi_j}\right)\right)\right|^\sigma\right)$$

Furthermore,

$$\begin{aligned}D^\sigma\left(\tilde{\alpha},\tilde{\beta}\right)&=\left(\frac{1}{3n}\sum_{j=1}^{n}\left(\left|\tilde{\mu}_j^{\tilde{\alpha}}-\tilde{\mu}_j^{\tilde{\beta}}\right|^\sigma+\left|\tilde{\gamma}_j^{\tilde{\alpha}}-\tilde{\gamma}_j^{\tilde{\beta}}\right|^\sigma+\left|\tilde{\pi}_j^{\tilde{\alpha}}-\tilde{\pi}_j^{\tilde{\beta}}\right|^\sigma+\left|\frac{1}{2}\left(S\left(\widetilde{\alpha_j}\right)-S\left(\widetilde{\beta_j}\right)\right)\right|^\sigma\right)\right)^{\frac{1}{\sigma}}\\&\leq\left(\frac{1}{3n}\sum_{j=1}^{n}\left(\left|\tilde{\mu}_j^{\tilde{\alpha}}-\tilde{\mu}_j^{\tilde{\chi}}\right|^\sigma+\left|\tilde{\gamma}_j^{\tilde{\alpha}}-\tilde{\gamma}_j^{\tilde{\chi}}\right|^\sigma+\left|\tilde{\pi}_j^{\tilde{\alpha}}-\tilde{\pi}_j^{\tilde{\chi}}\right|^\sigma+\left|\frac{1}{2}\left(S\left(\widetilde{\alpha_j}\right)-S\left(\widetilde{\chi_j}\right)\right)\right|^\sigma\right)\right)^{\frac{1}{\sigma}}\\&=D^\sigma\left(\tilde{\alpha},\tilde{\chi}\right)\end{aligned}$$

$$\begin{aligned}D^\sigma\left(\tilde{\beta},\tilde{\chi}\right)&=\left(\frac{1}{3n}\sum_{j=1}^{n}\left(\left|\tilde{\mu}_j^{\tilde{\beta}}-\tilde{\mu}_j^{\tilde{\chi}}\right|^\sigma+\left|\tilde{\gamma}_j^{\tilde{\beta}}-\tilde{\gamma}_j^{\tilde{\chi}}\right|^\sigma+\left|\tilde{\pi}_j^{\tilde{\beta}}-\tilde{\pi}_j^{\tilde{\chi}}\right|^\sigma+\left|\frac{1}{2}\left(S\left(\widetilde{\beta_j}\right)-S\left(\widetilde{\chi_j}\right)\right)\right|^\sigma\right)\right)^{\frac{1}{\sigma}}\\&\leq\left(\frac{1}{3n}\sum_{j=1}^{n}\left(\left|\tilde{\mu}_j^{\tilde{\alpha}}-\tilde{\mu}_j^{\tilde{\chi}}\right|^\sigma+\left|\tilde{\gamma}_j^{\tilde{\alpha}}-\tilde{\gamma}_j^{\tilde{\chi}}\right|^\sigma+\left|\tilde{\pi}_j^{\tilde{\alpha}}-\tilde{\pi}_j^{\tilde{\chi}}\right|^\sigma+\left|\frac{1}{2}\left(S\left(\widetilde{\alpha_j}\right)-S\left(\widetilde{\chi_j}\right)\right)\right|^\sigma\right)\right)^{\frac{1}{\sigma}}\\&=D^\sigma\left(\tilde{\alpha},\tilde{\chi}\right)\end{aligned}$$

Accordingly, $D^\sigma\left(\tilde{\alpha},\tilde{\beta}\right)\leq D^\sigma\left(\tilde{\alpha},\tilde{\chi}\right)$ and $D^\sigma\left(\tilde{\beta},\tilde{\chi}\right)\leq D^\sigma\left(\tilde{\alpha},\tilde{\chi}\right)$.

Definition 8. *Let* $\tilde{\mathrm{A}}=\left(\widetilde{\alpha_{ij}}\right)_{m\times n}$ *and* $\tilde{\mathrm{B}}=\left(\widetilde{\beta_{ij}}\right)_{m\times n}$ *be two intuitionistic fuzzy matrices, where* $\widetilde{\alpha_{ij}}=\left(\mu_{\widetilde{\alpha_{ij}}},\gamma_{\widetilde{\alpha_{ij}}}\right)$ *and* $\widetilde{\beta_{ij}}=\left(\mu_{\widetilde{\beta_{ij}}},\gamma_{\widetilde{\beta_{ij}}}\right)$ *are IFNs. Then, the distance between intuitionistic fuzzy matrices* $\tilde{\mathrm{A}}$ *and* $\tilde{\mathrm{B}}$ *is defined as follows:*

$$\widehat{D}^\sigma\left(\tilde{\mathrm{A}},\tilde{\mathrm{B}}\right)=\left(\frac{1}{3mn}\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\left|\tilde{\mu}_{ij}^{\tilde{\mathrm{A}}}-\tilde{\mu}_{ij}^{\tilde{\mathrm{B}}}\right|^\sigma+\left|\tilde{\gamma}_{ij}^{\tilde{\mathrm{A}}}-\tilde{\gamma}_{ij}^{\tilde{\mathrm{B}}}\right|^\sigma+\left|\tilde{\pi}_{ij}^{\tilde{\mathrm{A}}}-\tilde{\pi}_{ij}^{\tilde{\mathrm{B}}}\right|^\sigma+\left|\frac{1}{2}\left(S\left(\tilde{\mathrm{A}}_{ij}\right)-S\left(\tilde{\mathrm{B}}_{ij}\right)\right)\right|^\sigma\right)\right)^{\frac{1}{\sigma}}. \tag{6}$$

when $\sigma=1$, $\sigma=2$ *and* $\sigma=+\infty$, $\widehat{D}^{\sigma}\left(\widetilde{\mathrm{A}},\widetilde{\mathrm{B}}\right)$ *are degenerated to the corresponding intuitionistic fuzzy Hamming distance* $\widehat{D}^{1}\left(\widetilde{\mathrm{A}},\widetilde{\mathrm{B}}\right)$, *Euclidean distance* $\widehat{D}^{2}\left(\widetilde{\mathrm{A}},\widetilde{\mathrm{B}}\right)$ *and Chebyshev distance* $\widehat{D}^{+\infty}\left(\widetilde{\mathrm{A}},\widetilde{\mathrm{B}}\right)$.

$$\widehat{D}^{1}\left(\widetilde{\mathrm{A}},\widetilde{\mathrm{B}}\right)=\frac{1}{3mn}\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\left|\tilde{\mu}_{ij}^{\widetilde{\mathrm{A}}}-\tilde{\mu}_{ij}^{\widetilde{\mathrm{B}}}\right|+\left|\tilde{\gamma}_{ij}^{\widetilde{\mathrm{A}}}-\tilde{\gamma}_{ij}^{\widetilde{\mathrm{B}}}\right|+\left|\tilde{\pi}_{ij}^{\widetilde{\mathrm{A}}}-\tilde{\pi}_{ij}^{\widetilde{\mathrm{B}}}\right|+\left|\frac{1}{2}\left(S\left(\widetilde{\mathrm{A}}_{ij}\right)-S\left(\widetilde{\mathrm{B}}_{ij}\right)\right)\right|\right). \tag{7}$$

$$\widehat{D}^{2}\left(\widetilde{\mathrm{A}},\widetilde{\mathrm{B}}\right)=\sqrt{\frac{1}{3mn}\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\left|\tilde{\mu}_{ij}^{\widetilde{\mathrm{A}}}-\tilde{\mu}_{ij}^{\widetilde{\mathrm{B}}}\right|^{2}+\left|\tilde{\gamma}_{ij}^{\widetilde{\mathrm{A}}}-\tilde{\gamma}_{ij}^{\widetilde{\mathrm{B}}}\right|^{2}+\left|\tilde{\pi}_{ij}^{\widetilde{\mathrm{A}}}-\tilde{\pi}_{ij}^{\widetilde{\mathrm{B}}}\right|^{2}+\left|\frac{1}{2}\left(S\left(\widetilde{\mathrm{A}}_{ij}\right)-S\left(\widetilde{\mathrm{B}}_{ij}\right)\right)\right|^{2}\right)}. \tag{8}$$

$$\widehat{D}^{+\infty}\left(\widetilde{\mathrm{A}},\widetilde{\mathrm{B}}\right)=\max_{\substack{1\le i\le m\\1\le j\le m}}\left(\left|\tilde{\mu}_{ij}^{\widetilde{\mathrm{A}}}-\tilde{\mu}_{ij}^{\widetilde{\mathrm{B}}}\right|,\left|\tilde{\gamma}_{ij}^{\widetilde{\mathrm{A}}}-\tilde{\gamma}_{ij}^{\widetilde{\mathrm{B}}}\right|,\left|\tilde{\pi}_{ij}^{\widetilde{\mathrm{A}}}-\tilde{\pi}_{ij}^{\widetilde{\mathrm{B}}}\right|,\left|\frac{1}{2}\left(S\left(\widetilde{\mathrm{A}}_{ij}\right)-S\left(\widetilde{\mathrm{B}}_{ij}\right)\right)\right|\right). \tag{9}$$

3.2. Problem Statement

For the MCGDM problem under the intuitionistic fuzzy environment, let $P_i(i=1,2,\cdots,m)$ be the set of urban rail transit system types, $Q_j(j=1,2,\cdots,n)$ be the set of criteria. $\omega_j(j=1,2,\cdots,n)$ is the weight of the criterion $Q_j(j=1,2,\cdots,n)$ and satisfying $0\le\omega_j\le1$, $\sum_{j=1}^{n}\omega_j=1$. $D_k(k=1,2,\cdots,K)$ is the set of experts. The corresponding weight of expert is expressed as $\lambda_k(k=1,2,\cdots,K)$ and satisfying $0\le\lambda_k\le1$, $\sum_{k=1}^{K}\lambda_k=1$. $\widetilde{E}^{k}=(\tilde{e}_{ij}^{k})_{m\times n}$ represents the evaluation value of the urban rail transit system P_i under criterion Q_j given by the kth expert.

3.3. Detailed Steps of the Hybrid Intuitionistic Fuzzy Group Decision Framework

This paper developed a hybrid group decision framework considering the psychological behavior of experts under the intuitionistic fuzzy environment. Firstly, experts express their qualitative evaluation through linguistic variables and then obtain the intuitionistic fuzzy decision matrix of experts. Secondly, the weight information of experts is determined by similarity method based on the proposed intuitionistic fuzzy distance measure, and then the aggregation decision matrix is obtained. Thirdly, the subjective weight and objective weight of attributes are obtained by DEMATEL and CRITIC methods, respectively, and the comprehensive weights of criteria are obtained by linear integration method. DEMATEL method can fully consider the relationship between criteria, making the final subjective weight results more accurate. CRITIC method is based on the contrast strength of criteria and the conflict between criteria to comprehensively measure the objective weight of criteria. The objective attribute of the data itself is fully used for scientific evaluation. In the stage of ranking, the COPRAS method based on regret theory is used to calculate the comprehensive evaluation value of the scheme and finally determine the ranking of the urban rail transit systems. COPRAS method is simple to operate, does not need standardization process and can reduce the lack of evaluation information. The detailed steps are as follows and the method framework is shown in Figure 1.

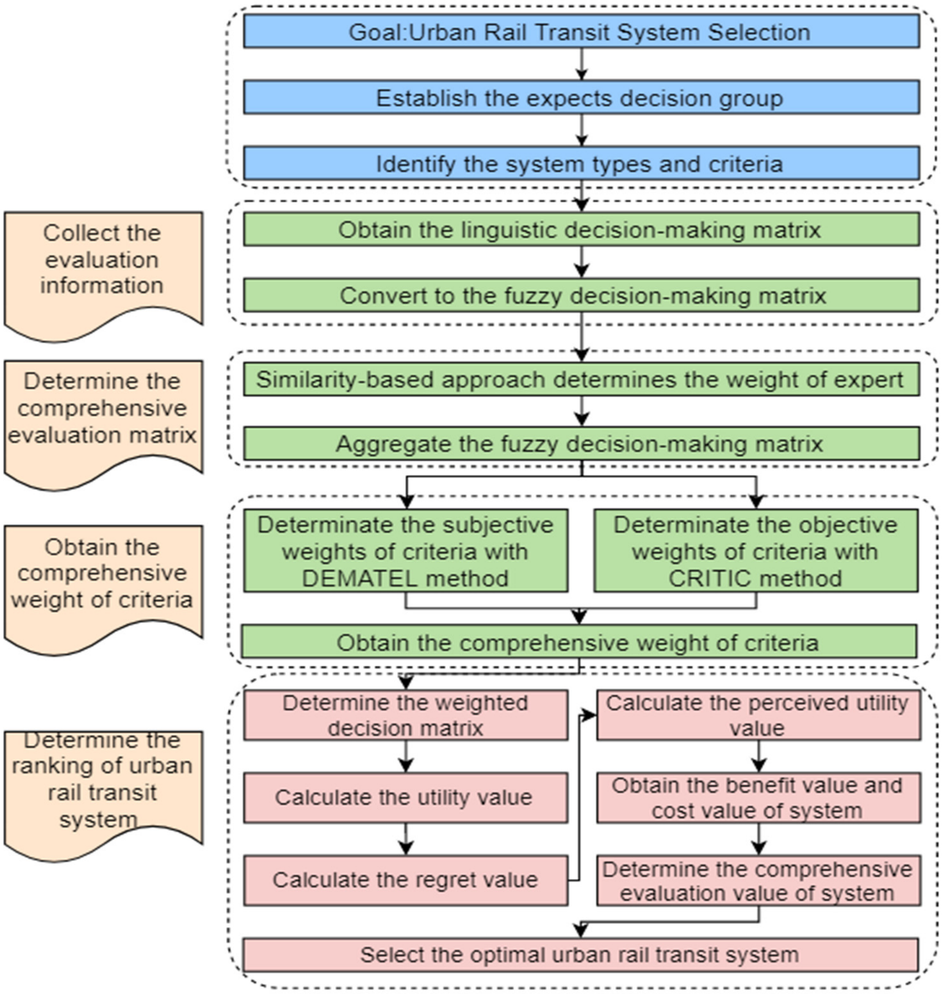

Figure 1. The framework of the proposed method.

(1) Stage 1 Collect the evaluation information

Step 1.1: Obtain the linguistic decision matrix.

The evaluation value of $P_i(i = 1, 2, \cdots, m)$ in criterion $Q_j(j = 1, 2, \cdots, n)$ is given by expert $D_k(k = 1, 2, \cdots, K)$ in the form of linguistic variables.

Step 1.2: Convert to the fuzzy decision matrix.

The linguistic evaluation value is transformed into intuitionistic fuzzy number, and then obtain the intuitionistic fuzzy evaluation matrix. Table 1 lists the linguistic variables, which reflect the transformation relationship between linguistic variables of decision matrix and IFNs.

$$\tilde{E}^k = \begin{pmatrix} \tilde{e}_{11}^k & \tilde{e}_{12}^k & \cdots & \tilde{e}_{1n}^k \\ \tilde{e}_{21}^k & \tilde{e}_{22}^k & \cdots & \tilde{e}_{2n}^k \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{e}_{m1}^k & \tilde{e}_{m2}^k & \cdots & \tilde{e}_{mn}^k \end{pmatrix}, \tilde{e}_{ij}^k = (\tilde{\mu}_{ij}^k, \tilde{\gamma}_{ij}^k).$$

Table 1. The transformation relationship of decision-making matrix linguistic variables [40].

Linguistic Variables	IFNs
Extremely Low (EL)	(0.10, 0.90, 0.00)
Very Low (VL)	(0.10, 0.75, 0.15)
Low (L)	(0.25, 0.60, 0.15)
Medium Low (ML)	(0.40, 0.50, 0.10)
Medium (M)	(0.50, 0.40, 0.10)
Medium High (MH)	(0.60, 0.30, 0.10)
High (H)	(0.70, 0.20, 0.10)
Very High (VH)	(0.80, 0.10, 0.10)
Extremely High (EH)	(0.90, 0.10, 0.00)

(2) Stage 2 Determine the comprehensive evaluation matrix

Step 2.1: Similarity-based approach determines the weight of expert.

The determination of weights of experts is a key to MCGDM problem. In this study, the weights of experts are determined by similarity method. Generally speaking, the closer the expert's evaluation is to the evaluation of the whole expert group, the greater the expert's weight is.

Step 2.1.1 Obtain the average evaluation matrix of the expert group from Equation (10)

$$\overline{e_{ij}} = \left(\overline{\mu_{ij}}, \overline{\gamma_{ij}}\right) = IFWA_{\omega}\left(e_{ij}^{1}, e_{ij}^{2}, \cdots, e_{ij}^{K}\right) = \left(1 - \prod_{k=1}^{K}\left(1-\mu_{ij}^{k}\right)^{\frac{1}{K}}, \prod_{k=1}^{K}\left(\gamma_{ij}^{k}\right)^{\frac{1}{K}}\right). \quad (10)$$

where *IFWA* is intuitionistic fuzzy weighted average operator.

Step 2.1.2 According to Definition 8, the distance between the kth expert's evaluation matrix $E^{k} = \left(e_{ij}^{k}\right)_{m\times n}$ and the average evaluation matrix $\overline{E} = \left(\overline{e_{ij}}\right)_{m\times n}$ of the expert group is expressed as:

$$\widehat{D}^{1}\left(E^{k}, \overline{E}\right) = \frac{1}{3mn}\sum_{i=1}^{m}\sum_{j=1}^{n}\left(\left|\mu_{ij}^{k} - \overline{\mu}_{ij}\right| + \left|\gamma_{ij}^{k} - \overline{\gamma}_{ij}\right| + \left|\pi_{ij}^{k} - \overline{\pi}_{ij}\right| + \left|\frac{1}{2}\left(S\left(e_{ij}\right) - S\left(\overline{e}_{ij}\right)\right)\right|\right).$$
$$\widehat{D}^{+\infty}\left(E^{k}, \overline{E}\right) = \max_{\substack{1\le i\le m \\ 1\le j\le n}}\left\{\left|\mu_{ij}^{k} - \overline{\mu}_{ij}\right|, \left|\gamma_{ij}^{k} - \overline{\gamma}_{ij}\right|, \left|\pi_{ij}^{k} - \overline{\pi}_{ij}\right|, \left|\frac{1}{2}\left(S\left(e_{ij}\right) - S\left(\overline{e}_{ij}\right)\right)\right|\right\}. \quad (11)$$

Step 2.1.3 Through the control parameters, the comprehensive distance calculated from Equation (12) is:

$$D^{*}\left(E^{k}, \overline{E}\right) = \theta\widehat{D}^{1}\left(E^{k}, \overline{E}\right) + (1-\theta)\widehat{D}^{+\infty}\left(E^{k}, \overline{E}\right). \quad (12)$$

where $D^{*}\left(E^{k}, \overline{E}\right)$ represents comprehensive distance, θ represents balance coefficient, $0 \le \theta \le 1$.

Step 2.1.4 The smaller the distance $d\left(E^{k}, \overline{E}\right)$, the greater the weight of the expert. The corresponding weight λ_k is obtained from Equation (13):

$$\lambda_{k} = \frac{1 - D^{*}\left(E^{k}, \overline{E}\right)}{\sum_{k=1}^{K}\left(1 - D^{*}\left(E^{k}, \overline{E}\right)\right)}, k = 1, 2, \cdots, K. \quad (13)$$

Step 2.2: Aggregate the fuzzy decision-making matrix.

Using Equation (14), expert decision matrices are aggregated to obtain the comprehensive evaluation decision matrix:

$$e_{ij} = IFWA_{\omega}\left(e_{ij}^{1}, e_{ij}^{2}, \cdots, e_{ij}^{K}\right) = \left(1 - \prod_{k=1}^{K}\left(1 - \tilde{\mu}_{ij}^{k}\right)^{\lambda_k}, \prod_{k=1}^{K}\left(\tilde{\gamma}_{ij}^{k}\right)^{\lambda_k}\right). \tag{14}$$

(3) Stage 3 Obtain the comprehensive weight of criteria

Firstly, the subjective weights of criteria are calculated by DEMATEL method, and then the objective weights of criteria are calculated by CRITIC. Finally, the comprehensive weights of criteria are obtained by combining the weight preference coefficient with the subjective and objective weight.

Step 3.1: Determine the subjective weights of criteria with DEMATEL method.

Step 3.1.1 Construct the fuzzy direct-influence matrix

The direct influence relation matrix of criterion Q_j to Q_l is given by expert $D_k (k = 1, 2, \cdots, K)$ in the form of linguistic variables and then transformed into intuitionistic fuzzy numbers to obtain the intuitionistic fuzzy direct-influence matrix $T^k = (t_{jl}^k)_{n\times n}$.

Step 3.1.2 Aggregate the direct-influence matrices with Equation (15) to determine the group direct-influence matrix $\widetilde{T} = \left(\widetilde{t_{jl}}\right)_{n\times n}$:

$$\widetilde{t_{jl}} = IFWA_{\omega}(t_{jl}^{1}, t_{jl}^{2}, \cdots, t_{jl}^{K}) = \left(1 - \prod_{k=1}^{K}\left(1 - \mu_{jl}^{k}\right)^{\lambda_k}, \prod_{k=1}^{K}\left(\gamma_{jl}^{k}\right)^{\lambda_k}\right). \tag{15}$$

where $\mu_{jl} = 1 - \prod_{k=1}^{K}\left(1 - \mu_{jl}^{k}\right)^{\lambda_k}$, $\gamma_{jl} = \prod_{k=1}^{K}\left(\gamma_{jl}^{k}\right)^{\lambda_k}$, λ_k is the weight of kth expert, $\lambda_k = \dfrac{1}{K}$.

Step 3.1.3 Use Equation (16) to standardize the direct-influence matrix to obtain the standardized direct-influence matrix $T' = (t'_{jl})_{n\times n}$:

$$t'_{jl} = \frac{t_{jl}}{\max\limits_{1\le j\le n}\left(\sum_{l=1}^{n} t_{jl}\right)}, j, l = 1, 2, \cdots, n. \tag{16}$$

where $t_{jl} = \mu_{jl} - \gamma_{jl} - \pi_{jl} \times \dfrac{\log_2\left(1 + \pi_{jl}\right)}{100}$, $\pi_{jl} = 1 - \mu_{jl} - \gamma_{jl}$.

Step 3.1.4 Utilize Equation (17) to calculate the total impact matrix $T^* = \left(t_{jl}^*\right)_{n\times n}$:

$$T^* = T' \times \left(I - T'\right)^{-1}. \tag{17}$$

where I is the identity matrix.

Step 3.1.5 Employ Equations (18) and (19) to calculate importance ξ and influence ζ:

$$\xi_j = R_j + C_j, j = 1, 2, \cdots, n. \tag{18}$$

$$\zeta_j = R_j - C_j, j = 1, 2, \cdots, n. \tag{19}$$

where $R_j = \sum_{l=1}^{n} t_{jl}$, $C_j = \sum_{j=1}^{n} t_{jl}$.

Step 3.1.6 Use Equation (20) to obtain the subjective weight ω_j^s of criterion Q_j:

$$\omega_j^s = \frac{\sqrt{\xi_j^2 + \zeta_j^2}}{\sum_{j=1}^{n} \sqrt{\xi_j^2 + \zeta_j^2}}. \tag{20}$$

Step 3.2: Determinate the objective weights of criteria with CRITIC method.

Step 3.2.1 Use Equation (21) to normalize the fuzzy decision-making matrix $\widetilde{E}^k = (\tilde{e}_{ij}^k)_{m\times n}$:

$$\begin{aligned} e_{ij}^k &= \left(\mu_{ij}^k, \gamma_{ij}^k\right) = \left(\widetilde{\mu}_{ij}^k, \widetilde{\gamma}_{ij}^k\right), \text{ for benefit criterion} \\ e_{ij}^k &= \left(\mu_{ij}^k, \gamma_{ij}^k\right) = \left(\widetilde{\gamma}_{ij}^k, \widetilde{\mu}_{ij}^k\right), \text{ for cost criterion} \end{aligned} \tag{21}$$

Step 3.2.2 Use Equation (22) to aggregate the fuzzy decision-making matrix:

$$e_{ij}^* = IFWA_\omega\left(e_{ij}^1, e_{ij}^2, \cdots, e_{ij}^K\right) = \left(1 - \prod_{k=1}^{K}\left(1-\mu_{ij}^k\right)^{\lambda_k}, \prod_{k=1}^{K}\left(\gamma_{ij}^k\right)^{\lambda_k}\right). \tag{22}$$

Step 3.2.3 Use Equation (23) to obtain the standard deviation τ_j of the criterion:

$$\tau_j = \sqrt{\frac{1}{n-1}\sum_{i=1}^{m}\left(D^\sigma\left(e_{ij}^*, \overline{e_j}\right)\right)^2}, j = 1, 2, \cdots, n. \tag{23}$$

where $\overline{e_j} = \frac{1}{m}\sum_{i=1}^{m} e_{ij}^* = IFWA_\omega\left(e_{1j}^*, e_{2j}^*, \cdots, e_{mj}^*\right) = \left(1 - \prod_{i=1}^{m}\left(1-\mu_{ij}^*\right)^{\frac{1}{m}}, \prod_{i=1}^{m}\left(\gamma_{ij}^*\right)^{\frac{1}{m}}\right)$.

Use Equation (24) to evaluate correlation coefficient ρ_{jl} between criteria:

$$\rho_{jl} = \frac{\sum_{i=1}^{m}\left[D^\sigma\left(e_{ij}^*, \overline{e_j}\right)\cdot D^\sigma\left(e_{ij}^*, \overline{e_j}\right)\right]}{\sqrt{\sum_{i=1}^{m}\left(D^\sigma\left(e_{ij}^*, \overline{e_j}\right)\right)^2}\sqrt{\sum_{i=1}^{m}\left(D^\sigma\left(e_{ij}^*, \overline{e_j}\right)\right)^2}}, j, l = 1, 2, \cdots, n. \tag{24}$$

where $\overline{e_j} = \frac{1}{m}\sum_{i=1}^{m} e_{ij}^*, \overline{e_l} = \frac{1}{m}\sum_{i=1}^{m} e_{ij}^*, j, l = 1, 2, \cdots, n$.

Step 3.2.4 Use Equation (25) to obtain the objective weight ω_j^o of criterion Q_j:

$$\omega_j^o = \frac{\tau_j \sum_{l=1}^{n}\left(1-\rho_{jl}\right)}{\sum_{j=1}^{n}\left[\tau_j \sum_{l=1}^{n}\left(1-\rho_{jl}\right)\right]}, j = 1, 2, \cdots, n. \tag{25}$$

Step 3.3: Obtain the comprehensive weights ω_j of criteria.

$$\omega_j = \varphi\omega_j^s + (1-\varphi)\omega_j^o. \tag{26}$$

where $\varphi(0 \le \varphi \le 1)$ indicates the relative importance of subjective weight and objective weight severally. Here, it is assumed that the subjective and objective weights are of equal importance, so $\varphi = 0.5$.

(4) Stage 4 Determine the ranking of urban rail transit systems

In this paper, the power function $u(x) = x^{\varepsilon}$ is used as the utility function of attribute value, where $\varepsilon(0 \le \varepsilon \le 1)$ is risk aversion coefficient, to describe the risk attitude of experts in decision-making, and, the smaller it is, the higher the risk aversion degree of experts is. $R(x) = 1 - \exp(-\vartheta \cdot x)$ is used as the regret and joy function, where it is the regret avoidance coefficient of experts, and the greater the $\vartheta(\vartheta \in [0, +\infty])$ is, the higher the expert's regret avoidance degree is [41].

Let the evaluation value of $P_i(i = 1, 2, \cdots, m)$ be $y_i(i = 1, 2, \cdots, m)$, and then the perceived utility value of experts on P_i is $u_i = v(y_i) + R\left(v(y_i) - v(y^*)\right)$. Where $y^* = \max_{1 \le i \le m}\{y_i\}$ is the utility value of the ideal urban rail transit system type. $R\left(v(y_i) - v(y^*)\right) \le 0$ indicates the regret value when the decision-maker chooses P_i and abandons the ideal urban rail transit system type. Therefore, the perceived utility value of experts on the urban rail transit system type includes the utility value of the P_i and the regret value of P_i compared with the ideal urban rail transit system type.

Step 4.1: Determinate comprehensive evaluation value of urban rail transit systems based on COPRAS method considering regret theory.

Step 4.1.1 Determinate the weighted decision matrix:

$$\widehat{U} = \begin{pmatrix} \widehat{u_{ij}} & \widehat{u_{ij}} & \cdots & \widehat{u_{ij}} \\ \widehat{u_{ij}} & \widehat{u_{ij}} & \cdots & \widehat{u_{ij}} \\ \vdots & \vdots & \ddots & \vdots \\ \widehat{u_{ij}} & \widehat{u_{ij}} & \cdots & \widehat{u_{ij}} \end{pmatrix}$$

where $\widehat{u_{ij}} = w_j \cdot u_{ij}$.

Step 4.1.2 Use Equation (27) to calculate the utility value of the P_i under the criterion:

$$\kappa_{ij} = \left(D^{\sigma}\left(e_{ij}, e_j^*\right)\right)^{\varepsilon}. \tag{27}$$

where ε is the risk aversion coefficient of decision-making experts. Based on the previous studies [39,42], $\varepsilon = 0.88$, e_j^* is ideal point. For benefit criteria, $e_j^* = \left(\max\limits_{1 \le i \le m} \mu_{ij}, \min\limits_{1 \le i \le m} \gamma_{ij}\right)$; for cost criteria, $e_j^* = \left(\min\limits_{1 \le i \le m} \mu_{ij}, \max\limits_{1 \le i \le m} \gamma_{ij}\right)$.

Step 4.1.3 Use Equation (28) to calculate the regret value of P_i:

$$\xi_{ij} = 1 - \exp\left(-\vartheta \bullet (\Delta u)\right). \tag{28}$$

where $\Delta u = \kappa_j^* - \kappa_{ij}$, $\kappa_j^* = \min\limits_{1 \le i \le m}\{\kappa_{ij}\}$ is the utility value of ideal point. ϑ is the regret avoidance coefficient of expert.

Step 4.1.4 Utilize Equation (29) to calculate the perceived utility value of P_i:

$$u_{ij} = \kappa_{ij} + \xi_{ij}. \tag{29}$$

Step 4.1.5 Obtain the benefit value and cost value of P_i:

For benefit criteria, use Equation (30) to calculate comprehensive benefit value G_i^+ of P_i:

$$G_i^+ = \sum_{j=1}^{r} {u_{ij}}^+, i = 1, 2, \cdots, m. \tag{30}$$

For cost criteria, use Equation (31) to calculate comprehensive cost value G_i^+ of P_i :

$$G_i^- = \sum_{j=r+1}^{n} {u_{ij}}^-, i = 1, 2, \cdots, m. \tag{31}$$

where "+" and "-" represent "benefit" and "cost", respectively, r is the number of benefit criteria.

Step 4.1.6 Use Equation (32) to determine the comprehensive evaluation value of P_i:

$$H_i = G_i^+ + \frac{\min_i G_i^- \sum_{i=1}^{m} G_i^-}{G_i^- \sum_{i=1}^{m} \frac{\min_i G_i^-}{G_i^-}} = G_i^+ + \frac{\sum_{i=1}^{m} G_i^-}{G_i^- \sum_{i=1}^{m} \frac{1}{G_i^-}}, i = 1, 2, \cdots, m; \min_i G_i^- = \min_{1 \le i \le m} \left\{ G_i^- \right\} \tag{32}$$

Step 4.2: Select the optimal urban rail transit system.

During the process of urban rail transit system selection, the optimal urban rail transit system shall be determined according to the comprehensive utility value H_i calculated by Equation (32). That is, sort H_i from small to large. The larger H_i is, the better the scheme is.

4. Case Study

In this part, firstly, seven types of urban rail transit systems and eight criteria are listed. Secondly, the proposed hybrid decision model is used for the selection of the urban rail transit system of City N, and the optimal urban rail transit system is selected to prove the applicability and effectiveness of the proposed method. Finally, the stability and robustness of the model are verified through sensitivity analysis and comparative analysis.

Therefore, the types and related evaluation criteria of urban rail transit are systematically studied. Based on the existing research and discussion with four experts (Table 2 for experts' background), seven types of urban rail transit and eight criteria were determined to evaluate the types of urban rail transit (Table 3). After the preliminary analysis, an expert group composed of four experts was responsible for the evaluation of urban rail transit types. These decision-makers have played a role in rail transit, universities and government agencies. Next, the steps of the developed method in evaluating the type selection of urban rail transit will be introduced.

Table 2. The background of experts.

Experts	Major	Occupation	Working Experience
D_1	Transportation	Professor	26 years
D_2	Transportation	Professor	22 years

D_3	Transportation	Associate professor	15 years
D_4	Transportation	Researcher	8 years

Table 3. The evaluation criteria of urban rail transit system.

Primary Index	Secondary Index	Type	Description
Characteristic	Transportation capacity (Q_1)	Benefit	It refers to the average number of passengers transported by the rail transit system per hour.
	Transportation speed (Q_2)	Benefit	It refers to the average operating distance of the rail transit system per hour.
Technology	Technology maturity (Q_3)	Benefit	It refers to the maturity of the technology used in the construction of the rail transit system.
	Application degree of green technology (Q_4)	Benefit	It refers to the degree of application of green technology in the design and construction stage of the rail transit system, such as land saving, energy saving, environmental protection technology, etc.
	Construction difficulty (Q_5)	Cost	It refers to the environmental conditions required for the construction of the rail transit system, such as underground, ground, soil requirements, etc.
Economy	Construction cost (Q_6)	Cost	It refers to the average construction cost per kilometer of the rail transit system.
	Operation and maintenance cost (Q_7)	Cost	It refers to the cost required for the operation and maintenance of the rail transit system after the completion of construction.
Environment	Environmental harmony (Q_8)	Benefit	It refers to the influence degree of the noise generated during the operation of the rail transit system on the environment and the environmental quality and aesthetics of the internal environment (vehicles and stations).

4.1. The Types of Urban Rail Transit System

As the backbone of urban public transport, urban rail transit has the characteristics of being fast, convenient, efficient, safe and comfortable. Under the current green and sustainable development policy, this type of system caters to the needs of the new era. According to the research on the classification of various forms of urban rail transit systems, this paper divides the urban rail transit system into seven forms: metro system, light rail system, monorail system, modern tram system, mid–low-speed maglev system, automatic guided track system and municipal railway system.

(1) Metro System (P_1). A metro system is a kind of urban rail transit. It adopts a steel wheel and rail system and mainly operates in tunnels built in underground space of big cities. When conditions permit, it can also pass through the ground and operate on the ground or viaduct.
(2) Light Rail System (P_2). A light rail system refers to the tram or train running on all streets or viaducts. It is a kind of urban rail transit system.
(3) Monorail System (P_3). A monorail system is a medium-volume rail transportation system in which vehicles and special track beams are combined into one. Its track beam is not only the load-bearing structure of vehicles but also the guide track for vehicle operation.

(4) Modern Tram System (P_4). A tram is a rail transit vehicle driven by electricity and running on the track. Because it runs on the street, it is also called road tram, or tram for short.
(5) Mid–Low-Speed Maglev System (P_5). A medium–low-speed maglev is a new technology with independent intellectual property rights in China, and it is also the most advanced technology in urban rail transit. It is applicable to the traffic connection between urban areas, close cities and scenic spots.
(6) Automatic Guided Track System (P_6). Automatic guided track system trains run along special guiding devices. The vehicle operation and stations can be controlled by computer. It can realize full automation and unmanned driving. The automatic guided track system is suitable for urban airport lines and point-to-point transportation lines with relatively concentrated urban passenger flow. When necessary, it can operate with fewer stops in the middle.
(7) Municipal Railway System (P_7). A municipal railway, also known as commuter railway and suburban railway, refers to the passenger rail transit system within the metropolitan area, serving cities and suburbs, central cities and satellite cities, key cities and towns, etc.

4.2. Relevant Criteria

The criteria for urban rail transit system selection are obtained based on literature research and expert consultation summary. The evaluation criteria proposed in this study is from the perspectives of characteristic, technology, economy and environment, with a total of eight criteria, including five benefit criteria and three cost criteria. The detailed description of the criteria is shown in Table 3.

4.3. Method Implementation

In this subsection, based on the above-listed seven urban rail transit system types and eight urban rail transit evaluation criteria, City N is selected as an example to implement the hybrid group decision framework in order to select the most suitable urban rail transit system type for City N. By the end of 2020, the total resident population of city N was 9.404 million, and the population density was 622.52 people per square kilometer. Throughout the year, the whole society completed 75.1333 million passenger trips, including 24.264 million road passenger trips and 40.516 million railway passenger trips. In terms of public transport, at the end of the year, there were 10,035 standard public transport vehicles in the city. Further, 1272 lines were operated, an increase of 8.3%. Rail transit completed 158 million passenger trips in the whole year. At the end of the year, there were 42,000 public bicycles in the city, with a total of 22.597 million car rentals in the whole year. At the end of the year, there were 6281 taxis in the city.

The decision group is still composed of the above four experts, who provide the linguistic evaluation decision matrix and the linguistic attribute direct influence matrix, respectively, as shown in Tables 4 and 5.

Table 4. The linguistic decision-making matrix.

DEs	Urban Rail Transit System	Criteria							
		Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8
D_1	P_1	EH	H	EH	H	VH	VH	VH	H
	P_2	H	H	EH	H	MH	MH	H	VH
	P_3	M	MH	H	VH	L	ML	MH	VH
	P_4	ML	ML	H	VH	ML	L	L	VH
	P_5	M	VH	M	H	H	H	MH	H
	P_6	M	MH	H	H	M	M	M	VH
	P_7	H	EH	VH	H	M	H	H	VH
D_2	P_1	VH	VH	VH	MH	M	M	M	M
	P_2	H	H	VH	MH	M	M	M	M
	P_3	M	M	H	MH	M	ML	M	MH
	P_4	ML	ML	H	MH	M	ML	M	ML
	P_5	M	EH	ML	H	H	H	H	H
	P_6	ML	L	M	MH	M	ML	M	MH
	P_7	VH	VH	VH	MH	M	MH	MH	M
D_3	P_1	VH	VH	VH	MH	M	EH	EH	H
	P_2	MH	MH	VH	MH	M	H	EH	H
	P_3	ML	MH	MH	MH	ML	H	EH	EH
	P_4	ML	ML	MH	ML	H	M	M	M
	P_5	ML	MH	VL	VH	H	H	EH	H
	P_6	VL	ML	VL	MH	ML	M	M	M
	P_7	EH	EH	VH	MH	M	H	VH	H
D_4	P_1	VH	VH	H	M	H	VH	VH	MH
	P_2	MH	MH	H	M	M	MH	ML	H
	P_3	MH	MH	ML	M	ML	M	M	H
	P_4	M	M	ML	M	M	ML	ML	VH
	P_5	H	H	L	MH	MH	H	VH	VH
	P_6	M	M	L	M	MH	VH	VH	MH
	P_7	VH	VH	VH	M	MH	M	M	M

Table 5. The fuzzy direct-influence matrix.

DEs	Criteria	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8
D_1	Q_1	EL	VL	VL	VL	ML	ML	H	ML
	Q_2	H	EL	VL	VL	MH	MH	H	H
	Q_3	MH	MH	EL	M	VH	VH	VH	H
	Q_4	VL	VL	VL	EL	MH	MH	H	EH
	Q_5	VL	VL	VL	ML	EL	EH	L	L
	Q_6	M	M	VL	VL	MH	EL	L	ML
	Q_7	L	L	VL	VL	VL	VL	EL	VL
	Q_8	VL	VL	VL	VL	VL	VL	VL	EL
D_2	Q_1	EL	MH	ML	MH	ML	ML	ML	MH
	Q_2	M	EL	ML	MH	ML	ML	ML	MH
	Q_3	VH	VH	EL	H	H	M	M	MH
	Q_4	L	L	ML	EL	ML	ML	ML	M
	Q_5	M	H	L	ML	EL	M	ML	M
	Q_6	L	L	H	M	H	EL	ML	ML
	Q_7	ML	M	H	H	MH	M	EL	ML

	Q_8	MH	MH	VH	EH	MH	H	VH	EL
D_3	Q_1	EL	MH	L	ML	ML	VH	VH	M
	Q_2	VH	EL	MH	ML	VH	MH	VH	M
	Q_3	L	MH	EL	VH	H	M	MH	M
	Q_4	L	ML	VH	EL	H	VH	VH	VH
	Q_5	ML	VH	H	H	EL	VH	VH	VH
	Q_6	VH	MH	M	VH	VH	EL	H	H
	Q_7	VH	VH	MH	VH	H	H	EL	VH
	Q_8	M	M	M	VH	H	H	VH	EL
D_4	Q_1	EL	EL	H	H	VH	VH	VH	M
	Q_2	EL	EL	VH	MH	VH	VH	VH	VH
	Q_3	H	VH	EL	VH	VH	VH	VH	EH
	Q_4	H	MH	VH	EL	M	VH	VH	EH
	Q_5	VH	VH	VH	M	EL	EH	EH	EH
	Q_6	VH	VH	VH	VH	EH	EL	M	M
	Q_7	VH	VH	VH	VH	EH	M	EL	L
	Q_8	M	VH	EH	EH	M	M	L	EL

Then, the linguistic assessment matrix is transformed into a fuzzy evaluation matrix and a fuzzy direct influence matrix represented by intuitionistic fuzzy numbers by the intuitionistic fuzzy scale (adapted from Refs. [33,40]) listed in Tables 1 and 6, as shown in Tables 7 and 8. Then, the expert weight (Table 9) is calculated from Equations (10)–(13), the subjective weight is calculated from Equations (15)–(20), the objective weight is calculated from Equations (21)–(25) and the final comprehensive weight (Table 10) is calculated from Equation (26), and then the ranking of the urban rail transit system most suitable for City N is calculated according to Equations (27)–(32), as shown in Table 11.

Table 6. The transformation relationship of directly affected matrix linguistic variables.

Linguistic Variables	IFNs
Extremely Low (EL)	(0.10, 0.80, 0.10)
Very Low (VL)	(0.20, 0.70, 0.10)
Low (L)	(0.30, 0.60, 0.10)
Medium Low (ML)	(0.40, 0.50, 0.10)
Medium (M)	(0.55, 0.40, 0.05)
Medium High (MH)	(0.65, 0.30, 0.05)
High (H)	(0.75, 0.20, 0.05)
Very High (VH)	(0.90, 0.05, 0.05)
Extremely High (EH)	(1.00, 0.00, 0.00)

Table 7. The fuzzy decision-making matrix.

DEs.	Urban Rail Transit System	Criteria							
		Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8
D_1	P_1	(0.90, 0.10, 0.00)	(0.70, 0.20, 0.10)	(0.90, 0.10, 0.00)	(0.70, 0.20, 0.10)	(0.80, 0.10, 0.10)	(0.80, 0.10, 0.10)	(0.80, 0.10, 0.10)	(0.70, 0.20, 0.10)
	P_2	(0.70, 0.20, 0.10)	(0.70, 0.20, 0.10)	(0.90, 0.10, 0.00)	(0.70, 0.20, 0.10)	(0.60, 0.30, 0.10)	(0.60, 0.30, 0.10)	(0.70, 0.20, 0.10)	(0.80, 0.10, 0.10)
	P_3	(0.50, 0.40, 0.10)	(0.60, 0.30, 0.10)	(0.70, 0.20, 0.10)	(0.80, 0.10, 0.10)	(0.25, 0.60, 0.15)	(0.40, 0.50, 0.10)	(0.60, 0.30, 0.10)	(0.80, 0.10, 0.10)
	P_4	(0.40, 0.50, 0.10)	(0.40, 0.50, 0.10)	(0.70, 0.20, 0.10)	(0.80, 0.10, 0.10)	(0.40, 0.50, 0.10)	(0.25, 0.60, 0.15)	(0.25, 0.60, 0.15)	(0.80, 0.10, 0.10)
	P_5	(0.50, 0.40, 0.10)	(0.80, 0.10, 0.10)	(0.50, 0.40, 0.10)	(0.70, 0.20, 0.10)	(0.70, 0.20, 0.10)	(0.70, 0.20, 0.10)	(0.60, 0.30, 0.10)	(0.70, 0.20, 0.10)

	P_6	(0.50, 0.40, 0.10)	(0.60, 0.30, 0.10)	(0.70, 0.20, 0.10)	(0.70, 0.20, 0.10)	(0.50, 0.40, 0.10)	(0.50, 0.40, 0.10)	(0.50, 0.40, 0.10)	(0.80, 0.10, 0.10)
	P_7	(0.70, 0.20, 0.10)	(0.90, 0.10, 0.00)	(0.80, 0.10, 0.10)	(0.70, 0.20, 0.10)	(0.50, 0.40, 0.10)	(0.70, 0.20, 0.10)	(0.70, 0.20, 0.10)	(0.80, 0.10, 0.10)
D_2	P_1	(0.80, 0.10, 0.10)	(0.80, 0.10, 0.10)	(0.80, 0.10, 0.10)	(0.60, 0.30, 0.10)	(0.50, 0.40, 0.10)	(0.50, 0.40, 0.10)	(0.50, 0.40, 0.10)	(0.50, 0.40, 0.10)
	P_2	(0.70, 0.20, 0.10)	(0.70, 0.20, 0.10)	(0.80, 0.10, 0.10)	(0.60, 0.30, 0.10)	(0.50, 0.40, 0.10)	(0.50, 0.40, 0.10)	(0.50, 0.40, 0.10)	(0.50, 0.40, 0.10)
	P_3	(0.50, 0.40, 0.10)	(0.50, 0.40, 0.10)	(0.70, 0.20, 0.10)	(0.60, 0.30, 0.10)	(0.50, 0.40, 0.10)	(0.40, 0.50, 0.10)	(0.50, 0.40, 0.10)	(0.60, 0.30, 0.10)
	P_4	(0.40, 0.50, 0.10)	(0.40, 0.50, 0.10)	(0.70, 0.20, 0.10)	(0.60, 0.30, 0.10)	(0.50, 0.40, 0.10)	(0.40, 0.50, 0.10)	(0.50, 0.40, 0.10)	(0.40, 0.50, 0.10)
	P_5	(0.50, 0.40, 0.10)	(0.90, 0.10, 0.00)	(0.40, 0.50, 0.10)	(0.70, 0.20, 0.10)	(0.70, 0.20, 0.10)	(0.70, 0.20, 0.10)	(0.70, 0.20, 0.10)	(0.70, 0.20, 0.10)
	P_6	(0.40, 0.50, 0.10)	(0.25, 0.60, 0.15)	(0.50, 0.40, 0.10)	(0.60, 0.30, 0.10)	(0.50, 0.40, 0.10)	(0.40, 0.50, 0.10)	(0.50, 0.40, 0.10)	(0.60, 0.30, 0.10)
	P_7	(0.80, 0.10, 0.10)	(0.80, 0.10, 0.10)	(0.80, 0.10, 0.10)	(0.60, 0.30, 0.10)	(0.50, 0.40, 0.10)	(0.60, 0.30, 0.10)	(0.60, 0.30, 0.10)	(0.50, 0.40, 0.10)
D_3	P_1	(0.80, 0.10, 0.10)	(0.80, 0.10, 0.10)	(0.80, 0.10, 0.10)	(0.60, 0.30, 0.10)	(0.50, 0.40, 0.10)	(0.90, 0.10, 0.00)	(0.90, 0.10, 0.00)	(0.70, 0.20, 0.10)
	P_2	(0.60, 0.30, 0.10)	(0.60, 0.30, 0.10)	(0.80, 0.10, 0.10)	(0.60, 0.30, 0.10)	(0.50, 0.40, 0.10)	(0.70, 0.20, 0.10)	(0.90, 0.10, 0.00)	(0.70, 0.20, 0.10)
	P_3	(0.40, 0.50, 0.10)	(0.60, 0.30, 0.10)	(0.60, 0.30, 0.10)	(0.60, 0.30, 0.10)	(0.40, 0.50, 0.10)	(0.70, 0.20, 0.10)	(0.90, 0.10, 0.00)	(0.90, 0.10, 0.00)
	P_4	(0.40, 0.50, 0.10)	(0.40, 0.50, 0.10)	(0.60, 0.30, 0.10)	(0.40, 0.50, 0.10)	(0.70, 0.20, 0.10)	(0.50, 0.40, 0.10)	(0.50, 0.40, 0.10)	(0.50, 0.40, 0.10)
	P_5	(0.40, 0.50, 0.10)	(0.60, 0.30, 0.10)	(0.10, 0.75, 0.15)	(0.80, 0.10, 0.10)	(0.70, 0.20, 0.10)	(0.70, 0.20, 0.10)	(0.90, 0.10, 0.00)	(0.70, 0.20, 0.10)
	P_6	(0.10, 0.75, 0.15)	(0.40, 0.50, 0.10)	(0.10, 0.75, 0.15)	(0.60, 0.30, 0.10)	(0.40, 0.50, 0.10)	(0.50, 0.40, 0.10)	(0.50, 0.40, 0.10)	(0.50, 0.40, 0.10)
	P_7	(0.90, 0.10, 0.00)	(0.90, 0.10, 0.00)	(0.80, 0.10, 0.10)	(0.60, 0.30, 0.10)	(0.50, 0.40, 0.10)	(0.70, 0.20, 0.10)	(0.80, 0.10, 0.10)	(0.70, 0.20, 0.10)
D_4	P_1	(0.80, 0.10, 0.10)	(0.80, 0.10, 0.10)	(0.70, 0.20, 0.10)	(0.50, 0.40, 0.10)	(0.70, 0.20, 0.10)	(0.80, 0.10, 0.10)	(0.80, 0.10, 0.10)	(0.60, 0.30, 0.10)
	P_2	(0.60, 0.30, 0.10)	(0.60, 0.30, 0.10)	(0.70, 0.20, 0.10)	(0.50, 0.40, 0.10)	(0.50, 0.40, 0.10)	(0.60, 0.30, 0.10)	(0.40, 0.50, 0.10)	(0.70, 0.20, 0.10)
	P_3	(0.60, 0.30, 0.10)	(0.60, 0.30, 0.10)	(0.40, 0.50, 0.10)	(0.50, 0.40, 0.10)	(0.40, 0.50, 0.10)	(0.50, 0.40, 0.10)	(0.50, 0.40, 0.10)	(0.70, 0.20, 0.10)
	P_4	(0.50, 0.40, 0.10)	(0.50, 0.40, 0.10)	(0.40, 0.50, 0.10)	(0.50, 0.40, 0.10)	(0.50, 0.40, 0.10)	(0.40, 0.50, 0.10)	(0.40, 0.50, 0.10)	(0.80, 0.10, 0.10)
	P_5	(0.70, 0.20, 0.10)	(0.70, 0.20, 0.10)	(0.25, 0.60, 0.15)	(0.60, 0.30, 0.10)	(0.60, 0.30, 0.10)	(0.70, 0.20, 0.10)	(0.80, 0.10, 0.10)	(0.80, 0.10, 0.10)
	P_6	(0.50, 0.40, 0.10)	(0.50, 0.40, 0.10)	(0.25, 0.60, 0.15)	(0.50, 0.40, 0.10)	(0.60, 0.30, 0.10)	(0.80, 0.10, 0.10)	(0.80, 0.10, 0.10)	(0.60, 0.30, 0.10)
	P_7	(0.80, 0.10, 0.10)	(0.80, 0.10, 0.10)	(0.80, 0.10, 0.10)	(0.50, 0.40, 0.10)	(0.60, 0.30, 0.10)	(0.50, 0.40, 0.10)	(0.50, 0.40, 0.10)	(0.50, 0.40, 0.10)

Table 8. The intuitionistic fuzzy direct-influence matrix.

DEs	Criteria	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8
D_1	Q_1	(0.10, 0.80, 0.10)	(0.20, 0.70, 0.10)	(0.20, 0.70, 0.10)	(0.20, 0.70, 0.10)	(0.40, 0.50, 0.10)	(0.40, 0.50, 0.10)	(0.75, 0.20, 0.05)	(0.40, 0.50, 0.10)
	Q_2	(0.75, 0.20, 0.05)	(0.10, 0.80, 0.10)	(0.20, 0.70, 0.10)	(0.20, 0.70, 0.10)	(0.65, 0.30, 0.05)	(0.65, 0.30, 0.05)	(0.75, 0.20, 0.05)	(0.75, 0.20, 0.05)
	Q_3	(0.65, 0.30, 0.05)	(0.65, 0.30, 0.05)	(0.10, 0.80, 0.10)	(0.55, 0.40, 0.05)	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(0.75, 0.20, 0.05)

	Q_4	(0.20, 0.70, 0.10)	(0.20, 0.70, 0.10)	(0.20, 0.70, 0.10)	(0.10, 0.80, 0.10)	(0.65, 0.30, 0.05)	(0.65, 0.30, 0.05)	(0.75, 0.20, 0.05)	(1.00, 0.00, 0.00)
	Q_5	(0.20, 0.70, 0.10)	(0.20, 0.70, 0.10)	(0.20, 0.70, 0.10)	(0.40, 0.50, 0.10)	(0.10, 0.80, 0.10)	(1.00, 0.00, 0.00)	(0.30, 0.60, 0.10)	(0.30, 0.60, 0.10)
	Q_6	(0.55, 0.40, 0.05)	(0.55, 0.40, 0.05)	(0.20, 0.70, 0.10)	(0.20, 0.70, 0.10)	(0.65, 0.30, 0.05)	(0.10, 0.80, 0.10)	(0.30, 0.60, 0.10)	(0.40, 0.50, 0.10)
	Q_7	(0.30, 0.60, 0.10)	(0.30, 0.60, 0.10)	(0.20, 0.70, 0.10)	(0.20, 0.70, 0.10)	(0.20, 0.70, 0.10)	(0.20, 0.70, 0.10)	(0.10, 0.80, 0.10)	(0.20, 0.70, 0.10)
	Q_8	(0.20, 0.70, 0.10)	(0.20, 0.70, 0.10)	(0.20, 0.70, 0.10)	(0.20, 0.70, 0.10)	(0.20, 0.70, 0.10)	(0.20, 0.70, 0.10)	(0.20, 0.70, 0.10)	(0.10, 0.80, 0.10)
D_2	Q_1	(0.10, 0.80, 0.10)	(0.65, 0.30, 0.05)	(0.40, 0.50, 0.10)	(0.65, 0.30, 0.05)	(0.40, 0.50, 0.10)	(0.40, 0.50, 0.10)	(0.40, 0.50, 0.10)	(0.65, 0.30, 0.05)
	Q_2	(0.55, 0.40, 0.05)	(0.10, 0.80, 0.10)	(0.40, 0.50, 0.10)	(0.65, 0.30, 0.05)	(0.40, 0.50, 0.10)	(0.40, 0.50, 0.10)	(0.40, 0.50, 0.10)	(0.65, 0.30, 0.05)
	Q_3	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(0.10, 0.80, 0.10)	(0.75, 0.20, 0.05)	(0.75, 0.20, 0.05)	(0.55, 0.40, 0.05)	(0.55, 0.40, 0.05)	(0.65, 0.30, 0.05)
	Q_4	(0.30, 0.60, 0.10)	(0.30, 0.60, 0.10)	(0.40, 0.50, 0.10)	(0.10, 0.80, 0.10)	(0.40, 0.50, 0.10)	(0.40, 0.50, 0.10)	(0.40, 0.50, 0.10)	(0.55, 0.40, 0.05)
	Q_5	(0.55, 0.40, 0.05)	(0.75, 0.20, 0.05)	(0.30, 0.60, 0.10)	(0.40, 0.50, 0.10)	(0.10, 0.80, 0.10)	(0.55, 0.40, 0.05)	(0.40, 0.50, 0.10)	(0.55, 0.40, 0.05)
	Q_6	(0.30, 0.60, 0.10)	(0.30, 0.60, 0.10)	(0.75, 0.20, 0.05)	(0.55, 0.40, 0.05)	(0.75, 0.20, 0.05)	(0.10, 0.80, 0.10)	(0.40, 0.50, 0.10)	(0.40, 0.50, 0.10)
	Q_7	(0.40, 0.50, 0.10)	(0.55, 0.40, 0.05)	(0.75, 0.20, 0.05)	(0.75, 0.20, 0.05)	(0.65, 0.30, 0.05)	(0.55, 0.40, 0.05)	(0.10, 0.80, 0.10)	(0.40, 0.50, 0.10)
	Q_8	(0.65, 0.30, 0.05)	(0.65, 0.30, 0.05)	(0.90, 0.05, 0.05)	(1.00, 0.00, 0.00)	(0.65, 0.30, 0.05)	(0.75, 0.20, 0.05)	(0.90, 0.05, 0.05)	(0.10, 0.80, 0.10)
D_3	Q_1	(0.10, 0.80, 0.10)	(0.65, 0.30, 0.05)	(0.30, 0.60, 0.10)	(0.40, 0.50, 0.10)	(0.40, 0.50, 0.10)	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(0.55, 0.40, 0.05)
	Q_2	(0.90, 0.05, 0.05)	(0.10, 0.80, 0.10)	(0.65, 0.30, 0.05)	(0.40, 0.50, 0.10)	(0.90, 0.05, 0.05)	(0.65, 0.30, 0.05)	(0.90, 0.05, 0.05)	(0.55, 0.40, 0.05)
	Q_3	(0.30, 0.60, 0.10)	(0.65, 0.30, 0.05)	(0.10, 0.80, 0.10)	(0.90, 0.05, 0.05)	(0.75, 0.20, 0.05)	(0.55, 0.40, 0.05)	(0.65, 0.30, 0.05)	(0.55, 0.40, 0.05)
	Q_4	(0.30, 0.60, 0.10)	(0.40, 0.50, 0.10)	(0.90, 0.05, 0.05)	(0.10, 0.80, 0.10)	(0.75, 0.20, 0.05)	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)
	Q_5	(0.40, 0.50, 0.10)	(0.90, 0.05, 0.05)	(0.75, 0.20, 0.05)	(0.75, 0.20, 0.05)	(0.10, 0.80, 0.10)	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)
	Q_6	(0.90, 0.05, 0.05)	(0.65, 0.30, 0.05)	(0.55, 0.40, 0.05)	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(0.10, 0.80, 0.10)	(0.75, 0.20, 0.05)	(0.75, 0.20, 0.05)
	Q_7	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(0.65, 0.30, 0.05)	(0.90, 0.05, 0.05)	(0.75, 0.20, 0.05)	(0.75, 0.20, 0.05)	(0.10, 0.80, 0.10)	(0.90, 0.05, 0.05)
	Q_8	(0.55, 0.40, 0.05)	(0.55, 0.40, 0.05)	(0.55, 0.40, 0.05)	(0.90, 0.05, 0.05)	(0.75, 0.20, 0.05)	(0.75, 0.20, 0.05)	(0.90, 0.05, 0.05)	(0.10, 0.80, 0.10)
D_4	Q_1	(0.10, 0.80, 0.10)	(0.10, 0.80, 0.10)	(0.75, 0.20, 0.05)	(0.75, 0.20, 0.05)	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(0.55, 0.40, 0.05)
	Q_2	(0.10, 0.80, 0.10)	(0.10, 0.80, 0.10)	(0.90, 0.05, 0.05)	(0.65, 0.30, 0.05)	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)
	Q_3	(0.75, 0.20, 0.05)	(0.90, 0.05, 0.05)	(0.10, 0.80, 0.10)	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(1.00, 0.00, 0.00)
	Q_4	(0.75, 0.20, 0.05)	(0.65, 0.30, 0.05)	(0.90, 0.05, 0.05)	(0.10, 0.80, 0.10)	(0.55, 0.40, 0.05)	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(1.00, 0.00, 0.00)

Q_5	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(0.55, 0.40, 0.05)	(0.10, 0.80, 0.10)	(1.00, 0.00, 0.00)	(1.00, 0.00, 0.00)	(1.00, 0.00, 0.00)
Q_6	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(1.00, 0.00, 0.00)	(0.10, 0.80, 0.10)	(0.55, 0.40, 0.05)	(0.55, 0.40, 0.05)
Q_7	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(0.90, 0.05, 0.05)	(1.00, 0.00, 0.00)	(0.55, 0.40, 0.05)	(0.10, 0.80, 0.10)	(0.30, 0.60, 0.10)
Q_8	(0.55, 0.40, 0.05)	(0.90, 0.05, 0.05)	(1.00, 0.00, 0.00)	(1.00, 0.00, 0.00)	(0.55, 0.40, 0.05)	(0.55, 0.40, 0.05)	(0.30, 0.60, 0.10)	(0.10, 0.80, 0.10)

Table 9. The weight of DEs.

DEs	λ_k
D_1	0.2548
D_2	0.2521
D_3	0.2431
D_4	0.2499

Table 10. The weight of criteria and ranking.

Criteria	ω_j^s	**Ranking**	ω_j^o	**Ranking**	ω_j	**Ranking**
Q_1	0.0764	8	0.1631	3	0.1198	6
Q_2	0.1066	7	0.1813	2	0.1439	2
Q_3	0.1468	2	0.2039	1	0.1754	1
Q_4	0.1168	6	0.0385	8	0.0776	8
Q_5	0.1522	1	0.1185	5	0.1353	3
Q_6	0.1245	5	0.1168	6	0.1206	5
Q_7	0.1404	3	0.1261	4	0.1332	4
Q_8	0.1363	4	0.0519	7	0.0941	7

Table 11. The ranking of urban rail transit system type.

Urban Rail Transit System	G_i^+	G_i^-	H_i	**Ranking**
P_1	−0.1409	−1.0936	−0.2057	1
P_2	−0.5312	−0.2748	−0.7893	3
P_3	−1.3059	−0.1643	−1.7376	4
P_4	−1.9230	−0.0440	−3.5346	7
P_5	−1.7623	−0.8585	−1.8449	5
P_6	−2.4013	−0.2118	−2.7362	6
P_7	−0.0762	−0.3434	−0.2828	2

It can be seen from Table 10 that the ranking of the subjective weight and objective weight of criteria are quite different. The weight determination method combining subjective and objective weight can make the evaluation results more objective. The top three final criteria are technology maturity Q_3, transportation speed Q_2 and construction difficulty Q_5. The ranking of criteria may change due to different cities. For City N, the first consideration is the three attributes of technology maturity, transportation speed and construction difficulty.

It can be seen from Table 11 that the ranking of the urban rail transit system in City N can be obtained through the comprehensive evaluation value. Here, the comprehensive evaluation value is negative because the regret theory is considered. P_1 ranks first; that is, the type of urban rail transit most suitable for City N is metro system. City N is the third largest city in Z Province, with a large population and high requirements for transportation capacity. In addition, the metro system has high technical maturity and fast transportation speed. The natural geographical environment of city N also makes the construction of the metro system relatively difficult. Therefore, the metro system is the most suitable urban rail transit for city N. The municipal railway system (P_7) and light rail system (P_2) rank second and third, respectively. These two types are two other options that can be considered for construction in city N in addition to the metro system. They also have the characteristics of high technical maturity and fast transportation speed. Other criteria can be comprehensively considered for selection. The final results of the ranking of the urban rail transit system type can prove the applicability and effectiveness of the evaluation index and evaluation framework proposed in this study.

4.4. Sensitivity Analysis

In this subsection, the stability and robustness of the proposed hybrid intuitionistic fuzzy group decision framework will be explored through sensitivity analysis. The sensitivity analysis of this study is divided into two parts. The first part is the sensitivity analysis of the relative importance coefficient of subjective and objective weights. The second part is the sensitivity analysis of the regret avoidance coefficient of experts.

4.4.1. The Impact Analysis of Parameter φ on Decision Results

The relative importance coefficient φ of subjective and objective weights can express the preference of decision-making experts for weights. In the previous example analysis, the value of φ is 0.5. Next, by changing the value of φ, different criteria weight values are obtained, and then the adjusted criteria ranking results are observed. In this paper, $\varphi \in [0,1]$, first, let $\varphi = 0$, increasing by 0.1; the final ranking results and ranking changes are shown in Table 12 and Figure 2.

Table 12. The ranking of urban rail transit types under different φ values.

	φ = 0	φ = 0.1	φ = 0.2	φ = 0.3	φ = 0.4	φ = 0.5	φ = 0.6	φ = 0.7	φ = 0.8	φ = 0.9	φ = 1
P_1	1	1	1	1	1	1	1	1	1	1	1
P_2	3	3	3	3	3	3	3	3	3	3	3
P_3	4	4	4	4	4	4	4	4	4	4	5
P_4	7	7	7	7	7	7	7	7	7	7	7
P_5	5	5	5	5	5	5	5	5	5	5	4
P_6	6	6	6	6	6	6	6	6	6	6	6
P_7	2	2	2	2	2	2	2	2	2	2	2

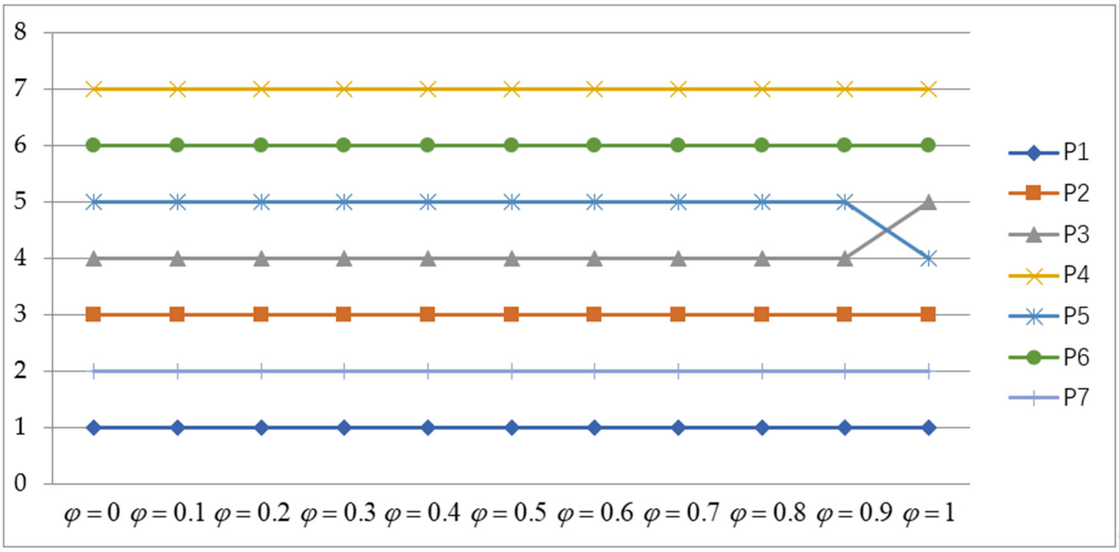

Figure 2. The ranking change of decision results under different parameter φ values.

As can be seen from Figure 2, the final ranking is relatively stable by changing the proportion of subjective and objective weights, and the top three are always $P_1 \succ P_7 \succ P_2$. When $\varphi = 0$ and 1, it means that only objective weight and only subjective weight are considered, respectively. When only the subjective weight is considered, the ranking of the fourth and fifth types will be exchanged and the other rankings will not change. Therefore, comprehensive consideration of the subjective and objective weight can make the decision-making results more stable.

4.4.2. The Impact Analysis of Parameter ϑ on Decision Results

The second part considers the influence of the expert regret avoidance coefficient on the final decision outcome. The larger ϑ is, the higher the degree of the regret of experts. The initial value of ϑ is 5. In the analysis, ϑ takes 1 to 10 and increases by 1. The ranking and changes of the decision results are shown in Table 13 and Figure 3.

Table 13. The ranking of urban rail transit types under different ϑ values.

	$\vartheta=1$	$\vartheta=2$	$\vartheta=3$	$\vartheta=4$	$\vartheta=5$	$\vartheta=6$	$\vartheta=7$	$\vartheta=8$	$\vartheta=9$	$\vartheta=10$
P_1	1	1	1	1	1	1	1	1	1	1
P_2	3	3	3	3	3	3	3	3	3	3
P_3	5	5	4	4	4	4	4	4	4	4
P_4	7	7	7	7	7	7	7	7	7	7
P_5	4	4	5	5	5	5	5	5	5	5
P_6	6	6	6	6	6	6	6	6	6	6
P_7	2	2	2	2	2	2	2	2	2	2

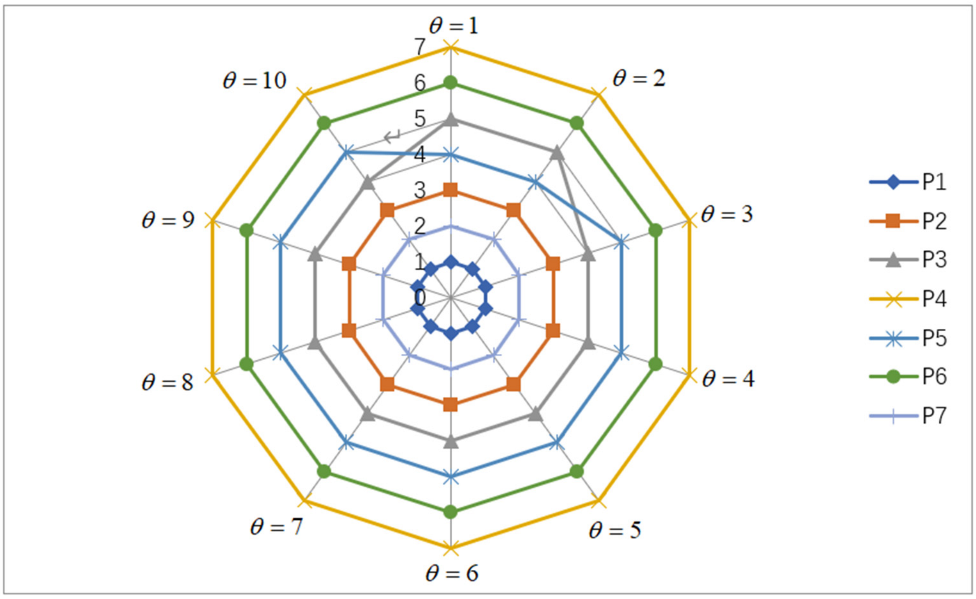

Figure 3. The ranking change in decision results under different parameter ϑ values.

As can be seen from Figure 3, changing the value of the regret avoidance coefficient has little impact on the final ranking result, which is still relatively stable, and the top three are still $P_1 \succ P_7 \succ P_2$; only when the value of $\vartheta=1$ and 2, the medium–low-speed maglev system (P5) and monorail system (P_3) rank fourth and fifth, respectively. When the value of ϑ is greater than or equal to 3, the rankings of the two types are exchanged. Monorail system (P_3) ranks fourth, while medium–low-speed maglev system (P_5) ranks fifth. From the sensitivity analysis of the above two parts, it can be seen that the model proposed in this paper has strong stability.

4.5. Comparative Analysis

The same as this study uses IFS to deal with the uncertainty and inaccuracy in decisions, the weight determination method remains unchanged based on IFS in the comparative analysis part. Three MCDM methods are selected to compare with the results of this study. The first is the traditional COPRAS method, which does not consider the regret theory. The other two methods are TOPSIS and ARAS. The comparison results are shown in Table 14 and Figure 4.

Table 14. The ranking under different evaluation methods.

Urban Rail Transit System	This Paper	IF-COPRAS	IF-TOPSIS	IF-ARAS
P_1	1	3	1	3
P_2	3	2	4	2
P_3	4	4	6	4
P_4	7	5	7	5
P_5	5	6	3	6
P_6	6	7	5	7
P_7	2	1	2	1

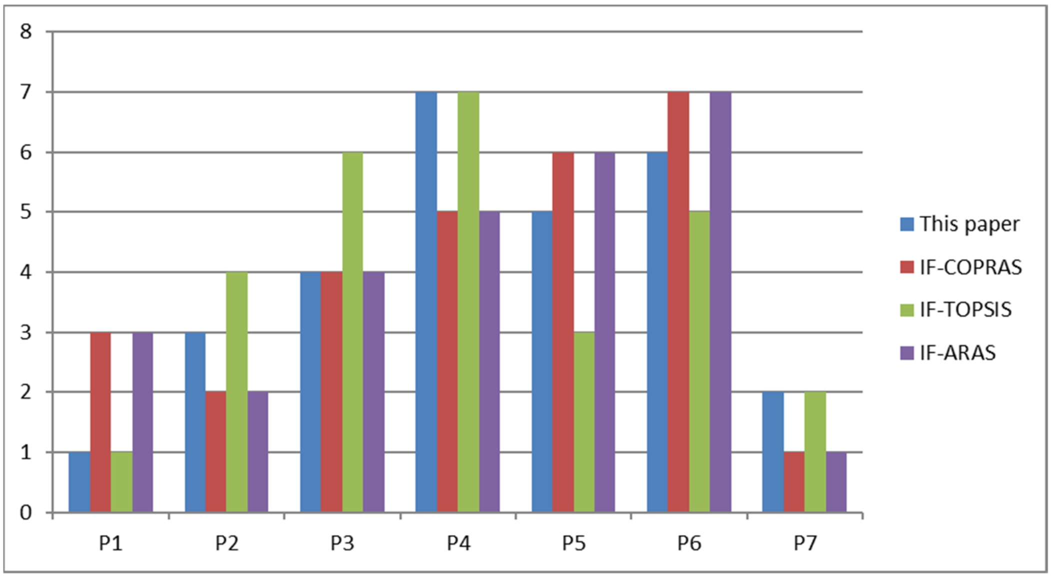

Figure 4. The ranking results based on different evaluation methods.

Figure 4 shows the comparison of the ranking results under the four methods. It can be seen that the ranking results under different evaluation methods are different, but the overall trend is the same. The top three are mainly P_1, P_2 and P_7. The best scheme changes between P_1 and P_7, and the last three are concentrated among P_4, P_5 and P_6. By calculating the Spearman correlation coefficient of the ranking results of the original method and other methods, it can be seen that all the correlation coefficients are greater than 0.78, which shows that the evaluation model proposed in this study is relatively stable. The detailed comparison analyses with other intuitionistic fuzzy decision approaches are illustrated below.

Compared with the results of the traditional IF-COPRAS method, it is found that the results obtained by the two methods are different, and the Spearman correlation coefficient is 0.786. The reason for this difference is that the evaluation model proposed in this study considers the regret theory; that is, the expert risk aversion coefficient and regret aversion coefficient are considered at the same time. The result is the optimization of the traditional IF-COPRAS method.

Compared with the results of the IF-TOPSIS method, the ranking results obtained by the two methods are more consistent, and the ranking of 1, 2 and 7 are the same. This can also be proven by the Spearman correlation coefficient of 0.821. The TOPSIS method is a classical MCDM method, which has wide applicability. Through the consistency of the results of the two methods, it can be seen that the method proposed in this study has stability and robustness.

Compared with the results of the IF-ARAS method, the results of the ARAS method are the same as those of the traditional COPRAS method. Therefore, the Spearman correlation coefficient is also 0.786. This indicates that regret theory will affect the results.

Based on the above discussion and comparative analysis, the proposed hybrid intuitionistic fuzzy group decision framework for the urban rail transit system selection of this paper has the following advantages:

(1) The proposed framework describes the uncertainty and fuzziness in the decision-making process through IFS, which makes the decision-making results closer to the uncertain cognitive thinking of decision-makers.
(2) The proposed framework can effectively solve the decision problem with completely unknown weight information, so it has a wider scope of application.
(3) The proposed framework determines the model through the comprehensive weight, and reasonably considers the subjective and objective factors to make the importance of the criterion more credible.

(4) The proposed framework combines regret theory and the COPRAS method and comprehensively considers the inconsistency of psychological behavior and the attribute transformation process in the process of expert decision-making, so it improves the rationality and reliability of decision outcomes.

5. Conclusions

In view of the shortcomings of the existing research, the main goal of this study is to develop a hybrid MCGDM evaluation model for the selection of an urban rail transit system. In order to overcome the uncertainty and inaccuracy in the process of expert evaluation and make the evaluation information more reliable, this study put forward a hybrid intuitionistic fuzzy group decision framework to select the satisfactory urban rail transit system. The DEMATEL and CRITIC methods were selected to determine the subjective and objective weight of the criteria, and the COPRAS method based on regret theory was used to rank the types of urban rail transit systems and select the optimal urban rail transit system. The sensitivity analysis and comparative analysis prove the stability and robustness of the evaluation model. The results show that, no matter how the coefficient changes, the top three schemes have not changed. Furthermore, the ranking results still have high consistency by a detailed comparison analysis with other prior methodologies. Therefore, the hybrid decision-making framework model proposed in this study has strong practicability. It not only considers the subjective randomness of experts in the decision-making process but also considers the risk preference and regret degree of experts. It is more comprehensive and has more advantages in evaluating the selection of urban rail transit.

The method proposed in this study also has some limitations. For example, when calculating the weights of experts, only the relative distance of expert evaluation information is considered, and the information, such as experts' own experience, is ignored. In the process of expert information fusion, the relationship of decision information under different criteria is not considered. In the future, it can be further studied from the following aspects. Firstly, this research model can be applied to other related MCGDM problems [43,44]. Secondly, this research is based on the intuitionistic fuzzy environment. In the future, different fuzzy linguistic environments and MCDM methods can be applied to this research model. Thirdly, in the face of decision-making experts from different fields, it is difficult to reach a consensus on the preference information provided by different experts, and small-group-decision-making cannot fully ensure the credibility of the final decision-making results; therefore, it is a hot issue to establish a large-scale group consensus decision-making model [45–47] in an intuitionistic fuzzy environment and solve the actual group-decision-making problem combined with big data artificial intelligence technology.

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Abbreviations

Decision-Making Trial and Evaluation Laboratory	DEMATEL
Criteria Importance Through Inter-criteria Correlation	CRITIC
Complex Proportional Assessment	COPRAS
Intuitionistic Fuzzy Sets	IFS
VlseKriterijuska Optimizacija I Komoromisno Resenje	VIKOR
Technique for Order Preference by Similarity to an Ideal Solution	TOPSIS
Multi-Criteria Group-Decision-Making	MCGDM
Multi-Criteria Decision-Making	MCDM
Multi-Attribute Border Approximation Area Comparison	MABAC
Intuitionistic Fuzzy Number	IFN
Additional Ratio Assessment	ARAS

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