

Article

Using Linguistic VIKOR and Fuzzy Cognitive Maps to Select Virtual Reality Games Development Project

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Abstract: In the entertainment industry, providing games to players is a main business activity with a long history. There are various kinds of game types such as the computer game, web game, pocket game, mobile game developed for play. Virtual reality is a new technology which can integrate into the computer or mobile for generating virtual reality games. The goal of this study is to develop a framework to evaluate and select the virtual reality games development project. In the proposed framework, Linguistic VIKOR is integrated with fuzzy cognitive maps to select the project. For readers to understand the proposed method, a case study has been introduced to evaluate the project based on the proposed method. Finally, the conclusion and future research are discussed as an ending.

Keywords: virtual reality; linguistic variables; entertainment industry; game; fuzzy cognitive maps



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1. Introduction

Virtual reality games are a new development trend in the entertainment market. In the traditional game market, players have played the TV game, computer game, and mobile phone game. Players play games and compete with each other by internet. In the game fields, the market share of different kinds of games is relatively stable (Refer to Figure 1). Based on Newzoo company data, we can know that the mobile game will be the most important industry in game fields.

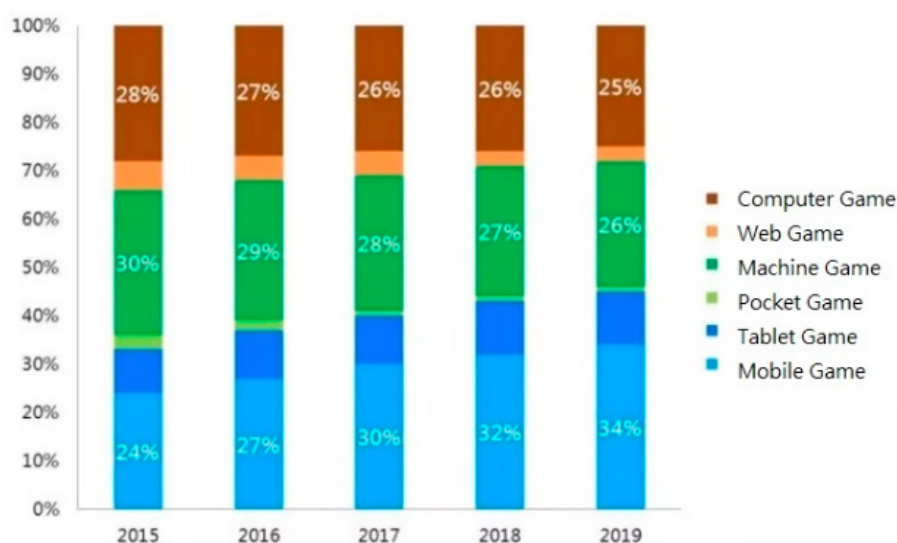


Figure 1. Market share in different kind of games. Data source: Newzoo company.

Virtual reality has been applied in various kinds of fields such as dynamic cinema, leisure machine, sports machine, stereo cinema, etc. [1]. Virtual reality games are one kind

of virtual reality application. This kind of game entered the game market in recent years. Based on the Institute for Information Industry, the global virtual reality market size is estimated to be USD 3 billion in 2016 and will reach USD 32 billion in 2020. However, there are a lot of VR technologies (Refer to Figure 2) and each kind has been developed for some machine for use of playing games (Refer to Table 1).

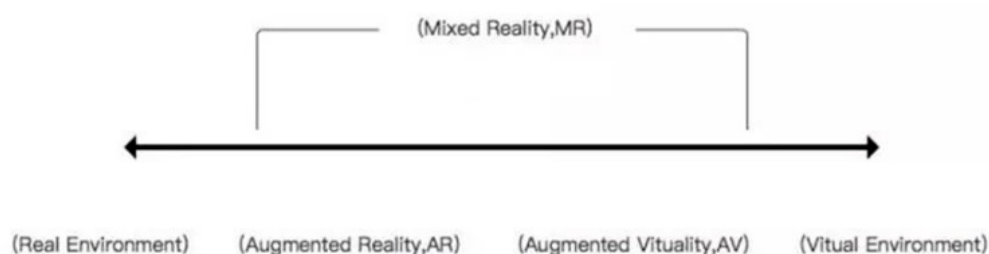


Figure 2. Different kind of VR game.

Table 1. Main machine brand in VR game.

VR Type	Machine
VR	HTC Vive Oculus Rift Sony PlayStation VR
AR	Google Glass app MSQRD app LINE Camera app
MR	Magic Leap Hololens
CR	HTC Vive Oculus Rif Hololens Google Glass

There are various kinds of machines that have been developed for designing the VR game. The VR game should compete with the traditional game and it is hard to let the consumer start to play the VR game. In this stage, there are not enough talents that can be used to develop the virtual reality games development project. So, developing the VR game needs talent not easily acquired and the profit of the VR game is uncertain. However, developing the VR game is the trend for game enterprise. Because of the above reason, VR game project selection is important. However, it is also a hard task for the game enterprise to execute the VR game project selection because a few of the VR game development projects can be executed by enterprises under the limitation of VR game design talents. The goal of this research is to develop a framework to analyze the virtual reality games development project in order to let the software development enterprise understand how to select a suitable project to develop. The reason for designing a new framework to evaluate the VR game development project is that the traditional game development project evaluation framework cannot evaluate the VR game development project reasonably because the importance of each criterion for the VR game development project evaluation problem is different by comparing that with the traditional game development project evaluation problem based on the reason that talent volume of the VR game industry is lower than it exists in the traditional game industry.

The execution procedure of this research is as follows. In Section 2, some game evaluation literature is collected and arranged. Further, some basic notions, definitions, and the execution process of proposed methods are discussed in Section 3. A case study is

discussed in the next section for reader understanding of the proposed method. Finally, a conclusion and future research are discussed as an ending.

2. Literature Review

There are a lot of researchers who try to develop methods to evaluate the game project. Relative literatures are as follows.

Chen et al. (2007) integrated fuzzy theory with multi-attribute decision-making to evaluate online gaming for providing useful information to beginners, players, and game providers [2]. Su et al. (2013) developed an evaluation model by integrating rough set theory, Delphi, AHP, and TOPSIS to select multimedia gaming for designing. In this method, the fuzzy Delphi method is applied to select evaluation criteria. Fuzzy AHP is utilized to determine the evaluation weight of criteria and fuzzy TOPSIS is used to determine the evaluations sequence. According to the analysis result, we can know that playfulness, skills, attention, and personalized are the four most important criteria in the game development selection process [3]. Hai et al. (2014) interviewed 90% of youth players in Taiwan and used AHP to analyze critical failure factors in E-sports games. Research results showed that a problem occurred in the Taiwan government and society. Besides, game technology is also not good enough to support E-sports games for players to play games [4].

Chen (2016) analyzed and compared the index generated from different kinds of multi criteria decision methods for evaluating recommendation mechanism software. The analysis index includes precision, recall, and F1-Measure. TOPSIS, VIKOR, ELECTRE, AHP, PROMETHEE, and SAW are multiple criteria decision-making (MCDM) methods used to evaluate recommendation mechanism software. Based on analysis result, all of above MCDM methods do not generate a significant difference in evaluating recommendation mechanism software [5]. Moradi et al. (2018) collected relative information and applied the analytic hierarchy process (AHP) and balanced scorecard (BSC) to execute performance evaluation of the digital game industry [6]. Politowski et al. (2018) designed a systematic framework to evaluate video game projects. In this framework, an algorithm rule was developed to evaluate the game based on quantitative and qualitative information [7]. Rumeser and Emsley (2018) built the systematic review to improve serious games application in project management [8]. Liu et al. (2019) promoted game quality by game tester feedback and reduced the uncertainty of unpredictable customer preferences. In this research, 102 game development projects participated. The research results show that iterative feedback of the game tester has a moderating effect on the relationship between game planning and game quality [9]. Albaghajati and Ahmed (2020) designed the framework to evaluate usefulness of the automated game testing technique which can be applied in game project selection [10]. According to above literature, we find that a few studies discuss VR game project selection because VR game is a novel kind of game generated in recent years and it needs time to generate relative literature.

Based on the above analysis, we know that the games development project will be influenced by the top leader of the company, the tester, and new technology which can be applied in game development. Iterative feedback of the game tester can increase game quality. Games development can be broken down by the problem of government, society, and noble information technology.

3. Proposed Method

In this study, the fuzzy cognitive map is applied to evaluate the importance (weight) of each criterion according to the influence relationship among the entire criteria. Then, linguistic VIKOR is used to decide the rank sequence of each VR game project. The reason of using the fuzzy cognitive map to evaluate the importance (weight) of each criterion in the VR game project selection problem is that the criteria such as cost, human resource demand, time, interest level, and technology difficulty in this problem can be influenced with each other. In the criteria weight evaluation aspect, this research decides to use the

fuzzy cognitive map to evaluate the weight of criteria. The analytic hierarchy process (AHP) can only deal with the problem whose criteria will influence each other. The entropy method can handle the problem whose weight of criteria should be generated based on experts' opinion automatically. However, the entropy method cannot dynamically analyze the importance of each criteria. Compared with the AHP and Entropy method, fuzzy cognitive map is relatively suitable to cope with the VR game project selection problem.

Linguistic VIKOR is the complete ranking and stable multi criteria decision-making method. Based on this method, experts can acquire analysis fast without applying complex calculation formula. ELECTRE cannot generate the overall ranking result. PROMETHEE needs a lot of parameters for executing pairwise comparison and its analysis process is relatively complex. Compared with ELECTRE and PROMETHEE, linguistic VIKOR is relatively suitable to cope with the VR game project selection problem. So, this research integrates linguistic VIKOR with the fuzzy cognitive map to rank the VR game project.

3.1. Linguistic Variable

Definition 1. Let $L = \{L_{-z}, \dots, L_{-2}, L_{-1}, L_0, L_1, L_2, \dots, L_z\}$ be linguistic term set. The linguistic variable in linguistic term set possesses two characteristics [11,12].

(1) Ordered characteristics: L_g is better than L_h if $g > h$.

(2) Symmetry characteristics: It exists a convert function $\varphi()$. The function of $\varphi()$ is as follows [10,11]:

$$\varphi(L_g) = L_{-g} \quad (1)$$

where L_g is one of linguistic variable in $L = \{L_{-z}, \dots, L_{-2}, L_{-1}, L_0, L_1, L_2, \dots, L_z\}$.

Definition 2. Let $\Delta()$ be the linguistic translation function. This function can translate linguistic variable into crisp value (μ) $\mu \in [0, 1]$ by following equation [11,12]:

$$\mu = \Delta(L_g) = \frac{g+z}{2z} \quad (2)$$

Definition 3. Let $\Delta^{-1}()$ be the linguistic translation inverse function, this function can translate crisp value (μ) $\mu \in [0, 1]$ into linguistic variable according to the following equation [11,12]:

$$\Delta^{-1}(\mu) = L_{(\mu-0.5)*2z} \quad (3)$$

3.2. Notation of Proposed Method

In fact, the virtual reality games development project selection problem can be described by means of the following sets [13,14]:

- (i) A set of virtual reality games development projects (alternatives) is called $P = \{P_1, P_2, \dots, P_m\}$; m means the volume of reality games development project.
- (ii) A set of decision-makers is called $E = \{E_1, E_2, \dots, E_o\}$; o means the volume of decision makers.
- (iii) A set of criteria $C = \{C_1, C_2, \dots, C_n\}$. n means the volume of criteria.
- (iv) A set of performance ratings of project with respect to criteria is called $X = [x_{ij}]$, $i = 1, 2, \dots, m$; $j = 1, 2, \dots, n$.
- (v) A status value set of each criterion is called $S = \{s_1, \dots, s_2, \dots, s_n\}$;
- (vi) A weight value set of each criterion is called $W = \{w_1, \dots, w_2, \dots, w_n\}$;
- (vii) A set of relation value between each criterion is called $R = [r_{ab}]$, $a = 1, 2, \dots, n$; $b = 1, 2, \dots, n$.

3.3. Execution Process of Proposed Method

The process of proposed method is as follows:

Step 1. Organize a committee

In order to select the suitable virtual reality games development project, enterprise should organize a committee and invite some experts to deal with this problem.

Step 2. Decide criteria and virtual reality games development project

At first, experts should collect relative information and discuss with each other for deciding criteria. Then, some virtual reality games development projects should also be generated.

Step 3. Collect experts' opinion

Experts should express their opinions about performance ratings of project, relation between each criterion, and initial status of each criterion.

Step 4. Integrate experts' opinion

Experts' opinion should be integrated for executing the proposed method.

Experts' opinion about performance ratings of each project can be integrated by the following equation [11,12]:

$$x_{ij} = \Delta^{-1} \left(\sum_{k=1}^o \Delta(x_{ij}^k) \right) \quad (4)$$

where x_{ij}^k represents expert k 's opinion about performance ratings of project i with respect to criterion j .

Experts' opinion about initial status of each criterion can be integrated by the following equation [11,12]:

$$s_j = \Delta^{-1} \left(\sum_{k=1}^o \Delta(s_j^k) \right) \quad (5)$$

where s_j^k represents expert k 's opinion about initial status of criterion j .

Experts' opinion about relation value between each criterion can be integrated by the following equation [11,12]:

$$r_{ab} = \Delta^{-1} \left(\sum_{k=1}^o \Delta(r_{ab}^k) \right) \quad (6)$$

where r_{ab}^k represents expert k 's opinion about relation value between criterion a and criterion b .

Step 5. Execute fuzzy cognitive map decision process

Fuzzy cognitive map (FCM) is the cognitive map. This map includes the relations between the elements (In this research, the elements are criteria). FCM can be employed to compute the "strength of impact" of these elements (criteria). In this study, the fuzzy cognitive map can be used for acquiring weight of each criterion. The experts should threshold each function for avoiding the value of criterion exceeding the interval $[0, 1]$.

Further, the initial status of each criterion should transfer as crisp value $s_j^{cv} = \Delta(s_j)$. Relation value between criterion a and criterion b should transfer as crisp value $r_{ab}^{cv} = \Delta(r_{ab})$ [15].

S is initial status matrix. S^{t-1} is the status of each criterion at the $t - 1$ -th period. S^t is the new status of each criterion at the t -th period. The new status of each criterion can be calculated by following equation [15]:

$$S^t = \frac{R * S^{t-1} + q}{2 * q} \quad (7)$$

where q is adjustment parameter. Formula (7) can make sure that the new status of each criterion is in the range of 0 and 1.

Finally, the weight of each criterion is as follows:

$$w_{un} = \frac{s_{un}}{\sum_{j=1}^n s_j} \quad (8)$$

Step 6. Calculate linguistic positive-ideal solution

Linguistic positive-ideal solution means ideal (best) status in the virtual reality games development project. The linguistic positive-ideal solution can be calculated by the following equation [16]:

$$x_j^+ = \Delta^{-1} \left(\max_i \left(\Delta(x_{ij}) \right) \right) \quad (9)$$

where x_j^+ means the best performance respect to criterion j among the entire virtual reality games development project (alternatives).

Step 7. Calculate linguistic negative-ideal solution

Linguistic negative-ideal solution means worst status in the virtual reality games development project. The linguistic negative-ideal solution can be calculated by the following equation [16]:

$$x_j^- = \Delta^{-1} \left(\min_i \left(\Delta(x_{ij}) \right) \right) \quad (10)$$

where x_j^- means the worst performance respect to criterion j among the entire virtual reality games development project (alternatives).

Step 8. Calculate the group utility for the majority of each project

The group utility for the majority of each project can be calculated by the following equation [16]:

$$G_i = \sum_{j=1}^n w_j * \frac{x_j^+ - x_j}{x_j^+ - x_j^-} \quad (11)$$

Group utility for the majority of each project means the entire performance of each project.

Step 9. Calculate individual regret rating for the opponent of each project

The individual regret rating for the opponent of each project can be calculated by the following equation [16]:

$$\zeta_i = \max_j \left(w_j * \frac{x_j^+ - x_j}{x_j^+ - x_j^-} \right) \quad (12)$$

Individual regret rating for the opponent of each project means the maximum regret degree if the decision-maker selects this project to execute.

Step 10. Calculate the index of each project

The index of each project can be calculated by the following equation [16]:

$$\theta_i = y * \frac{G_i - G^*}{G^- - G^*} + (1 - y) * \frac{\zeta_i^- - \zeta_i^*}{\zeta_i^- - \zeta_i^*} \quad (13)$$

$$G^* = \min_i(G_i), G^- = \max_i(G_i), \zeta_i^* = \max_i(\zeta_i), \zeta_i^- = \min_i(\zeta_i).$$

The y represents decision-making coefficient and $y \in [0, 1]$. When y is closed to 0, it means that experts select the project who mainly considers one criterion whose performance of the project is worst in this special dimension. On the other hand, it means that experts choose the project according to the entire performance when y is closed to 1.

4. Case Study

An enterprise wants to develop a virtual reality games development project in this intense competitive market. So, the case enterprise executes the proposed method as follows:

Step 1. Organize a committee

The case enterprise organizes a committee and invites seven experts to handle the game project selection problem. The experts include two scholars, two employees in the case enterprise, one employee in the competitors' enterprise, and two civil servants. Experts come from different organizations, so those experts can reasonably evaluate and judge the performance of virtual reality games development projects.

Step 2. Decide criteria and project

Four projects provided by the case enterprise will be evaluated by experts. Experts collect relative literatures to decide criteria. Seven criteria have been selected to evaluate the virtual reality games development project. Selected Criteria includes Cost (C_1), Time (C_2), Technology Difficulty (C_3), Human Resource Demand (C_4), Interest level (C_5). Although Cost (C_1), Time (C_2), Technology Difficulty (C_3), Human Resource Demand (C_4), Interest level (C_5) also fit with the traditional game industry, the importance of each criterion for traditional game project selection and VR game project selection is different. There are many traditional game developers. However, VR game developers are relatively few because the development history of the VR game is smaller than the traditional game.

Step 3. Collect experts' opinion

Experts use the five scale linguistic variable (Refer to Table 2) to express their opinions about performance ratings of project, relation between each criterion, and initial status of each criterion (Refer to Tables 3–5).

Table 2. 5 Scale linguistic variables.

		Linguistic Variables
Performance of Project		Very Poor (VP) (L_{-2}^5), Poor(P) (L_{-1}^5), Medium(M) (L_0^5), Good(G) (L_1^5), Very Good (VG) (L_2^5)
Status value of criterion		Very Poor (VP) (L_{-2}^5), Poor(P) (L_{-1}^5), Medium(M) (L_0^5), Good(G) (L_1^5), Very Good (VG) (L_2^5)
Relation value between two criteria		High Negative Relation (HNR) (L_{-2}^5), Low Negative Relation (LNR) (L_{-1}^5), Ordinary(O) (L_0^5), Low Positive Relation (LPR) (L_1^5), High Positive Relation (HPR) (L_2^5)

Table 3. Performance ratings of project.

		C_1	C_2	C_3	C_4	C_5
P_1	E_1	G	VP	G	VP	G
	E_2	P	M	M	M	P
	E_3	VG	VP	P	P	G
	E_4	M	M	M	VP	P
	E_5	M	M	VP	VG	G
	E_6	P	VG	G	VG	P
	E_7	P	P	M	G	VG
P_2	E_1	G	VP	M	VP	VP
	E_2	P	VP	P	P	M
	E_3	VP	G	VG	M	P
	E_4	G	P	G	G	P
	E_5	G	M	M	P	VP
	E_6	VP	M	P	G	M
	E_7	P	M	M	VG	P

Table 3. Cont.

		C_1	C_2	C_3	C_4	C_5
P_3	E_1	G	P	G	VG	VG
	E_2	G	M	M	P	P
	E_3	G	G	P	G	VP
	E_4	P	P	M	M	G
	E_5	P	VP	P	G	VP
	E_6	VG	VG	VG	M	VG
	E_7	VP	G	VP	M	P
P_4	E_1	P	VP	VG	M	M
	E_2	G	P	M	M	M
	E_3	VP	G	G	VG	VG
	E_4	VG	P	G	VG	M
	E_5	M	P	VG	P	G
	E_6	G	P	VP	M	M
	E_7	G	G	G	VG	VG

Table 4. Relation value between two criteria.

		C_1	C_2	C_3	C_4	C_5
E_1	C_1	O	O	O	O	LPR
	C_2	O	O	O	LNR	LNR
	C_3	HPR	LPR	O	HNR	LNR
	C_4	HPR	LPR	O	O	LNR
	C_5	HPR	LPR	O	O	O
E_2	C_1	O	LNR	LPR	LPR	O
	C_2	LPR	O	HPR	LNR	LPR
	C_3	HNR	O	O	LNR	O
	C_4	LNR	O	O	O	HPR
	C_5	LNR	HNR	O	LNR	O
E_3	C_1	O	O	LPR	HNR	LNR
	C_2	O	O	LNR	LPR	LPR
	C_3	LPR	HNR	O	LPR	HNR
	C_4	HPR	HNR	HNR	O	LPR
	C_5	HNR	HNR	O	LPR	O
E_4	C_1	O	LNR	LPR	HPR	LNR
	C_2	HNR	O	LNR	LNR	O
	C_3	LNR	O	O	O	HPR
	C_4	LPR	LPR	LPR	O	O
	C_5	LPR	LNR	O	HNR	O
E_5	C_1	O	LNR	LPR	LPR	O
	C_2	HPR	O	LPR	HNR	LPR
	C_3	LPR	O	O	LPR	O
	C_4	LNR	HNR	HNR	O	LNR
	C_5	LPR	LPR	LNR	LPR	O
E_6	C_1	O	HPR	LPR	LPR	LNR
	C_2	LPR	O	O	LNR	HPR
	C_3	HNR	LNR	O	LPR	HNR
	C_4	LPR	LNR	LNR	O	LNR
	C_5	O	O	LPR	LPR	O
E_7	C_1	O	LNR	HPR	LPR	O
	C_2	HNR	O	LPR	LNR	O
	C_3	O	O	O	LPR	HNR
	C_4	LPR	HNR	O	O	HPR
	C_5	LNR	LNR	O	O	O

Table 5. Status value of criterion.

	C_1	C_2	C_3	C_4	C_5
E_1	VP	M	G	VG	G
E_2	P	G	G	G	VG
E_3	P	VG	M	P	M
E_4	M	P	P	M	P
E_5	M	G	G	VP	M
E_6	VG	M	P	M	M
E_7	G	VP	VG	VG	P

Step 4. Integrate experts' opinion

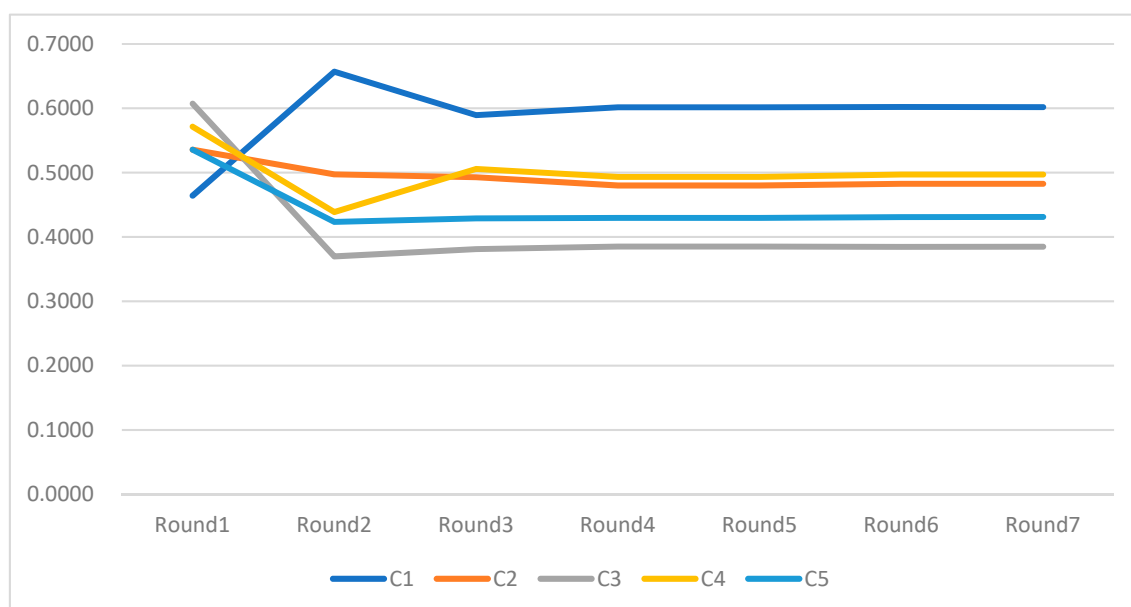
Experts' opinion can be integrated by using Formulas (4)–(6).

Step 5. Execute fuzzy cognitive map decision process

After transferring initial status of each criterion and relation value between each criterion into crisp value, fuzzy cognitive map can be starting to execute. Experts choose linear threshold function, compute the new status matrix, and experts decide y as 1 c in the system. The interactive trend of each criterion can refer to Table 6 and Figure 3.

Table 6. Interactive trend of each criterion.

	Round1	Round2	Round3	Round4	Round5	Round6	Round7
C_1	0.4643	0.6569	0.5894	0.6017	0.6017	0.6020	0.6019
C_2	0.5357	0.4974	0.4929	0.4801	0.4801	0.4826	0.4826
C_3	0.6071	0.3699	0.3811	0.3852	0.3852	0.3847	0.3848
C_4	0.5714	0.4388	0.5059	0.4934	0.4934	0.4970	0.4972
C_5	0.5357	0.4235	0.4289	0.4296	0.4296	0.4310	0.4311

**Figure 3.** Interactive trend of each criterion.

The weight of each criterion will be calculated by using formula 8 ($C_1 = 0.2511$, $C_2 = 0.2013$, $C_3 = 0.1605$, $C_4 = 0.2074$, $C_5 = 0.1795$).

Step 6. Calculate linguistic positive-ideal solution.

The linguistic positive-ideal solution can be calculated by using Equation (9) (Refer to Table 7).

Table 7. Positive-ideal solution and negative-ideal solution.

	C_1	C_2	C_3	C_4	C_5
positive-ideal solution	0.5714	0.5000	0.6786	0.6786	0.6786
negative-ideal solution	0.3929	0.3571	0.4643	0.5000	0.2500

Step 7. Calculate linguistic negative-ideal solution

The linguistic negative-ideal solution can be calculated by following 10 (Refer to Table 7).

Step 8. Calculate the group utility for the majority of each project

The group utility for the majority of each project can be calculated by Equation (11) (Refer to Table 8)

Table 8. Group utility, individual regret rating, index, and rank of each project.

	P_1	P_2	P_3	P_4
Group utility	0.6642	0.9465	0.3836	0.2013
Individual regret rating	0.2074	0.2511	0.1605	0.2013
Index	0.5519	0.5000	0.6223	0.2749
Rank	3	2	4	1

Step 9. Calculate individual regret rating for the opponent of each project

The individual regret rating for the opponent of each project can be calculated by Equation (12) (Refer to Table 8).

Step 10. Calculate the index of each project

The value of each virtual reality games development project can be calculated by Equation (13) (Refer to Table 8). Based on analysis result, the rank of the project is $P_4 > P_2 > P_1 > P_3$.

5. Conclusions and Future Research

Project selection is a high-risk activity if the new game has been developed without earning enough profit to comeback. Especially, uncertainty of consumer preference exists and competitors may design similar games for the market. Besides, product life cycle becomes more and more short in this period. Enterprises should consider more dimensions and select the virtual reality games development project to be carried out effectively.

The goal of this study is to develop a framework to evaluate and select virtual reality games development project. Based on our analysis result, we can know that the important sequence of criteria for evaluating the virtual reality games development project is cost, human resource demand, time, interest level, and technology difficulty. In the future, relative scholars can try to design decision support systems for enterprise to use. Relative scholars can also try to analyze proposed methods with traditional methods such as SAW, AHP, ANP, TOPSIS, VIKOR, PROMETHEE, and DEMATEL in selecting game projects.

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