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THE MULTI-CASE INTERDEPENDENCY EQUILIBRIUM INTERACTIVE APPLICATION TO ESTABLISH APPROPRIATE PAYOFF MATRICES AND THE NASH EQUILIBRIUM STATISTICAL TEST

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ABSTRACT

The Nash equilibrium applications encounter novelty, content, and visibility problems. This study aims to design and operate the Nash equilibrium interactive application, inspect the multi-case interdependency payoff matrices, and test the Nash equilibrium. The methods are designing and operating an interactive application, establish through simulation Prisoner's Dilemma, Stag and Rabbit Hunting, and Price Strategy payoff matrices, and testing by Runs test the equilibrium in the payoff matrices. The results show that the MIEIA has four interesting features and successfully produces 25 appropriate payoff matrices for each case. Another result is that the Runs test provides Z scores -2,62 and -3,27 that prove the Nash equilibrium in the Prisoner's Dilemma and Stag and Rabbit Hunting cases, and -0,23 that prove the non-Nash equilibrium in the Price Strategy. All results discuss the importance of a sophisticated Nash equilibrium application that has an impact in solving problems in various sectors regarding decision making which is constrained by the risk aversion strategy.

Keywords: Nash Equilibrium Application; Pricing Strategy; Prisoner's Dilemma; Stag and Rabbit Hunting; Runs Test

1. INTRODUCTION

The Nash equilibrium is an interdependency competition equilibrium that occurs for two reasons. First, each player needs more information about the other. Second, they avoid risk. As a result, they compete and make tactical decisions that construct a risk minimizing equilibrium.

The Prisoner's Dilemma case is a famous example of the Nash equilibrium. Various studies have discussed the Prisoner's Dilemma case. There are three variants. The first variant develops the prisoner's dilemma idea (1–4). The second variant applies the Prisoner's Dilemma to human realities such as economics and business (5–8), and other fields (9,10). The third variant designs film footage and computer program (11–15). Some of the software are protected by patent (16–18).

Other cases that show a Nash equilibrium are the Stag and Rabbit Hunting and the Price Strategy cases. Studies on Stag and Rabbit hunting focus on stag hunting to analyze the difficulty of hunting stag jointly, the importance of cooperativeness, and to evaluate coordination failure (19–22). Studies on Price Strategy analyze that the tight competition ends in the low-price strategy(23–26).

The Nash equilibrium software development should be considered. The development causes the theory is easier to be understood and constructs the theory into product that can be innovated as a patent protected product. Moreover, it brings the theory closer to the internet of things. However, the development needs to catch up with the recent progress as website application. Other sectors such risk management, security, education, business, engineering, health, and machine have applied the web application since years ago. Some of them has been developed artificial intelligence. (27–32).

In addition, Nash equilibrium software faces two main problems: Content and visibility problems. The content problems means that software does not design a comprehensive concept. For example, some software does not accommodate Nash equilibrium cases, real competition, player's objectivity, and equilibrium establishment evaluation.

The visibility problem lies in the difference between visibility display and design. A programming error causes features appear visually but not as expected. This problem is a usual problem coming from the programmer limitations. However, the problem can be solved by program testing (33–37) including by user acceptance test (38,39).

An up to date and easy to handle Nash equilibrium interactive application that covers all the Nash equilibrium competition theory is very urgent. It improves previous applications and serves as a gate for practical and future technological progress in the Nash equilibrium application. Therefore, this study aims to design and operate a comprehensive Nash equilibrium application, inspect the Nash equilibrium payoff matrices, and test statistically the equilibrium in the payoff matrices.

2. MATERIALS AND METHODS

The research aims were derived into materials, procedures and outputs as in Figure 1. Materials consisted of flowchart, main materials, additional materials, and output. Flowchart were the technical planning to design the application. Main materials were the Sublime Text Editor and XAMPP software. Additional material were pictures, the Multi-case Nash equilibrium model, Definition-Participants list, and Runs Test table. Outputs are operable Nash Equilibrium application, payoff matrices and Runs Test score. Procedures were essential steps in the material utilization to achieve research aims and generated outputs. Outputs served as material for the succeeding step.

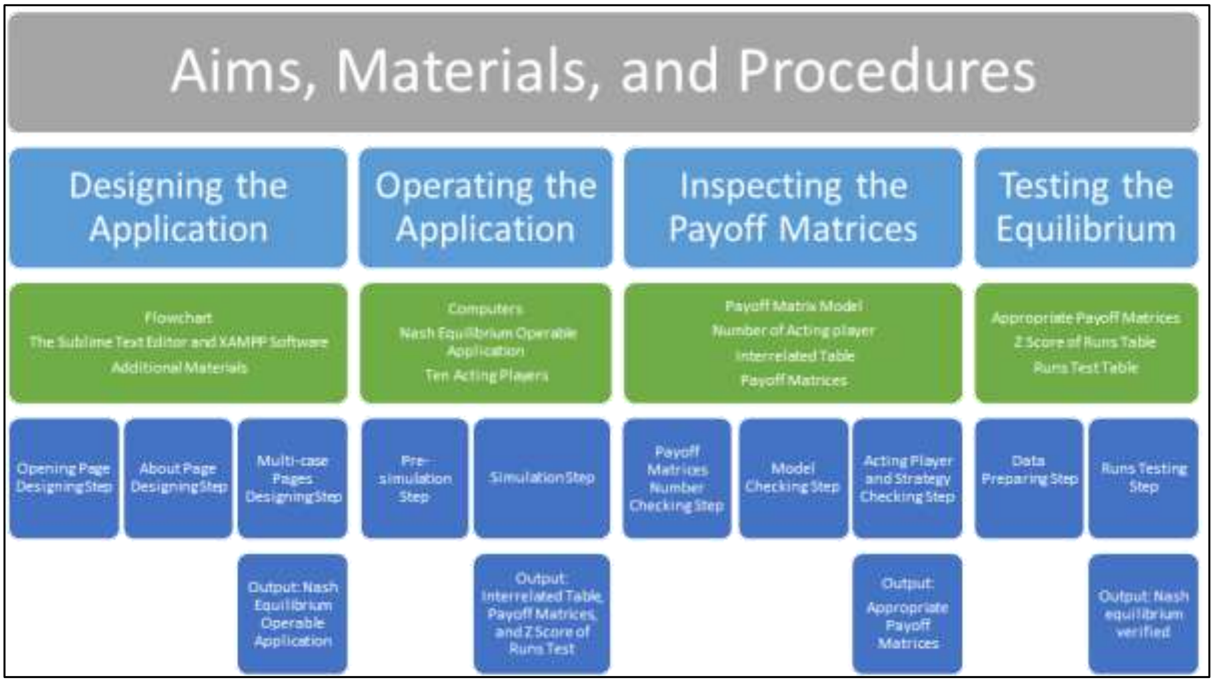


Figure 1. Deriving the Method from Research Aims

2.1. Designing the Interactive Application

The application was sequentially designed based on the flowchart using the Sublime Text Editor and displayed using The XAMPP local host mode. The design testing was based on the displayed application and simulation. The application was improved if visibility problems were found.

The opening page were created firstly. Three form and fields were created. The first was field to display an interesting picture, application management, and institution. The second was form and field to join the application. The third was form and field to access About, Prisoner's Dilemma, Stag and Rabbit Hunting, and Price Strategy pages.

The About page was designed by writing the Definition and Participant Roles list in the About field. The Definition was designed to explain that the competition and application objectives were to establish Nash equilibrium. The Participants and their roles were listed to maintain appropriate participant activities.

The Prisoner's Dilemma, Stag and Rabbit Hunting, and Price Strategy pages were programmed in three steps. The first was the Competition Preparation step, the second was the Competition Playing step, and the third was the Competition Output step. The Competition Preparation step was done by programming four fields in one form to explain the competition. The first and second fields were to explain narratively the Multi-case Equilibrium table containing strategies and payoff that establish Nash and non-Nash equilibria and to insert related payoff matrix picture. The Table is as seen in the Table 1. The third and fourth blank fields were to explain the user's competition case narratively and an in image related payoff matrix.

Table 1. Strategies, Payoffs, and Resulted Equilibrium

Strategy					
Prisoner's Dilemma		**Stag and Rabbit Hunting**		**Price Strategy**	
To Confess (If chosen, its box becomes pink box)		Rabbit Shooting (If chosen, its box becomes a pink box)		Cheap Strategy (If chosen, its box becomes pink box)	
Not to Confess (If chosen, its box becomes green box)		Stag Shooting (If chosen, its box becomes green box)		Expensive Price (If chosen, its box becomes green box)	
Payoff					
Nash Equilibrium					
A and B choose to Confess: (1,1)	A: Light leniency (1 year)	**A and B choose Rabbit Shooting: (1,1)**	A: Small quantities of meat (1)	**A and B choose a cheap price: (4000, 5000)**	A: Small amount of revenue (4000)
	B: Light leniency (1 year)		B: Small quantities of meat (1)		B Small amount of revenue (5000)
Non-Nash Equilibrium					
A and B Choose not to Confess: (0,0)	A: No punishment (0 years)	**A and B choose to Stag Shooting at the same time: (2,2)**	A: Large quantities of meat (2)	**A and B choose to expensive price: (6000, 7500)**	A: A large amount of revenue (6000)
	B: No punishment (0 years)		B: Large quantities of meat (2)		B: A large amount of revenue (7500)
A: To Confess, B:	A: Light leniency (1	**A: Rabbit Shooting: B**	A: Small quantities of	**A: Choose to Cheap**	A: A large amount of

Not to Confess: (1,3)	year)	**Stag Shooting: (1,0)**	meat (1)	**Price, B: Choose to Expensive price 6000, 4500)**	revenue (6000)
	B: Severe Punishment (3 years)		B: No meat obtained (0)		B: Minimal amount of revenue (4500)
A: Not to Confess, B: To Confess: (3,1)	A: Severe Punishment (3 years)	**A: Stag Shooting: B: Rabbit Shooting: (0,1)**	A: No Meat obtained (0)	**A: Choose to Expensive Price, B: Choose to Cheap Price 6000, 4500)**	A: Minimal amount of revenue (4500)
	B: Light leniency (1 year)		B: Small Quantities of meat (1)		B: A large amount of revenue (6000)

The Competition Playing step was done by constructing competition forms and fields for A and B acting players to compete each other. The A activities were designed to be done in the A form, while B activities is in the B form. Every field in each form was prepared to enable player to choose the best strategy based on the player's prediction of rival's strategy. Every field were also designed to record players' identities and their strategies. All recorded data were exhibited in the interrelated tables form.

The Competition Output Step was designed by forms and fields to display and print the interrelated table, payoff matrices, and statistical analysis. All forms were designed to have field to print the displayed outputs. The interrelated table form was designed also to have fields for acting player to delete and change the incorrect data.

2.2. Operating the Interactive Application

Pre-simulation and simulation steps were prepared to operate the operable Nash equilibrium application. The participant readiness was prepared according the role as in Table 2. The Participant role manual is prepared and inserted in the about page. Every Programmer ensured that the computers and the application ready to be operated, users checked that acting players ready to play the competition as A or B player, and all acting players were ready to compete fairly each other.

Table 2. The MIEIA Participants and Roles

Participants	Roles
Programmer	Designing the Nash equilibrium interactive application as requested by the user
	Preparing the computer and application
	Facilitating acting players to run the application

User	Designing the competition and assumption
	Grouping players into A and B groups
	Analyzing the payoff matrix and statistical test output
Players	Understanding the application
	Understanding the competition
	Ensuring independency and objectivity
	Playing the competition

Three simulations were conducted in the simulation step. Several acting players were assumed to face the Nash equilibrium misunderstanding problem. Players expect best payoff, but without any prediction to competitor strategy and risk consideration. The number three acting player that acted as the A player (Mhsw3_A) and the number eight acting player that acted as the B player (Mhsw8_B) were chosen to play the assumption.

The first simulation was in the Prisoner's Dilemma case. The Mhsw3_A chose the Not to Confess strategy. The second simulation was in the Stag and Rabbit Hunting case. The Mhsw3_A switched the Mhsw5_A order. Mhsw3_A was in the fifth order, while Mhsw5_A was in the third order. The third simulation was in the Price Strategy case. The Mhsw3_A that acted as the A Player and Mhsw8_B that acted as the B player misunderstood chose the expensive Strategy. Without any visibility problem, all simulations were displayed appropriately in the interrelated table and payoff matrices.

2.3. Inspecting The payoff matrices

The payoff matrices were inspected one by one. Three inspections were imposed. The appropriate payoff matrices were the payoff matrices that match to the acting player number, payoff matrix model, and interrelated table.

2.4. Testing The equilibrium in the appropriate payoff matrices

The testing steps were consisted of data preparation and testing steps. The Data preparation step numbered and initialed the appropriate Nash equilibrium payoff matrices. The Numbering step sequenced the payoff matrices based on the row-column order. The Matrix 1 was generated from the Mhsw1_A-Mhsw6_B matrix competition, the Matrix 13 was generated from the Mhsw3_A-Mhsw8_B competition, and Matrix 25 was generated from Mhsw5_A-Mhsw10_B competition. The initialling step initialled every Equilibrium by "Y" and "T" symbols. The Nash Equilibria were initialled by "Y" symbol and the non-Nash equilibria were initialled by "T" symbol.

The Runs test step started by calculates the Z-Score of the Runs test based on Equation 1. After that, the score was compared by the value in the Runs Table under the null hypothesis that the equilibrium was not a Nash equilibrium.

$$Z = \frac{R - \frac{2n_1 n_2}{n_1 + n_2} + 1}{\sqrt{\frac{2n_1 n_2 (2n_1 n_2 - N)}{N^2 (N-1)}}} \qquad (1)$$

where Z is the Runs test score, R is the number of Runs, i.e., the number of changes from the matrix that establishes a Nash equilibrium to the matrix that establishes a non-Nash equilibrium, n1 is the number of matrices that establish the Nash equilibrium, n2 is the number of matrices that establish a non-Nash equilibrium, and N is total equilibrium.

3. Results and Discussion

3.1. The Interactive Application

The design is the Multi-case Interdependency Equilibrium Interactive Application (The MIEIA). The flowchart, all materials, and the visibility test are vital. The Application has four exciting features: (1) Interactive competition, (2) Prisoner’s Dilemma, Stag and Rabbit Hunting, and Price Strategy cases, (3) Acting player independency, and (4) The interrelationship table, appropriate payoff matrices, and equilibrium statistical test output. It is the latest Nash Equilibrium application.

The MIEIA is a complete Nash equilibrium operable website application, while previous Nash equilibrium applications are not programmed and displayed as web application. Therefore, the MIEIA application is the best interactive application and equivalent to the web application in other sectors.

In addition, the MIEIA is the most complete Nash equilibrium application. It is better than the ‘Student Application’ that featured by education and student creation purpose (15). The MIEIA can be used not only for education purpose, but also for research and practical purposes. The participant independence, Nash equilibrium cases, and user case option allow it to be used on multi purposes. Furthermore, with the adjustment in the application, the Nash equilibrium application and user cases option enable the MIEIA to play wide-range Nash equilibrium studies such as Battle of Sexes and Chicken Game cases (4), the current practices (25,40), and players (2,14)

The MIEIA is also better than the NEFinder and Oyun application. They are characterized by payoff matrix development (11,14). The MIEIA develops payoff matrices and test statistically the equilibrium in the payoff matrices.

3.2. The Display and Simulation

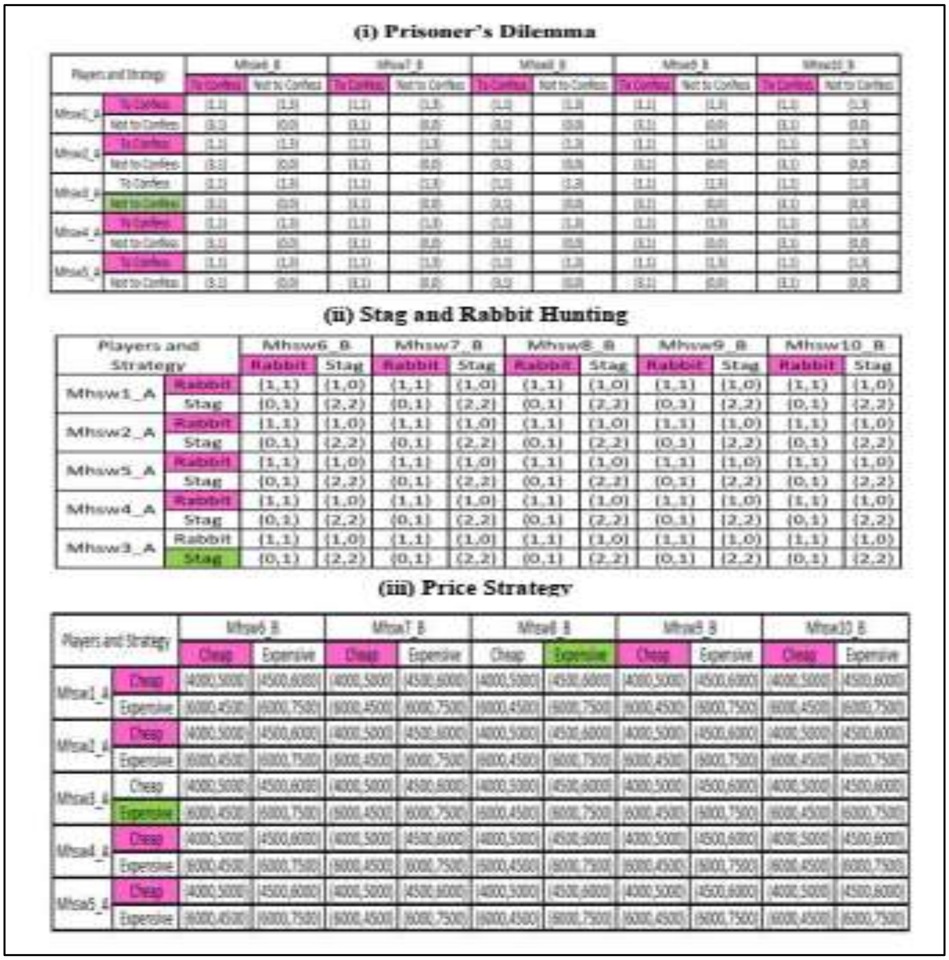
The MIEIA operates properly. All displays and simulation indicate that no visibility problems. All pages display the flowchart. Opening Page displays clearly pictures, institution and management, About Page displays Nash equilibrium definition, and participants’ role, and case Pages shows cases to be competed and the competition. Another thing that shows it as a proper application is data printing. The interrelated table, payoff matrices, and Run test score can be printed.

The simulation shows that acting players understand the application and competes each other without any serious confusion and complaint. Transition to other cases runs smoothly. Data entry errors can be resolved by deleting and re-entering before continuing the competition.

All displays and simulation show that The MIEIA passed successfully the visibility problem based on software and user acceptance tests. The software test (33,34) was approached by local host displaying and checking during application designing. The user acceptance test (38) was conducted by simulation.

3.3. Appropriate Payoff Matrices

The inspection ensures that the payoff matrices are the appropriate matrices. As in Figure 2, the number of the payoff matrices is 25 per case. The payoff matrices are derived from the payoff matrix model designed by user. The acting player identities, strategies, and payoff in the matrices match to the data in the interrelationship table. In addition, all matrices indicate the selected strategy by a colored box and unselected strategy by an uncolored box.



(i) Prisoner's Dilemma

(ii) Stag and Rabbit Hunting

Players and Strategy		Mhsw6_B		Mhsw7_B		Mhsw8_B		Mhsw9_B		Mhsw10_B	
		Rabbit	Stag	Rabbit	Stag	Rabbit	Stag	Rabbit	Stag	Rabbit	Stag
Mhsw1_A	Rabbit	(1,1)	(1,0)	(1,1)	(1,0)	(1,1)	(1,0)	(1,1)	(1,0)	(1,1)	(1,0)
	Stag	(0,1)	(2,2)	(0,1)	(2,2)	(0,1)	(2,2)	(0,1)	(2,2)	(0,1)	(2,2)
Mhsw2_A	Rabbit	(1,1)	(1,0)	(1,1)	(1,0)	(1,1)	(1,0)	(1,1)	(1,0)	(1,1)	(1,0)
	Stag	(0,1)	(2,2)	(0,1)	(2,2)	(0,1)	(2,2)	(0,1)	(2,2)	(0,1)	(2,2)
Mhsw5_A	Rabbit	(1,1)	(1,0)	(1,1)	(1,0)	(1,1)	(1,0)	(1,1)	(1,0)	(1,1)	(1,0)
	Stag	(0,1)	(2,2)	(0,1)	(2,2)	(0,1)	(2,2)	(0,1)	(2,2)	(0,1)	(2,2)
Mhsw4_A	Rabbit	(1,1)	(1,0)	(1,1)	(1,0)	(1,1)	(1,0)	(1,1)	(1,0)	(1,1)	(1,0)
	Stag	(0,1)	(2,2)	(0,1)	(2,2)	(0,1)	(2,2)	(0,1)	(2,2)	(0,1)	(2,2)
Mhsw3_A	Rabbit	(1,1)	(1,0)	(1,1)	(1,0)	(1,1)	(1,0)	(1,1)	(1,0)	(1,1)	(1,0)
	Stag	(0,1)	(2,2)	(0,1)	(2,2)	(0,1)	(2,2)	(0,1)	(2,2)	(0,1)	(2,2)

(iii) Price Strategy

Players and Strategy		Mhsa6_B		Mhsa7_B		Mhsa8_B		Mhsa9_B		Mhsa10_B	
		Cheap	Expensive	Cheap	Expensive	Cheap	Expensive	Cheap	Expensive	Cheap	Expensive
Mhsa1_A	Cheap	(4000,5000)	(4500,6000)	(4000,5000)	(4500,6000)	(4000,5000)	(4500,6000)	(4000,5000)	(4500,6000)	(4000,5000)	(4500,6000)
	Expensive	(6000,4500)	(6000,7500)	(6000,4500)	(6000,7500)	(6000,4500)	(6000,7500)	(6000,4500)	(6000,7500)	(6000,4500)	(6000,7500)
Mhsa2_A	Cheap	(4000,5000)	(4500,6000)	(4000,5000)	(4500,6000)	(4000,5000)	(4500,6000)	(4000,5000)	(4500,6000)	(4000,5000)	(4500,6000)
	Expensive	(6000,4500)	(6000,7500)	(6000,4500)	(6000,7500)	(6000,4500)	(6000,7500)	(6000,4500)	(6000,7500)	(6000,4500)	(6000,7500)
Mhsa3_A	Cheap	(4000,5000)	(4500,6000)	(4000,5000)	(4500,6000)	(4000,5000)	(4500,6000)	(4000,5000)	(4500,6000)	(4000,5000)	(4500,6000)
	Expensive	(6000,4500)	(6000,7500)	(6000,4500)	(6000,7500)	(6000,4500)	(6000,7500)	(6000,4500)	(6000,7500)	(6000,4500)	(6000,7500)
Mhsa4_A	Cheap	(4000,5000)	(4500,6000)	(4000,5000)	(4500,6000)	(4000,5000)	(4500,6000)	(4000,5000)	(4500,6000)	(4000,5000)	(4500,6000)
	Expensive	(6000,4500)	(6000,7500)	(6000,4500)	(6000,7500)	(6000,4500)	(6000,7500)	(6000,4500)	(6000,7500)	(6000,4500)	(6000,7500)
Mhsa5_A	Cheap	(4000,5000)	(4500,6000)	(4000,5000)	(4500,6000)	(4000,5000)	(4500,6000)	(4000,5000)	(4500,6000)	(4000,5000)	(4500,6000)
	Expensive	(6000,4500)	(6000,7500)	(6000,4500)	(6000,7500)	(6000,4500)	(6000,7500)	(6000,4500)	(6000,7500)	(6000,4500)	(6000,7500)

Note: All are reproduced figures from the printed version to get clear appearance. Source: Payoff Matrices Outputs

Figure 2. Payoff Matrices

All matrices show the equilibrium output. Some matrices create Nash equilibrium, while others create non-Nash equilibrium. It is easy to differentiate the Nash equilibrium from the non-Nash equilibrium. Every matrix lies the Nash equilibrium on the top left payoff box and is established by the similar pink-colored strategy boxes combination. Besides the top-left payoff boxes are the Non-Nash Equilibrium payoff boxes. Green colored strategy boxes, uncolored strategy boxes or the different colored strategy boxes combination show them. The appropriate payoff matrices are better than the a single matrix (12,14,26) and repeated matrix (2,4,22). The matrices open an opportunity to evaluate statistically the equilibrium, while the single matrix does not open an opportunity to equilibrium evaluation and the repeated matrix open an opportunity to evaluate non-statistical evaluation.

3.4. The Runs Test

The test proves that the payoff matrices equilibrium in the Prisoner's Dilemma and Stag and Rabbit Hunting are the Nash equilibrium. At the same time, the Price Strategy is the non-Nash equilibrium. The Runs test, as seen in Table 3, shows that the Z-scores for Prisoner’s Dilemma and Stag and Rabbit Hunting are lower than -1.96 indicating that the null hypothesis is rejected, while for Price Strategy are between -1.96 and 1.96 indicating that the null hypothesis is accepted (See Table 3). As a result, Prisoner's Dilemma and Stag and Rabbit Hunting matrices establish the Nash equilibrium. In contrast, the Price Strategy matrices establish the non-Nash equilibrium.

Table 3. Runs Test Z-Score

Cases	R	n1	n2	Z-Score	Decision
Prisoner’s Dilemma	3	20	5	-2,61861	Reject the null hypothesis
Stag and Rabbit Hunting	2	20	5	-3,27327	Reject the null hypothesis
Price Strategy	10	16	9	-0,23141	Accept the null hypothesis

Source: Payoff Matrices Outputs.

The Runs test findings follow previous studies that a risk aversion decision due to the limited information and competitor strategy prediction as studied in the prisoner’s dilemma cases at idea and practical levels (3,5,10), in the Stag and Rabbit hunting case (20,22), and in Price Strategy (23,25). The number of the acting player that plays without any concern to the risk aversion in the Prisoner’s Dilemma and Stag and Rabbit Hunting cases is limited and interpreted by the Runs test in the form of a low R value and a high n1 value relative to n2. As a result, the Runs test calculates the absolute Z-score that is greater than its Table value and rejects the null hypothesis that the equilibrium is not a Nash equilibrium. Conversely, the number of risk-averse players in the Price Strategy case increases. The Runs test interprets by a high R value and a low n1 value relative to n2, produces the low absolute value of Z-score, and accepts the null hypothesis that the equilibrium is not Nash equilibrium.

Another thing should be considered is that the appropriate payoff matrices and the Runs test strengthen the MIEIA as a competition-oriented Nash equilibrium application. The independent acting player indicates the competition orientation. The appropriate payoff matrices show the competition process, and the Runs test proves the competition result.

4. CONCLUSIONS

The MIEIA solved the novelty problem by designing a web interactive application, the content problem by accommodating all Nash equilibrium competition cases, promoting fair competition, providing completely competition outputs, and examining competition equilibrium statistically, and the visibility problem by software and user acceptance test. In addition, the appropriate payoff matrices and the Runs test strengthen the MIEIA's competition orientation. As a result, The MIEIA is success to cause the Nash equilibrium theory to be understood easily, create the Nash equilibrium product and be accessed by online mode, and extend the use of the web application.

It is essential to develop sustainably the Nash equilibrium system. Future studies should concern with developing the competition orientation, the mobile technology implementation, and high-technology implementation such as blockchain and artificial intelligence. Another paramount concern is playing systematically the case to solve current dynamic problem such as playing the Prisoner's Dilemma case to solve the organized crime, playing the Stag and Rabbit Hunting case to encourage a teamwork, and playing Price Strategy case to solve the tight business competition.

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Declaration of conflicts of interest

The authors declare that no competing interest that influence the article content and writing

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