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From Product Attributes to Market Advantage: Game Theory Applications in Bicycle Industry Competition

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Abstract

This study addresses the competitive challenge between two mountain bike brands, Senator MTB and Aviator MTB, in capturing consumer preference within the East Java market. The research object focuses on product attribute comparison between the two brands, aiming to identify the optimal strategic positioning for each. The objective is to determine competitive strategies that minimize losses and maximize gains using a quantitative approach. Data were collected through a closed-ended Google Form survey distributed to 31 respondents, consisting of MTB users in East Java. The analysis employed paired comparison, Game Theory, and the primal–dual Simplex method, supported by validity, reliability, and data sufficiency tests. Results showed that Aviator, as the column player, minimized its loss to -7,714 units with a mixed strategy equally focusing (50.7% each) on a lightweight and rigid frame and a strong derailleur, while Senator, as the row player, maximized its gain to -7,715 units through a pure strategy fully (100%) leveraging the durability of the seatpost–stem–handlebar combination. The study concludes that Game Theory can effectively identify and quantify optimal strategies in product competition. The contribution of this research lies in providing empirical evidence of applying Game Theory in the bicycle industry to guide strategic product development and market positioning.

1. Introduction

Game theory also plays an important role in strategy management.(Ma et al., 2024)developed a cooperative game model to determine fair pricing strategies in Vehicle-to-Grid (V2G) programs, encouraging active participation from companies. A similar approach was also implemented by(Yin et al., 2025)by using a master-slave game model to determine optimal capacity tariffs in a Virtual Power Plant (VPP). This demonstrates that game theory can be a powerful tool for balancing the interests of various parties in a distributed energy system. In the manufacturing sector,(Yuwono et al., 2025)introduced a hierarchical Stackelberg game framework to achieve self-optimization in distributed production systems. This strategy proved effective in aligning local and global objectives and improving adaptive



response to disturbances.(Marousi et al., 2024)used a game theory-based bilevel optimization model to design a more resilient gas industry supply chain by considering strategic customer behavior. In computing, game theory is used to improve operational efficiency.(Maldonado-Carrascosa et al., 2024)developed a non-cooperative model for managing virtual machine migration in data centers, resulting in significant energy savings. The combination of game theory with advanced technology is also evident in the research.(Antonius, 2024), which uses Convolutional Neural Network (CNN) and game theory for efficient resource allocation in 5G/6G networks.

Game theory also extends to other fields(Perumalsamy et al., 2025)combined game theory with a Long Short-Term Memory (LSTM) deep learning model to analyze health impacts in industrial zones. This combination provides a powerful predictive tool for policy interventions.(Maleki Vishkaei & De Giovanni, 2025)integrates game theory with blockchain technology and IoT sensors (hardware oracles) to design transparent and efficient smart mobility systems that encourage sustainable behavior. Its ability to model strategic multi-actor interactions makes it a strong foundation for developing innovative and efficient solutions in various fields. Its integration with cutting-edge technologies such as artificial intelligence, blockchain, and deep learning is a significant trend in modern research to address increasingly complex challenges.Game theory is a highly relevant and versatile quantitative research method for addressing complex challenges across a wide range of sectors. Its ability to analyze strategic interactions between rational actors makes it an effective tool for optimizing systems and designing policies. Its applications are broad, ranging from improving renewable energy efficiency and managing complex power grids to optimizing supply chains and operations in the manufacturing and computing sectors. Furthermore, modern research trends demonstrate the integration of game theory with cutting-edge technologies such as artificial intelligence (AI), deep learning, and blockchain, resulting in innovative, predictive, and adaptive solutions to address issues ranging from environmental issues to public health issues to intelligent mobility systems. Thus, game theory not only provides a strong analytical foundation but also serves as a catalyst for the development of multidisciplinary solutions in today's technological era.

Previous studies on bicycle product strategy selection have generally focused on customer satisfaction surveys, technical benchmarking, or cost-benefit analysis without integrating a Game Theory-based strategy optimization approach. The lack of research combining instrument reliability measurements with competitive mathematical models has resulted in a lack of quantitative guidance for manufacturers in selecting superior attributes. This gap is exacerbated by the lack of research formulating the optimal proportions of product attribute implementation simultaneously based on consumer preferences and the results of

minimax-maximum analysis. In an increasingly competitive bicycle market, product differentiation through technical attributes is a key determinant of competitive advantage. However, product strategy decisions are often based on subjective preferences or limited descriptive data. This research is significant because it offers a quantitative, game-theory-based approach that can minimize the risk of suboptimal decisions. By combining empirical consumer evaluations of key attributes, a sturdy, lightweight frame, a soft, durable front fork, a strong derailleur, and a durable seatpost-stem-handlebar combination, this research provides an analytical framework that the bicycle manufacturing industry can adopt for production planning and innovation.

This study presents an integrated approach between the validity and reliability test of bicycle product instruments with the application of Game Theory based on the simplex dual and primal methods to quantitatively evaluate the competitive strategies of two brands, Senator and Aviator. The combination of statistical analysis (test of calculated r against r table, Cronbach's Alpha) and mathematical model of strategy optimization is rarely used in comparative studies of bicycle product attributes. The main novelty lies in modeling the interaction of product attributes into a pay-off matrix optimized by linear programming, resulting in the optimal proportion of attribute implementation to maximize market competitiveness.

This study aims to: (1) test the validity and reliability of the attributes of Senator and Aviator brand bicycles; (2) build a Game Theory model with a simplex dual and primal approach to determine the optimal strategy of each brand; and (3) identify the proportion of attribute use that is most effective in increasing competitiveness. This study expands the literature related to the application of Game Theory and linear programming in product strategy analysis based on consumer preferences. Not only that, it also provides data-based guidelines for strategic decision making in product development, which can improve production efficiency and strengthen the market position of bicycle manufacturers.

2. Research methodology

2.1. Design

This study uses a quantitative approach with a comparative paired comparison method to measure differences in consumer perceptions of the attributes of the Senator and Aviator brand bicycles. Validity and reliability tests are used to ensure instrument accuracy, while Game Theory analysis using the minimax–maximin approach and the simplex (primal–dual) method is used to determine the optimal strategy for each brand.

2.2. Population and Sample

The study population comprised consumers who use or would-be buyers of Senator and Aviator bicycles residing in the study area. The sample was drawn using a purposive sampling

technique, selecting respondents who had experience using or comparing the two brands. Based on this criterion, 31 respondents provided ratings for each product attribute.

2.3. Operational Research Variables

The research variables consist of two main variables representing the quality attributes of the Senator and Aviator brand products. Each variable is measured using specific indicators tested for validity and reliability (Table 1).

Table1. Research Indicators

Variables	Indicator	Item	Amount
Senator Brand Product Quality	Sturdy, lightweight frame, soft, durable front fork, strong derailleur, durable seatpost-stem-handlebar combination	1, 2, 3, 4	4
Aviator Brand Product Quality	Sturdy, lightweight frame, soft, durable front fork, strong derailleur, durable seatpost-stem-handlebar combination	1, 2, 3, 4	4

Source: Processed Primary Data, 2025

2.4. Observations and Interviews

Data collection was conducted through the distribution of paired comparison forms to obtain respondents' assessments of the attributes of both brands. Field observations were used to confirm the physical suitability and product specifications, while brief interviews were conducted to understand the reasons for respondents' preferences for certain attributes.

2.5. Research Tools

The research instrument in the form of a paired comparison form adapted from the paired comparison scale method, was used to measure respondents' perceptions of the product attributes of the two brands. Data analysis was carried out in four stages, namely: (1) validity and reliability tests to ensure the feasibility of the instrument; (2) preparation of a competitive value matrix to identify the strengths and weaknesses of each brand; (3) Game Theory analysis stages I–III which include strategy elimination, saddle point identification, and application of the simplex method (primal–dual).

2.6. Research Procedure

The data collection stage was carried out by distributing respondent forms as primary data to 31 Senator MTB and Aviator MTB bicycle users in the East Java region. The form is closed with three main sections, namely (1) characteristics of MTB bicycle users, (2) appearance of the Senator and Aviator bicycle products being compared, and (3) filling in strategy recommendations, which can be accessed via the link <https://forms.gle/eC5ANR5PMUQ6brBJ9>. The results of the form completion were automatically summarized in a spreadsheet via Google Forms as proof of completion and the basis for data tabulation. The data was then processed through validity, reliability, and data adequacy testing before being analyzed using Game Theory methods.

The Simplex method in Game Theory is applied when the payoff matrix does not have a saddle point, requiring the problem to be converted into a linear programming model. Let a_{ij} represent the payoff of strategy i (row player) against strategy j (column player), V the value

of the game, x_i the proportion of strategy i chosen by the row player, and y_j the proportion of strategy j chosen by the column player. For the row player, the primal model aims to maximize V subject to the condition that the sum of $(a_{ij} \times x_i)$ for each column j is greater than or equal to V , with the total sum of all x_i equal to 1 and each x_i non-negative. For the column player, the dual model aims to minimize V subject to the condition that the sum of $(a_{ij} \times y_j)$ for each row i is less than or equal to V , with the total sum of all y_j equal to 1 and each y_j non-negative. If the payoff matrix contains negative values, a constant K is added to each element so that all payoffs become non-negative, producing a transformed matrix $b_{ij} = a_{ij} + K$. The problem is then rewritten to maximize $Z = \sum x_i$ subject to $\sum (b_{ij} \times x_i) \geq 1$ for all j , with $x_i \geq 0$. The value of the game is calculated as $V = (1 / \sum x_i) - K$, and the optimal mixed strategy proportions for the row player are given by $p_i = x_i / \sum x_i$. Through iterative computation using the Simplex method, this process determines the optimal mix of strategies for each player to maximize gains or minimize losses.

2.7. Framework of thinking

The research process begins with the Research Design, which outlines the use of a quantitative approach with paired comparison and Game Theory methods. It proceeds to Data Collection via Google Forms distributed to 31 respondents who are users of Senator and Aviator MTB bicycles. The collected responses undergo Data Processing, including validity, reliability, and data sufficiency tests to ensure accuracy. Once validated, the study advances to Game Theory Analysis, involving the construction of a payoff matrix, elimination of dominated strategies, formulation of linear programming models, and solving through the Simplex method. Finally, the Results stage presents the optimal strategies and game values, providing insights for product development and positioning before the process concludes (Figure 1).



Figure1. Framework of thinking

Source: (Author, 2022)

3. Results and Discussion

3.1. Result

3.1.1 Form Data Testing

The results of the paired comparison validity test on bicycle attributes from the Senator and Aviator brands showed that all items were valid, with a calculated r value greater than the table r (0.355). Attributes such as a sturdy, lightweight frame, a soft, durable front fork, a strong derailleur, and a durable seatpost, stem, and handlebar combination can significantly differentiate the quality of the two products (Table 2).

Table 2. Pairwise Comparison Attribute Validation

Pairwise Comparison Attributes	Rhitung	Rtable	Decision	Pairwise Comparison Attributes	Rhitung	Rtable	Decision
A. Senator - Lightweight, Sturdy Frame				A. Senator - Strong Derailleur			
B. Aviator - Lightweight, Sturdy Frame	0.03	0.25	Valid	B. Aviator - Lightweight, Sturdy Frame	0.31	0.25	Valid
A. Senator - Lightweight, Sturdy Frame				A. Senator - Strong Derailleur			
B. Aviator - Soft, Durable Front Fork	0.39	0.25	Valid	B. Aviator - Soft, Durable Front Fork	0.29	0.25	Valid
A. Senator - Lightweight, Sturdy Frame				A. Senator - Strong Derailleur			
B. Aviator - Powerful Derailleur	0.29	0.25	Valid	B. Aviator - Powerful Derailleur	0.45	0.25	Valid
A. Senator - Lightweight, Sturdy Frame				A. Senator - Strong Derailleur			
B. Aviator - Durable Seatpost Stem Handlebar Combination	0.35	0.25	Valid	B. Aviator - Durable Seatpost Stem Handlebar Combination	0.41	0.25	Valid
A. Senator - Soft, Durable Front Fork				A. Senator - Durable Seatpost Stem Handlebar Combination			
B. Aviator - Lightweight, Sturdy Frame	0.26	0.25	Valid	B. Aviator - Lightweight, Sturdy Frame	0.37	0.25	Valid
A. Senator - Soft, Durable Front Fork				A. Senator - Durable Seatpost Stem Handlebar Combination			
B. Aviator - Soft, Durable Front Fork	0.41	0.25	Valid	B. Aviator - Soft, Durable Front Fork	0.03	0.25	Valid
A. Senator - Soft, Durable Front Fork				A. Senator - Durable Seatpost Stem Handlebar Combination			
B. Aviator - Powerful Derailleur	0.44	0.25	Valid	B. Aviator - Powerful Derailleur	0.25	0.25	Valid
A. Senator - Soft, Durable Front Fork				A. Senator - Durable Seatpost Stem Handlebar Combination			
B. Aviator - Durable Seatpost Stem Handlebar Combination	0.35	0.25	Valid	B. Aviator - Durable Seatpost Stem Handlebar Combination	0.32	0.25	Valid

Table 3. Cronbach Alpha's

Cronbach's Alpha	Number of Items	Standard Cronbach Alpha	Decision
0.797	16	0.600	Highly Reliable

The reliability test using Cronbach's Alpha obtained a value of 0.797 from 16 items, which exceeds the minimum standard of 0.600. This indicates that the instruments used were classified as highly reliable. This reliability confirms that the product attributes measured, such as bicycle components from the Senator and Aviator brands, have strong internal consistency (Table 3).

3.1.2 Game Theory Phase I

A recapitulation of the competitive value between Senator and Aviator brand bicycles based on the responses of 31 respondents to four strategic attributes: a sturdy, lightweight frame, a soft, durable front fork, a strong derailleur, and a durable seatpost, stem, and handlebar combination demonstrates consumer perceptions of the advantages of each brand. These results serve as an important reference for evaluating product quality and

competitiveness, as well as directing the development of more targeted production and innovation strategies according to market needs (Table 4).

Table 4. Competitive Value

Competitive Value		Aviator			
		Lightweight, Sturdy Frame	Soft, Durable Front Fork	Strong Derailleur	Durable Seatpost Stem Handlebar Combination
Senator	Lightweight, Sturdy Frame	20	18	14	16
		11	13	17	15
	Soft, Durable Front Fork	18	21	10	13
		13	10	20	18
Strong Derailleur	11	16	12	16	
		20	15	19	15
Durable Seatpost Stem Handlebar Combination	17	15	17	17	
		14	16	14	14

The payoff matrix between Senator and Aviator bicycles shows the difference in attribute values based on the reduction of Senator's value compared to Aviator's, for example, the lightweight, sturdy frame attribute with a difference of 9 (from 20–11). Minimax is the largest indicator value for Aviator, while maximin is the smallest value for Senator. These two values do not yet have a saddle point, so it is necessary to eliminate the smallest value for Senator and the largest value for Aviator (Table 5).

Table 5. Pay-Off Matrix of Mixed Minimax and Maximin Strategies Stage I

Pay-Off Matrix		Aviator				Maximin	Amount
		Lightweight, Sturdy Frame	Soft, Durable Front Fork	Strong Derailleur	Durable Seatpost Stem Handlebar Combination		
Senator	Lightweight, Sturdy Frame	9	5	-3	1	-3	12
	Soft, Durable Front Fork	5	11	-10	-5	-10	1
	Strong Derailleur	-9	1	-7	1	-9	-14
	Durable Seatpost Stem Handlebar Combination	3	-1	3	3	-1	8
Minimax		9	11	3	3		
Amount		8	16	-17	0		

Eliminating strategies in the mixed strategy approach due to the lack of a saddle point. The Senator attribute that was eliminated was the strong derailleur, as it produced the lowest total gain (-14), while on the Aviator side, the soft and resilient front fork attribute was eliminated because it produced the largest total loss (-17) (Table 6).

Table 6. Minimax and Maximin Mixed Strategy Pay-Off Matrix Stage II

Pay-Off Matrix		Aviator			Maximin
		Lightweight, Sturdy Frame	Strong Derailleur	Durable Seatpost Stem Handlebar Combination	
Senator	Lightweight, Sturdy Frame	9	-3	1	-3
	Soft, Durable Front Fork	5	-10	-5	-10
	Durable Seatpost Stem Handlebar Combination	3	3	3	3
	Minimax	9	3	3	

The saddle point value is the meeting point of the Durable Seatpost Stem Handlebar Combination attribute with a value of 3 with a strong derailleur with a value of 3. There are 2 saddle points, so the assumption used is the meeting point of the Durable Seatpost Stem Handlebar Combination matrix with a Strong Derailleur. Maximin is not the same as minimax,

the most detrimental Senator = -9, the most detrimental positive = 11, k value ≥ 1 . The assumption for k is 11 so that the linear program value is not negative. Thus, the solution to this case uses a linear program using the simplex method.

Aviator code notes:

y_1 =Lightweight, Sturdy Frame

y_3 = Strong Derailleur

y_4 = Durable Seatpost Stem Handlebar Combination

Senator code notes:

x_1 =Lightweight, Sturdy Frame

x_2 =Soft, Durable Front Fork

x_4 =Durable Seatpost Stem Handlebar Combination

The 3 x 3 matrix model used added a value of 11 to each Senator and Aviator attribute (Table 7).

Table 7. Dual Simplex Modeling

		Aviator		
		Lightweight Sturdy Frame (y_1)	Strong Derailleur (y_3)	Durable Seatpost Stem Handlebar Combination (y_4)
Senator	Lightweight Sturdy Frame (x_1)	20	8	12
	Shock-Resistant Soft Front Fork (x_2)	16	1	6
	Durable Seatpost Stem Handlebar Combination (x_4)	14	14	14

3.1.2 Game Theory Phase II

1. Dual Simplex Method

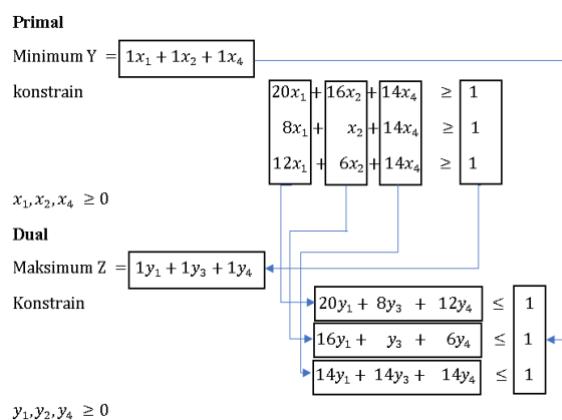


Figure 1. Dual Simplex

2. Linear Programming Formulation for Aviator (Dual)

The linear programming formulation for Aviator is:

$$\text{Maksimum } Z = y_1 + y_3 + y_4$$

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$$20y_1 + 8y_3 + 12y_4 \leq 1$$



$$16y_1 + y_3 + 6y_4 \leq 1$$

$$14y_1 + 14y_3 + 14y_4 \leq 1$$

$$y_1, y_2, y_4 \geq 0$$

Then it is changed into a model

$$Z_{maks} - y_1 - y_3 - y_4 - 0S_1 - 0S_3 - 0S_4 = 0$$

Additional constraint function with variable slack

$$20y_1 + 8y_3 + 11y_4 + S_1 = 1$$

$$16y_1 + y_3 + 6y_4 + S_3 = 1$$

$$14y_1 + 14y_3 + 14y_4 + S_4 = 1$$

$$y_1, y_3, y_4, S_1, S_3, S_4 \geq 0$$

Iteration 1		C _j	1	1	0	0	0	
B	CB	YB	y1	y3	y4	S1	S3	S4
S1	0	1	(20)	8	12	1	0	0
S3	0	1	16	1	6	0	1	0
S4	0	1	14	14	14	0	0	1
Z=0		Z _j	0	0	0	0	0	0
		Z _j -C _j	-1Up	-1	-1	0	0	0

The first iteration of the Z_j - C_j minimum negative value is -1 at the first column index, so the variable entering the basis is y₁. The minimum ratio is found in the first row with a value of 0.05 (1/20), so the variable leaving the basis is S₁. Thus, the pivot element or key element is located at position 20 to increase the effectiveness of the strategy.

$$\begin{array}{l} R1(\text{old}) = \\ R1(\text{new}) = R1(\text{old}) \div 20 \end{array} \quad \begin{array}{ccccccccc} 1 & 20 & 8 & 12 & 1 & 0 & 0 \\ 0.05 & 1 & 0.4 & 0.6 & 0.05 & 0 & 0 \end{array}$$

Thus, the new row model R2 follows:

$$\begin{array}{l} R2(\text{old}) = \\ R1(\text{new}) = \\ 16 \times R1(\text{new}) = \\ R2(\text{new}) = R2(\text{old}) - 16R1(\text{new}) \end{array} \quad \begin{array}{ccccccccc} 1 & 16 & 1 & 6 & 0 & 1 & 0 \\ 0.05 & 1 & 0.4 & 0.6 & 0.05 & 0 & 0 \\ 0.8 & 16 & 6.4 & 9.6 & 0.8 & 0 & 0 \\ 0.2 & 0 & -5.4 & -3.6 & -0.8 & 1 & 0 \end{array}$$

Meanwhile, the new R3 line models are as follows:

$$\begin{array}{l} R3(\text{old}) = \\ R1(\text{new}) = \\ 14 \times R1(\text{new}) = \\ R3(\text{new}) = R3(\text{old}) - 14R1(\text{new}) \end{array} \quad \begin{array}{ccccccccc} 1 & 14 & 14 & 14 & 0 & 0 & 1 \\ 0.05 & 1 & 0.4 & 0.6 & 0.05 & 0 & 0 \\ 0.7 & 14 & 5.6 & 8.4 & 0.7 & 0 & 0 \\ 0.3 & 0 & 8.4 & 5.6 & -0.7 & 0 & 1 \end{array}$$

Iteration 2		C _j	1	1	0	0	0	
B	CB	YB	y1	y3	y4	S1	S3	S4
y1	1	0.05	1	0.4	0.6	0.05	0	0
S3	0	0.2	0	-5.4	-3.6	-0.8	1	0
S4	0	0.3	0	(8.4)	5.6	-0.7	0	1
Z=0.05		Z _j	1	0.4	0.6	0.05	0	0
		Z _j -C _j	0	-0.6Up	-0.4	0.05	0	0

The negative minimum Z_j-C_j is -0.6 and the column index is 2. So, the incoming variable is y₃. The minimum ratio is 0.036 and the row index is 3. So, the remaining basic variable is S₃. The pivot element is 8.4.

Input =y₃, output =S₄, key element =8.4

So, the new R3 row model is as follows:

$$\begin{array}{l} R3(\text{old}) = \\ R3(\text{new}) = R3(\text{old}) \div 8.4 \end{array} \quad \begin{array}{ccccccccc} 0.3 & 0 & 8.4 & 5.6 & -0.7 & 0 & 1 \\ 0.036 & 0 & 1 & 0.667 & -0.083 & 0 & 0.119 \end{array}$$

The new R1 line models are as follows:

$$\begin{array}{llllllll}
 R1(\text{old}) = & 0.05 & 1 & 0.4 & 0.6 & 0.05 & 0 & 0 \\
 R3(\text{new}) = & 0.036 & 0 & 1 & 0.667 & -0.083 & 0 & 0.119 \\
 0.4 \times R3(\text{new}) = & 0.014 & 0 & 0.4 & 0.267 & -0.033 & 0 & 0.048 \\
 R1(\text{new}) = R1(\text{old}) - 0.4R3(\text{new}) & 0.036 & 1 & 0 & 0.333 & 0.083 & 0 & -0.048
 \end{array}$$

$$\begin{array}{llllllll}
 R2(\text{old}) = & 0.2 & 0 & -5.4 & -3.6 & -0.8 & 1 & 0 \\
 R3(\text{new}) = & 0.036 & 0 & 1 & 0.667 & -0.083 & 0 & 0.119 \\
 5.4 \times R3(\text{new}) = & 0.193 & 0 & 5.4 & 3.6 & -0.45 & 0 & 0.643 \\
 R2(\text{new}) = R2(\text{old}) + 5.4R3(\text{new}) & 0.393 & 0 & 0 & 0 & -1.25 & 1 & 0.643
 \end{array}$$

Iteration 3		C _j	1	1	1	0	0	0	MinRatio
B	CB	Y _B	y ₁	y ₃	y ₄	S ₁	S ₃	S ₄	
y ₁	1	0.036	1	0	0.333	0.083	0	-0.048	
S ₃	0	0.393	0	0	0	-1.25	1	0.643	
y ₃	1	0.036	0	1	0.667	-0.083	0	0.119	
Z=0.071		Z _j	1	1	1	0	0	0.071	
		Z _j -C _j	0	0	0	0	0	0.071	

Since all Z_j-C_j ≥ 0. Therefore, the optimal solution is the value of the variables as:

$$y_1 = 0.036$$

$$y_3 = 0.036$$

$$y_4 = 0$$

$$\text{Max } Z = 0.071$$

Furthermore,

$$v = \frac{1}{\text{Max } Z} - k = \frac{1}{0.071} - 11 = 3.286 \rightarrow \text{strategic value of 3.286}$$

$y_1 = \frac{y_1}{\text{Max } Z} = \frac{0.036}{0.071} = 0.507 \rightarrow$ Therefore, the Lightweight Sturdy Frame strategy is applied 50.7% of the time.

$y_3 = \frac{y_3}{\text{Max } Z} = \frac{0.036}{0.071} = 0.507 \rightarrow$ Thus, the Strong Derailleur strategy is applied 50.7% of the time.

$y_4 = \frac{y_4}{\text{Max } Z} = \frac{0}{0.071} = 0 \rightarrow$ Seatpost Stem Handlebar Combination Strategy Durable not apply

The game value calculation process is carried out by subtracting the v value of 3.256 from the constant 11, resulting in a game value of -7.714. This indicates that Aviator, as a column player, obtained a game value of -7.714 with a mixed strategy, namely using a sturdy and lightweight frame attribute of 50.7% and a strong derailleur of 50.7%.

3. Linear Programming Formulation for Senator (Primal)

The linear programming formulation for Senator is:

$$\text{Minimum } Y = x_1 + x_2 + x_4$$

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$$20x_1 + 16x_2 + 14x_4 \geq 1$$

$$8x_1 + x_2 + 14x_4 \geq 1$$

$$12x_1 + 6x_2 + 14x_4 \geq 1$$

$$x_1, x_2, x_4 \geq 0$$

Then it is changed into a model

$$Y_{\min} = x_1 - x_2 - x_4 - 0S_1 - 0S_2 - 0S_4 = 0$$

Additional constraint function with variable slack

$$20x_1 + 16x_2 + 14x_4 + S_1 = 1$$

$$8x_1 + x_2 + 14x_4 + S_2 = 1$$

$$12x_1 + 6x_2 + 14x_4 + S_4 = 1$$

$$x_1, x_2, x_4 \geq 0$$

Iteration 1		C _j	1	1	1	0	0	0	M	M	M	Min Ratio YB/x4
B	CB	YB	x1	x2	x4	S1	S2	S4	A1	A2	A4	
A1	M	1	20	16	(14)	-1	0	0	1	0	0	1/14=0.07→
A2	M	1	8	1	14	0	-1	0	0	1	0	1/14=0.07
A4	M	1	12	6	14	0	0	-1	0	0	1	1/14=0.07
Y=3M		Y _j	40M	23M	42M	-M	-M	-M	M	M	M	
					42M- 1Up	-M	-M	-M	0	0	0	
		Y _j -C _j	40M-1	23M-1								

The positive maximum of Y_j-C_j is 42M-1 and its column index is 3. So, the incoming variable is x4. The minimum ratio is 0.07 and its row index is 1. So, the remaining basic variable is A1. The pivot element is 14. Entering =x4, leaving =A1, the key element =14. Then it is done until the 6th iteration, until Y_j-C_j ≤ 0.

Iteration 6		C _j	1	1	1	0	0	0				MinRatio
B	CB	YB	x1	x2	X4	S1	S2	S4				
X4	1	0.07	0	-0.64	1	0.11	0	-0.18				
S2	0	0	0	0	0	0.5	1	-1.5				
x1	1	0	1	1.25	0	-0.12	0	0.12				
Y=0.07		Y _j	1	0.61	1	-0.02	0	-0.05				
		Y _j -C _j	0	-0.39	0	-0.02	0	-0.05				

Since all Y_j-C_j ≤ 0. Therefore, the optimal solution with variable values as:

$$x_1=0$$

$$x_2=0$$

$$x_4=0.07$$

$$\text{Min } Z=0.07$$

Furthermore,

$$v = \frac{1}{\text{Min } Y} - k = \frac{1}{0,07} - 11 = 3,825 \rightarrow \text{strategic value of 3.825}$$

$$x_1 = \frac{x_1}{\text{Min } Y} = \frac{0}{0,07} = 0 \rightarrow \text{Therefore, the Lightweight Solid Frame strategy is not implemented.}$$

$$x_2 = \frac{x_2}{\text{Min } Y} = \frac{0}{0,07} = 0 \rightarrow \text{Therefore, the Soft, Resilient Front Fork strategy is not implemented.}$$

$$x_4 = \frac{x_4}{\text{Min } Y} = \frac{0,07}{0,07} = 1 \rightarrow \text{The Durable Seatpost Stem Handlebar Combination Strategy is applied at 1.00.}$$

The process of generating the game value, then subtracting the value of v from the constant used is 11, then the game value = 3.825 - 11 = -7.175. Thus, the Senator as a line player gets a game value of -7.175 using the Durable Seatpost Stem Handlebar Combination strategy of 1.00.

3.2. Discussion

The research process begins with the Research Design, adopting a quantitative approach with paired comparison and Game Theory. Data Collection was conducted via Google Forms, targeting 31 respondents who are users of Senator MTB and Aviator MTB in East Java. The questionnaire consisted of three sections: respondent characteristics, comparative product display, and strategy recommendations. During Data Processing, a validity test showed all items met the requirement with r calculated greater than r table (0.355),

the reliability test produced a Cronbach's Alpha of 0.797 (above the 0.600 threshold), and the data sufficiency check confirmed adequacy. In Game Theory Analysis, a 4x4 payoff matrix was constructed, followed by elimination of dominated strategies to obtain a reduced 3x3 matrix with an added constant $K = 11$. Linear programming models were then formulated for both players and solved using the Simplex method until all $Z_j - C_j$ values were greater than or equal to 0. The results showed Aviator's optimal mixed strategy was $y_1 = 0.507$ (frame), $y_3 = 0.507$ (derailleur), and $y_4 = 0.000$ (combo seatpost–stem–handlebar) with a game value of -7.714, while Senator's optimal pure strategy was $x_4 = 1.000$ (combo seatpost–stem–handlebar) with a game value of -7.175. These findings provide clear guidance for product development and market positioning. The optimal game value obtained through the mixed strategy using the primal–dual method shows that Aviator, as the column player, will minimize its loss to -7,714 units by relying on the superior implementation of a lightweight and rigid frame and a strong derailleur, each contributing 50.7%. Meanwhile, Senator, as the row player, will maximize its gain to -7,715 units through a pure strategy, relying entirely on the durability of the seatpost–stem–handlebar combination attribute at 100%.

4. Conclusions and Recommendations

The study concludes that the application of paired comparison and Game Theory, analyzed using the primal–dual method, effectively identified optimal strategies for both brands. Aviator, as the column player, minimized its loss to -7,714 units by adopting a mixed strategy focusing equally (50.7% each) on a lightweight and rigid frame and a strong derailleur. Senator, as the row player, maximized its gain to -7,715 units through a pure strategy that fully (100%) leveraged the durability of the seatpost–stem–handlebar combination. These results demonstrate the ability of Game Theory to guide competitive decision-making in the bicycle industry. The findings provide actionable insights for product development and market positioning. Aviator should prioritize simultaneous improvements in frame and derailleur quality to maintain competitiveness. Senator should reinforce its dominance in the seatpost–stem–handlebar durability attribute and use this as a central marketing and branding advantage. Both brands can use these insights to optimize resource allocation, refine product differentiation, and target consumer segments more effectively. Future studies could expand the sample size beyond 31 respondents to increase statistical robustness. Incorporating a broader range of product attributes, including emerging features such as integrated smart components or advanced suspension systems, may yield deeper strategic insights. Additionally, applying alternative decision-making models such as Multi-Criteria Decision Analysis (MCDA) or Analytic Hierarchy Process (AHP) alongside Game Theory could provide a more comprehensive evaluation of competitive strategies in the bicycle market.

Declaration of Competing Interest

None.

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CRediT authorship contribution statement

Anang Siswanto: Conceptualization, methodology design, data analysis, and manuscript drafting. Saiful Rowi: Supervision, validation, and critical review of methodology and results. Venus Khatta Salsabillah: Data collection, tabulation, and preliminary analysis. Rudi Kurniawan: Statistical testing, Game Theory modeling, and result interpretation. Sindy Nindia Maretha Haris Tanti: Literature review, theoretical framework, and discussion development. Johan Alfian Pradana: Data visualization, preparation of figures and tables, and manuscript formatting.

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References

Antonius, F. (2024). Efficient resource allocation through CNN-game theory based network slicing recognition for next-generation networks. *Journal of Engineering Research (Kuwait)*, 12(4), 793–805. <https://doi.org/10.1016/j.jer.2024.01.018>

Ibrahim Fahad Sulaiman, Ahmed Abdul Malik, & Zainab Masud Abdul Raheem. (2024). The Role of Transformational Leadership Style on Islamic Management. *Journal of Scientific Research, Education, and Technology (JSRET)*, 3(1), 340–348. <https://doi.org/10.58526/jsret.v3i1.326>

Kurniawan, I., Muslihah, E., & Syarifudin, E. (2022). KYAI'S LEADERSHIP MODEL IN ISLAMIC EDUCATIONAL INSTITUTIONS, ISLAMIC BOARDING SCHOOL: A LITERATURE STUDY. *International Journal of Graduate Islamic Education*, 3, 302.

Ma, Y., Lu, Y., Yin, Y., & Lei, Y. (2024). Pricing strategy of V2G demand response for industrial and commercial enterprises based on cooperative game. *International Journal of Electrical Power and Energy Systems*, 160(March), 110051. <https://doi.org/10.1016/j.ijepes.2024.110051>

Maldonado-Carrascosa, F.J., García-Galán, S., Valverde-Ibáñez, M., Marciniak, T., Szczerska, M., & Ruiz-Reyes, N. (2024). Game theory-based virtual machine migration for energy sustainability in cloud data centers. *Applied Energy*, 372(January), 123798. <https://doi.org/10.1016/j.apenergy.2024.123798>

Maleki Vishkaei, B., & De Giovanni, P. (2025). A smart mobility game with blockchain and hardware oracles. *International Journal of Production Economics*, 282(December 2024), 109533. <https://doi.org/10.1016/j.ijpe.2025.109533>

Marousi, A., Thyagarajan, K., Pinto, J.M., Papageorgiou, L.G., & Charitopoulos, V.M. (2024). Game-theoretic optimization of supply chain design with customer contracts: The case of industrial gases market. *Computers and Chemical Engineering*, 184(October 2023), 108625. <https://doi.org/10.1016/j.compchemeng.2024.108625>

Noorhayati, SM, & Fahyuni, EF (2024). The Role of Leadership in Improving Managerial Accountability at Islamic Higher Education. *Nidhomul Haq: Journal of Islamic Education Management*, 9(2), 239–253. <https://doi.org/10.31538/ndh.v9i2.4584>

Perumalsamy, D., Johnson, S., & Thinakaran, R. (2025). Unraveling health impacts of individuals in industrial zones: Leveraging game theory-based LSTM approach for predictive analysis of public health dynamics. *Ain Shams Engineering Journal*, 16(10),

103579. <https://doi.org/10.1016/j.asej.2025.103579>

Sulthon Sulaiman, Achmad Patoni, Ngainun Naim, & Ahmad Supriyadi. (2024). Kiai Charismatic Leadership in Developing the Mamba'ul Ma'arif Denanyar Islamic Boarding School. *International Journal of Science, Technology & Management*, 5(1), 50–59. <https://doi.org/10.46729/ijstm.v5i1.1056>

Ubaidillah, M., Mustofa, A., Gultom, RZ, Fadlur, A., Bayuny, R., Aliyul, M., & Al Mustofa, H. (2022). Transactional And Transformational Leaderships In Islamic Perspectives. *Indonesian Journal of Development Studies (IJDS)*, 2022(1), 13–19.

Yin, S., Sun, W., & Wang, H. (2025). Virtual power plant capacity tariff pricing method based on master–slave game. *International Journal of Electrical Power and Energy Systems*, 169(May), 110774. <https://doi.org/10.1016/j.ijepes.2025.110774>

Yuwono, S., Hussain, AK, Schwung, D., & Schwung, A. (2025). Self-optimization in distributed manufacturing systems using Modular State-based Stackelberg games. *Journal of Manufacturing Systems*, 80(March), 578–594. <https://doi.org/10.1016/j.jmsy.2025.03.025>