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Game Theoretic Analysis of Kabaddi

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Abstract: Strategy making is important in daily life, especially in sports. Game Theory is useful for studying and analyzing various aspects of competitive games and for mathematically determining the best strategies to be employed. Such studies have not been conducted for Kabaddi. In this paper, an attempt is made to fill this gap. An attempt is made to improve the efficiency of game play by aiding the strategy making of coaches/players with the techniques of game theory. Towards this end, matrices are constructed by observing the matches for the season 7 of pro Kabaddi league 2019. Then the points gained using various strategies are noted down in a table. Utility matrices are computed for raiders and defenders and are then used to compute the Nash equilibrium values and construct a recommendation tool. The game theoretic model for Kabaddi, developed in this work for the first time, would enable further research.

Keywords: Co-opetitive game, Kabaddi, Defender, Raider, Recommendation tool

1 Introduction

Human reaction typically involves conscious or unconscious assessment of choices and decision making under different circumstances. The behavior presented is the consequence of such activities. Decision-making is essential in every domain of everyday life. Decision making is non-trivial in complex situations where sequences of activities could be performed in cooperation and competition with others. The human decision making typically combines rational, irrational and emotional aspects depending on the particular situation at hand. Game theory is helpful in decision support and analysis. Game theory powers attention-grabbing applications in multiple fields viz., social sciences, evolutionary theory, political science, ethics, artificial intelligence, cybernetics and many more. The motivation for utilization of Game theory is to create a framework in which the decision-makers act together with other players. In a game, the outcomes are determined by the interactions between several groups of players. The competitive field games and sports with time bound nature, nevertheless, necessitate rapid decisions in limited period available for winning. Researchers have attempted Game Theoretic analyses of various games [1] [2] [3] [4] [5]. Carter and Machol collected data from various matches and discerned that the expected value of possession of American football in first down and ten yards to go was negative. Their data was based on 56 matches of the first half of the National Football League (NFL), and their statistical analysis was grounded in the calculation of the expectation value. They observed that two types of errors may possibly come about. Type I error is occurrence of a time out when it could have been avoided, whereas type II error is not calling a time out when it should have been done [6]. Romer showed that the National Football League (NFL) teams do not play the strategies which could yield more points [7].Chiappori et al. developed a game-theoretic model of penalty kicks in soccer. Using this model, the group of players optimally decides which strategies to use based on the opponent's behavior. In this study, the model supports the assumptions and predictions of the dataset generated from game [8]. Palacios-Huerta constructed the empirical payoff matrices for left and right footed kickers. The Nash predicted frequencies were obtained from these matrices and found to be in accordance with the observed empirical frequencies [9].Alamar showed that coaches do not act rationally in Football. In practice, the figure of passing and running plays is approximately equal, despite the fact that passing plays has greater point advantage. Therefore, coaches need to suggest passing more frequently [10]. Hirotsu and Wright develop a zero-sum model of Football which analyzed how the quality of player choices affects the likelihood of winning [11]. Coloma showed that Football players obey mixed strategy Nash

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equilibrium by analyzing a study done on the foot used by players to kick the ball [12]. Rockerbie developed a simple model to use passing and running plays in a utility maximizing proportion in [13]. Auer and Hiller presented a comparative analysis of a newly proposed game theoretic approach and classical performance measures for soccer. The new game theoretic model has no significant benefit in comparison to classical performance measures except that it enhances the explanatory power of the model [14]. Cooperative game theory is used for ranking the German Bundesliga players and the ranks so obtained are compared with www.weltfussball.de player rankings [15]. Decision-making aspects of Volleyball have also been studied. In Volleyball, Bowles and Ram reported a study using Rasch model incorporating a partial credit model to obtain detailed information about players' ability and consistency. This was done for eleven players, twenty-seven matches and three skills [16]. Lin showed that the game has no pure strategy Nash equilibrium and, therefore, no stable or dominant strategy irrespective of how many blockers defend against a spiker. However, mixed strategy Nash equilibrium exists [17]. A variety of algorithms are developed for predicting outcomes and doing analyses related to Kabaddi matches [18]. A Nash equilibrium calculator "Game theory explorer" (GTE) is used [19]. The GTE uses the lrsNash (lexicographic reverse search) technique based on a vertex enumeration program lrs. An extension of the lrs technique is used to find out the Nash equilibrium. The GTE identifies the best response functions. The polyhedrons are then made from the best response function. The Nash equilibrium of the game is obtained by enumerating the vertices of the best response function, using the lrs technique. The Nash equilibrium is based on Nash's theorem, which guarantees the existence of a set of mixed strategies for finite, non-cooperative games with two or more players given that no player can improve his/her payoff by unilaterally changing the strategy. Dominating strategies are the most efficient strategies for a player, irrespective of the strategies of the other players. No study till date attempts to do a game theoretic analysis of Kabaddi, a South Asian game that is played between two teams. This study is the first such endeavor. The authors design matrices using the dataset constructed by watching match videos of the Pro Kabaddi league season 7. In the Pro Kabaddi league twelve best teams from around the world contest. The dataset is collected by observing matches played by professional players. They are highly motivated to win the game and their performance is extraordinary. Also, they are aware of the rules of the game. In the Pro Kabaddi league, the teams are kept in a double round robin format. The knockout stage includes two semifinals and the championship game. A total of fifteen matches are examined to create the dataset. A recommendation tool is presented. The recommendation tool is a table of optimal strategies for the defender against raider strategies and vice versa.

2 Kabaddi

The two competing teams are assigned opposite halves of the court. The court has measurements of 12.5m x 10m with four border lines called end lines. The court is divided by mid-line and each half is called a Half-court. Kabaddi matches typically last for forty-five minutes divided into two halves of twenty minutes each with a five-minute break. Each team has seven players on the court in addition to five players required to be present as reserves. A player must be mindful of his/her state of affairs, environments, court boundaries, and guidelines of the game. The team winning toss chooses to raid or defend first. Each team must send a raider to the half-court of the opposite team, turn by turn. The raider attempts to touch as many defenders as possible and return to his/her own half-court without breaking breath. The points are awarded based on the number of opponents touched. The raider tries to score maximum points whereas the defenders' attempt to stop the raider from scoring any points. A player is declared out if any part of his/her body is out of the court [20]. The teams switch court sides in the second half.

3 Model

In Kabaddi there are several possible strategies out of which one or more strategy is utilized for a given situation. Either attacker or defender may gain point(s); or none may gain. In rare and exceptional cases, both the teams may win points, as per rules of game. It is not in interest of both the parties to ensure that both gain points each time. Therefore, it is not co-opetitive game. At any point in the game, one player is the raider. Each point of the play is a strategic encounter between the raider and the defenders and a point is recorded in each such encounter. The objective of the defenders is to grab the raider to score more points. The law that is used to note the scores is linear. Each team tries hard to maximize its score, and that's why it is a competitive game. Players select strategies to maximize their points gained. The raiders as well as the defenders need to choose their respective strategies at each point in the game judiciously since Kabaddi is a game of strength as well as strategy. In a game, players may try to employ more than one strategy. In the present model, authors consider the strategy adopted by the raider or the defender to be the one that leads to scoring of points. Preventing the raider from scoring a point is also considered winning a point. There are several strategies available for the raiders and the defenders as depicted in Tables 1(b) and 1(c).

Table 1: Terminology in Kabaddi

Court	A piece of land with dimensions 12.5m x 10m.
Boundary	The edges of the court are called boundaries.
Mid-Line	This line divides the court into two halves.
Court	The two halves formed by the midline.
Chant	The repetition of the word Kabaddi without breaking the breath.
Raider	The player who goes to attack in the defenders' half court.
Defenders	Players of the team under attack by raider.
Touch	To score points, the raider has to touch a defender and return to their own half of the court without breaking the breath.
Struggle	The physical process involved while raiders and defenders are attempting to score points and the opponents are trying to prevent them from doing so.
Raid	The event when a raider goes to the defenders' half court while chanting 'kabaddi'.
Successful Raid	When the raider scores a point.
Side-Line	It can be used only during touch of attacker and defender.

Table 2: Table describing various defending strategies used in Kabaddi

Defenders' Moves	
BACK-HOLD **(BH)** (BACK/WAIST HOLD)	The defender reduces raider's chance of escape by grabbing the back or the waist and lifting him/her in midair.
ANKLE-HOLD **(AH)**	The defender drags the raider inside his/her half-court by the ankle, other team players can join.
THIGH-HOLD **(TH)**	The defender(s) hold the thigh of raider to disturb his/her balance.
BLOCK **(BL)**	The defenders stop the raider from crossing the mid line and go back to his/her court.
DASH **(DA)**	If raider moves towards the outer edge of the defenders' half-court, defenders can eliminate him/her by pushing through the half line.

Table 3: Table with diverse raider strategies used in Kabaddi

Raider Moves	
TOE-TOUCH **(TT)**	The raider touches defenders' feet just by tip of their toes without getting touched by defenders.
HAND-TOUCH **(HT)**	Raider swiftly touches the defender(s) without getting caught.
FRONT-KICK **(FK)**	The raider kicks strongly from the front without getting his/her leg caught.
BACK-KICK **(BK)**	When the defenders are fielding on the baulk line, the raider staying far from them kicks with his/her back towards the defenders and run swiftly without getting caught.
DUBKI **(DU)**	The raider ducks below the defenders to reach the half line.

By carefully observing the pro Kabaddi league 2019 season 7 match videos, authors selected the five most frequently used raiding and five most frequently used defending strategies. The less frequently used strategies viz., for raiding-JUMP, BONUS, THRUST, SQUAT LEG, TOUCHING OF HANDS THROUGH UPPER LIMBS and for defending-KNEE HOLD, WRIST HOLD, CHAIN TACKLE etc. are dropped from subsequent analysis. The five most employed strategies by raiders and defenders are as follows.

Raiders: TOE-TOUCH, HAND-TOUCH, FRONT-KICK, BACK-KICK, DUBKI Defenders: BACK-HOLD, ANKLE-HOLD, THIGH-HOLD, BLOCK, DASH A brief explanation of these strategies is given in Tables 1(b) and 1(c). A dataset is created with the following information: (i) the number of times a particular raider- defender strategy set is played (ii) the number of times that raider-defender strategy yields game point(s) for the raiders and / or the defenders. The detailed methodology employed for constructing the dataset by observing fifteen matches is as follows. The match 1 was amongst U Mumba and Telugu Titans which was played on Saturday, 20 July, 2019. U Mumba got 31 points and Telugu Titans got 25 points. U Mumba was the winner. When the matrix is constructed, the points gained by U Mumba are written as +1 and points gained by Telugu Titans are written as -1. Say, if U Mumba employs a strategy but does not gain a point out of it, it is written as +0 and if Telugu Titans adopts a strategy but does not gain a point out of it, it is

Table 4: Full match data for Match 1

	BH	AH	TH	BL	DA
TT	(1,3)	(2,0)	(0,0)	(3,2)	(0,1)
HT	(1,4)	(6,5)	(1,1)	(3,2)	(0,1)
FK	(0,0)	(0,0)	(0,0)	(1,0)	(0,0)
BK	(0,0)	(0,0)	(0,0)	(0,2)	(0,0)
DU	(1,1)	(0,0)	(0,0)	(0,1)	(0,0)

Table 5: Calculation of the matrix data

+1+0+0+0+1+0+1-0+0+0+0+0+0+0+0	3
-1-0-0-1-0-0-0	-2

Table 6: A sample matrix depicting the raider's and defenders' strategies

	BH	AH	TH	BL	DA
TT	πTT-BH	πTT-AH	πTT-TH	πTT-B	πTT-DASH
HT	πHT-BH	πHT-AH	πHT-TH	πHT-B	πHT-DASH
FK	πFK-BH	πFK-AH	πFK-TH	πFK-B	πFK-DASH
BK	πBK-BH	πBK-AH	πBK-TH	πBK-B	πBK-DASH
DU	πD-BH	πD-AH	πD-TH	πD-B	πD-DASH

Table 7: The matrix depicting total sum of points earned from all matches for each combination of raider-defender strategies

	BH	AH	TH	BL	DA
TT	(5,7)	(17,18)	(5,6)	(72,56)	(12,7)
HT	(10,16)	(56,56)	(19,16)	(102,89)	(24,27)
FK	(0,1)	(2,2)	(0,1)	(1,7)	(1,4)
BK	(2,1)	(7,7)	(2,6)	(10,11)	(5,6)
DU	(4,2)	(1,5)	(0,0)	(2,4)	(2,0)

written as -0. The points gained are written in brackets. The first entry in brackets represents points gained by U Mumba and second entry in the bracket represents points gained by Telugu Titans.

For the cell corresponding to Toe-touch and block, the admissible values are computed as shown in Table 3. In this table, +1 indicates a point scored by the raiders, -1 indicates the points scored by the defenders and +0 indicates if no point is scored by the raider and -0 indicated if no point is scored by the defender.

Thus, the number of points scored in the game by the raider's team while the raiders played TOE-TOUCH and the defenders played BACK-HOLD is written as the first entry in the bracket. Further, the number of points scored by the defenders' team when the same combination of strategies is played is written as the second entry in the bracket. Thus, each matrix entry depicted in Table 4 lists the number of points won by each team while utilizing the strategy corresponding to the row (for raiders) and column (for defenders); piA-B is (raider's strategy, defender's strategy).

A recommendation tool is created to suggest the best defending strategies for given raiding strategies using the concept of 'best strategy' from game theory. The recommendation tool computes the utility values for defenders' strategy for the corresponding raider strategy. The best response principle of game theory is used. For a given instance of the game, given a strategy si of the raider, the defenders have a set of preferable strategies (S) to be played. The output of the recommendation tool is the best strategy si* from the set S of all the possible strategies for the defenders.

4 Analysis and Results

Table 5 lists the sum of points gained in individual matches gained by playing a particular strategy by raiders and defenders. For example, the points corresponding to defender playing ANKLE-HOLD and raider playing TOE-TOUCH are 18 for defender and 17 for raider. Similarly, the other cells list the points gained by raider s and defenders when the corresponding combination of strategies is employed.

Amongst defender strategies, BLOCK is much more frequently employed than other strategies viz., THIGH-HOLD and DASH. For raiders HAND-TOUCH appears to be the most frequently employed strategy. On the other hand, DUBKI is attempted much less frequently. As claimed by game theorists, the game-theoretic exploration assists the coaches as

Table 8: The utility matrix for raider

	BH	AH	TH	BL	DA	Total
TT	0.024	0.083	0.024	0.351	0.059	0.542
HT	0.024	0.135	0.046	0.246	0.058	0.058
FK	0	0.105	0	0.053	0.053	0.21
BK	0.035	0.123	0.035	0.175	0.088	0.456
DU	0.2	0.05	0	0.1	0.1	0.45

Table 9: The utility matrix for defender

	BH	AH	TH	BL	DA	Total
TT	0.034	0.088	0.029	0.273	0.034	0.458
HT	0.039	0.135	0.039	0.214	0.065	0.491
FK	0.053	0.105	0.053	0.368	0.211	0.79
BK	0.018	0.123	0.105	0.193	0.105	0.544
DU	0.1	0.25	0	0.2	0	0.55

Table 10: The combined utility matrix of raider and defender

	BH	AH	TH	BL	DA
TT	0.024, 0.034	0.083, 0.088	0.024, 0.029	0.351, 0.273	0.059, 0.034
HT	0.024, 0.039	0.135, 0.135	0.046, 0.039	0.246, 0.214	0.058, 0.065
FK	0, 0.053	0.105, 0.105	0, 0.053	0.053, 0.368	0.053, 0.211
BK	0.035, 0.018	0.123, 0.123	0.035, 0.105	0.175, 0.193	0.088, 0.105
DU	0.2, 0.1	0.05, 0.25	0, 0	0.1, 0.2	0.1, 0

well as sportspersons who aim at improving their game by choosing a better strategy. The outcomes that are obtained are displayed in the matrix, where the (HAND-TOUCH, BLOCK) = (102,89) entry has the maximum occurrence. However, these cannot be deemed to be the payoffs directly as the number of points scored using a particular strategy could be higher than the other strategies just because it has been used more often. What is needed is a probabilistic measure of how often a particular strategy yields success. The concept of utility is employed towards this end.

The game is written as a tuple K (equation 1) where P = Raiders, Defenders, and S is the set of available strategies for the defenders

$$K =< P, (s_i)i\varepsilon I(u_i)i\varepsilon I > s_i, s_{-i}i\varepsilon S \tag{1}$$

$$u_i(s_i, s_{-i}) = P(s_i|s_{-i}) * P_{success}(s_i|s_{-i}) \tag{2}$$

where P (si | s-i) represents the probability of defender to play a strategy s-i for a given strategy si of the raider (or vice-versa) and Psuccess (si — s-i) represents the success rate of strategy si for s-i. Thus, from Equation 2, the value ui (si, s-i) expresses the utility of strategy s-i for raider with respect to strategy s-i of defender from raider point of view. The probabilities can be computed for each raider strategy and each defender strategy from the data in Table 5. The utility values can then be computed using Equation 2 and are shown for the raider and defender in Table 6 and Table 7, respectively.

The recommendation tool gives the best response for defender's strategy corresponding to the strategy of the raider. The utility matrix (table 6) gives the utilities of various combinations of raider and defender strategies. The utility matrix (table 7) gives the utilities of various combinations of raider and defender strategies. Table 8 gives the combined utility value pairs for raiders and defenders for each combination of strategies employed by them.

5 Nash Equilibrium

In a two-player competitive game, if each player has chosen a strategy and no one can increase one's own expected payoff by changing one's strategy while the other player keeps his or her strategy unchanged, then the current set of strategy choices constitutes a Nash equilibrium. A dominant strategy is a strategy that produces a higher payoff than any other possible strategy. No matter what the opponent might do, a player is better off playing the dominant strategy. In other words, if the first payoff number, in the payoff pair of the cell (as shown in Table 8), is the maximum of the column of the cell and if the second number is the maximum of the row of the cell - then the cell represents a dominant

Table 11: The recommendation tool for Defender

	AH	BL	DA
TT	0.088 (II)	0.273 (I)	
HT	0.135 (II)	0.214 (I)	
FK		0.368 (I)	0.211 (II)
BK	0.123 (II)	0.193 (I)	
DU	0.25 (I)	0.2 (II)	

strategy. A dominant strategy, if it exists, is always a Nash equilibrium too. However, the converse is not true. The Nash equilibrium value for the combined utility matrix is (TOE-TOUCH, BLOCK) with utility values (0.351, 0.273). As can be easily verified, these are also the dominant strategies for both the raider and the defender. An element of surprise is a very important component of competitive games. Therefore, even when a dominant strategy exists, some deviation in the strategy employed would always be useful. Towards this end, a recommendation tool is presented in Table 9 which suggests the two best possible strategies choices for the defender for each strategy employed by the raider as determined from the data presented.

6 Conclusion

In this paper, authors successfully apply game theoretic approaches for first time for efficient strategic decision making by Kabaddi players. The authors construct unique dataset from scratch. The data is collected by hand through inspection of every single match video. The table contains the frequency values of the strategies successfully attempted. But as the strategy chosen maximum number of times will have maximum frequency, and therefore hides the 'quality' of the data, utility values are computed. A recommendation tool is presented that prescribes the two best strategies for defenders against each possible strategy of the raiders using the utility matrix. To keep the element of surprise in the matches, it is important to mix and match the two strategies rather than becoming predictable by sticking to only one strategy.

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