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2020
MCM/ICM
Summary Sheet

The Optimal Teaming Strategy Based on NPC model

Summary

In this paper, we develop the **NPC** model, an innovate analysis system based on the features of passing network and the theory of probability transition, which can display the characterization of team cooperation in a football game.

Firstly, we create a general passing network based on the given data.We then define **passing quality** and **tacit understanding** as weights of edges in the network. The former is used to identify dyadic configurations and the latter is for triadic configurations. Besides, we find that the network structure of the team presents different changing trends with the change of time period.

Secondly, we measure the indicators of teamwork from three aspects.First, in the theory of group dynamics, we measure the number of passes to quantify the intrinsic pursuit of players. The **probability transition matrix** is used to calculate the degree of trust of each player.Next, we use probability transition matrix again and combine **dynamic programming algorithm** to quantify the Offensive Efficiency of the whole team.Then, we quantify the cooperation level between players using the existing dyadic and triadic configurations.After obtaining the indicators of the three aspects, we calculated the respective weights through linear regression analysis, and finally weighted the the performance indicators index is calculated by weighting.

In addition, we calculate the indicators of opponents by utilizing the evaluation model mentioned above. The comparison between the Huskies and others remind us to provide three kinds of **teamwork strategies** against different teams. Among which we figure out an optimal team configuration for the Huskies, and we propose practical recommendations to the coach.

Overall, although further improvements are needed, we have taken into account population dynamics and considered as many factors as possible. We also discuss how we can adapt and implement our models for general conditions.

Keywords: Passing Quality; Group Dynamics; Probability Transition Matrix; NPC model

Contents

1 Introduction

1.1 Background

Known as the 'world's first sport', football is the most influential sport in the world.In a normal football match, each team has at most eleven players.Football is a game that tests not only the physical abilities and skills of players, but also their strategies, their ability to improvise, and their capability of working together.Of course, every team can't do without a coach.In addition, home and away, real-time game situation will have a certain impact on the result of the game.

We were asked by the huskies to study the interactions that directly affect scoring in a game and explore team dynamics throughout the game and season to help identify specific strategies that can improve teamwork next season.

1.2 Restatement of the Problem

In the first question, we need to consider the interaction between players and build a network model, where each player is a node and each pass is a link between players.The model is used to identify the dyadic and triadic configurations between players.

The second question requires us to provide a performance evaluation model that is as comprehensive as possible to assess the performance of the entire team.

The third question requires us to build on the first two tasks and come up with an appropriate and efficient strategy to ensure that the team can play to its best in the next season and beyond.

Finally, We should refer to the theory of population dynamics to analyze the factors considered in our model.On this basis, we should consider the influence factors not mentioned, and then propose a universal team model.

1.3 Our work

We develop the NPC model, an innovate analysis system based on the features of passing network and the theory of probability transition, which can display the characterization of team cooperation in a football game. The structure of our work is shown below.

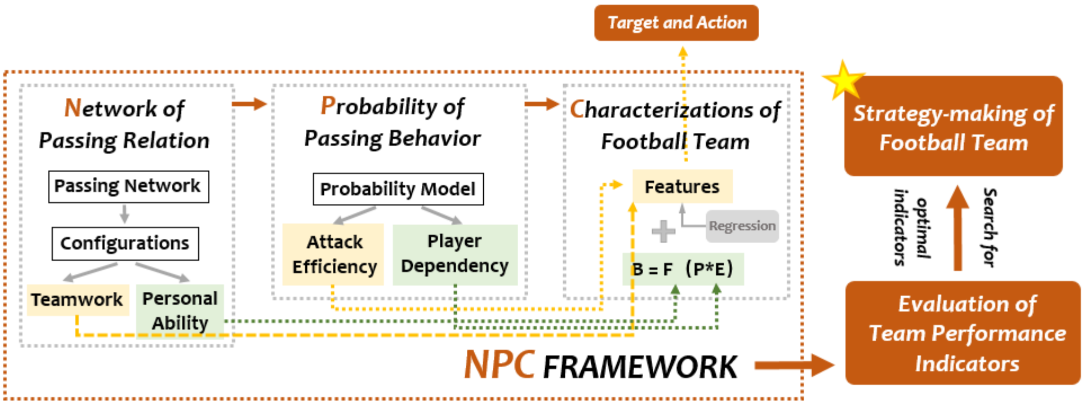

Figure 1: Framework of NPC

2 Assumptions

- Based on the big data analysis theory, it is assumed that the data volume is enough to infer other relevant data from the known data.
- Suppose the probability of a player passing the ball obeys a probability distribution.
- Suppose that the process of passing a football obeys a certain stationary distribution, that is, a probability distribution with some invariant (or stationary) property.
- It is assumed that the influence of the coach, the field, the home and away factors on a game is constant.

3 Notation

Symbol	Description
d_{ij}	the number of passes made by player i to player j
e_{ij}	the number of successful passes from player i to player j
f_{ij}	the number of failed passes that player i wishes to make to player j
A_e	successful pass matrix
A_f	the failed pass matrix
A_d	the total pass matrix
ρ_{suc}	the tendency of a player to pass successfully at his original level
ρ_{unsuc}	the tendency of a player to fail to pass at his original level
M	passing quality
f	the tacit understanding degree
α	the weight of the deviation in the y direction
β	the deviation in the x direction in the tacit understanding
γ	whether the pass crossed the center line
F	total tacit understanding degree
B	persons behavior
P	the interaction between internal needs
E	the external environmental forces
A_g	the probability of everyone passing to a teammate
r_i	the teams trust in player i
G	the pass transition matrix
`dp[i]`	the expected number of passes from i to the target state
f_i	the player with the number i is the forward
A	linear equation $Ax = b$
b	linear equation $Ax = b$
x	solution for linear equation $Ax = b$
η_1	weight for Group Dynamics
η_2	weight for Offense Efficiency
η_3	weight for Cooperation Level
k_1	the influence of home and away teams and coaches on the indicators
k_2	make sure that the end result is not negative
S	end result

4 NPC: Passing Network

4.1 The factors in Passing Network

In order to construct a passing network that can reflect the players' cooperative relationship model, we have defined a new indicator, the quality of passing[1], to quantify the weight of the relationship between players.

4.1.1 Passing Quality

Passing quality is the interaction between players.It is mainly determined by the level of passing between players.The quality of a player's passing depends on the success of the pass.A pass is considered successful only if it is later received by a teammate.By contrast, when an opponent intercepts or the ball leaves the field, the pass is not successful.[1]

Therefore, we define three asymmetric weighted adjacency matrices A_d, A_e and A_f.A_d is the total pass matrix, where d_{ij} represents the number of passes made by player i to player j.Notice that $d_{ij} \neq d_{ji}$.Similarly, A_e is the successful pass matrix, where e_{ij} represents the number of successful passes from player i to player j.Notice that $e_{ij} \neq e_{ji}$.Af is the failed pass matrix, where f_{ij} represents the number of failed passes that player i wishes to make to player j.Notice that $f_{ij} \neq f_{ji}$.In the expression above, $1 \leq i, j \leq n$, n represents the total number of players on a team. Obviously,

$$A_d = A_e + A_f. \tag{1}$$

Notice that we're ignoring the diagonals of the three matrices, because there is no point in players passing to themselves.

Then we define passing quality:

$$m_{ij} = \rho_{suc} * e_{ij} + \rho_{unsuc} * f_{ij}, \quad i \neq j, \tag{2}$$

wherein $M = [m_{ij}] \in \mathbb{R}^{n\times n}$, with $\rho_{suc} + \rho_{unsuc} = 1$. ρ_{suc} means the tendency of a player to pass successfully at his original level.ρ_{unsuc} indicates the tendency of a player to fail to pass at his original level.These two parameters are mainly determined by some objective factors during the match, such as home and away, coach and so on.As a matter of fact, the probability of these objective external factors causing extreme results is very small, and their changes have very little effect on the results, so we will ignore these factors. In this way, we assume that $\rho_{suc} = \rho_{unsuc} = 0.5$, approximate to an equilibrium state.At this point, the quality of the pass is equal to half the number of passes made by a player, i.e.

$$\forall 1 \leq i, j \leq n, m_{ij} = \frac{1}{2} d_{ij} \tag{3}$$

Note that there is only a two-fold relation in the numerical approximation, and the actual meaning of the expression is different.

4.1.2 The Tacit Understanding Degree

In a football match, the formations vary a lot. We believe that the dyadic configurations in a team is more about the relationship between two players (such as trust), which is reflected by the quality of passing.However, the triadic configurations pays more attention to the relationship mode of team cooperation, which has more practical significance for tactical adjustment.Therefore, we define a new indicator, the degree of tacit understanding, to identify the ternary structure of the team.

The degree of tacit understanding reflects the degree of cooperation between the players.The way to win in football is to kick the ball into the other team's goal.Obviously, the ball goes through a series of passes before it hits the net (the ball is always in the hands of the team).The task requires us to find triadic configurations, so we only consider three consecutive passes.Let the three passing players be $P1, P2$ and $P3$, and their passing coordinates are $P1(x1, y1), P2(x2, y2)$ and $P3(x3, y3)$.So the tacit understanding degree can be expressed as

$$f(x_1, y_1, y_2, x_3, y_3) = \alpha * (|y_2 - y_1| + |y_3 - y_2|) + \beta * (x_3 - x_1) + \gamma * (x_3 - 50), \quad (4)$$

with $0 < \alpha, \beta, \gamma < +\infty$. α and β represent the weight of the deviation in the y direction and the deviation in the x direction in the tacit understanding. γ represents whether the pass crossed the center line. We tried several pairs of values and found that the variation of α, β and γ had little effect on the level of agreement.Therefore, take the equation of $\alpha = 1, \beta = 0.1$ and $\gamma = 5$, which is intuitive and convenient for calculation.

4.1.3 Total Tacit Understanding Degree

We filter out all eligible coordinates from the given data, *passingevent.csv*. We enumerate all the three cross combinations, in order to calculate their total tacit understanding degree F:

$$F = \sum_{i=0}^{k} f(x_1, y_1, y_2, x_3, y_3), \quad (5)$$

with $k \geq 0, k \in \mathbb{Z}$. k represents the total number of passes made by the trio.

4.1.4 Time

During a match, time can affect a player's performance.For example, in the first half of the game, the players are energetic, so they mainly attack.They went into defensive mode in the second half due to lack of energy.Therefore, we set up three time periods, namely the first half, the second half and the full court, according to the existing length system in football matches. We also update the different network models of the two models in three time periods and the network structure embodied by them.

4.2 The model results and analysis

According to the above factors, in the dyadic configuration, the value of edge weight is passing quality.

With the degree of total tacit understanding as the edge weight, we establish the network model under triadic configurations.At the same time, we sorted the identified three groups according to the descending order of total tacit understanding, and defined the top 10 groups as the three-way structure required in the task.

Thus, two network models of dyadic and triadic configurations are established respectively.

4.2.1 Dyadic Configurations

We set up the following network model with players as nodes and passing quality as edges.

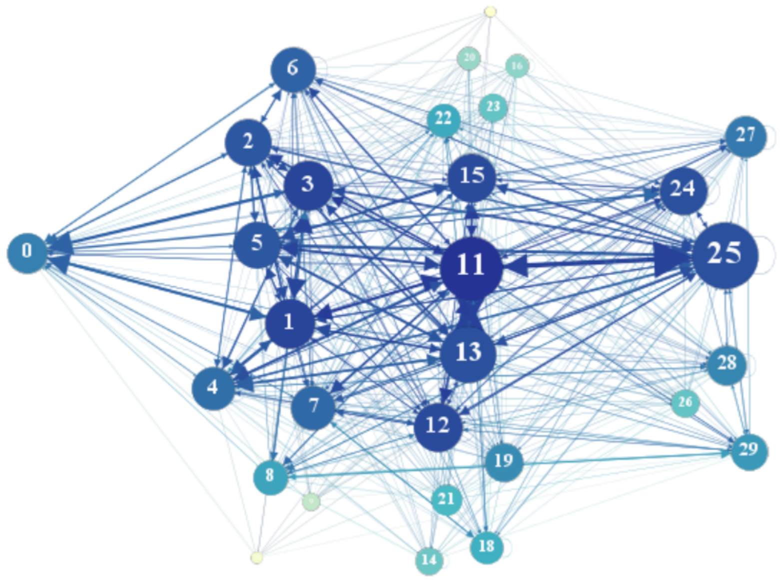

Figure 2: The network model corresponding to the dyadic configurations.

The graph shows only the relationships between players who are close to each other.We renumber each player, and the corresponding relationship between the number on the node and the player is shown in the appendix. Gray edges indicate a close relationship, but do not yet constitute a strong binary relationship.The black edges are combinations of dyadic configurations found in experiments.The thickness of the line represents the intensity of the relationship, and the thicker the line, the tighter the relationship.

Based on the analysis of the influence of the dyadic configurations on tactics, the following conclusions can be drawn:

1. The core of the team's offense is player 25 (Huskies_F2), who has a close

dyadic configuration with most centers.

2. Player 24 (Huskies_F1) is good at catching long passes from the goalkeeper.
3. The strongest relationship is the dyadic configuration between player 11 (Huskies_M1) and player 25 (Huskies_F2), reflecting the core status of player 25 (Huskies_F2).
4. It can be seen from the data that the binary relationship between player 11 (Huskies_M1) and player 13 (Huskies_M3) is strong, indicating mutual trust between the two players.

4.2.2 Triadic Configurations

We set up the following network model with players as nodes and tacit understanding as edges.

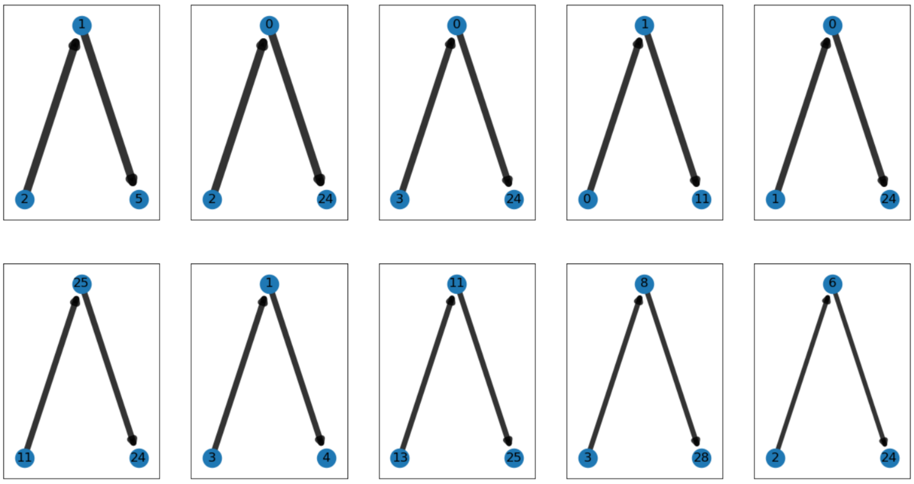

Figure 3: The network model corresponding to the triadic configurations(the full court).

Considering the influence of time, we also separately analyzed the first and second half.

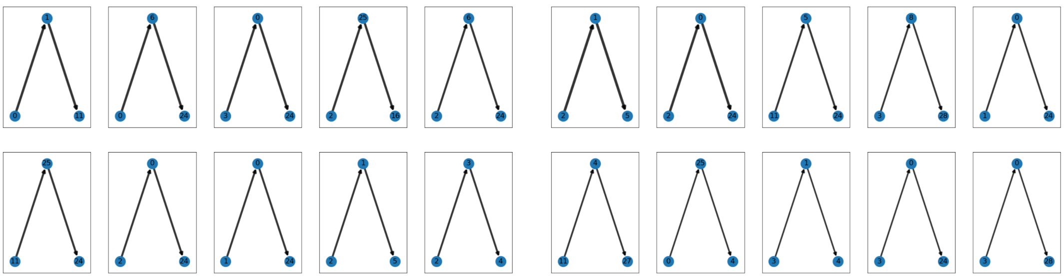

Figure 4: Network model of first (left) and second (right) half court.

The figure shows the top 10 strongest combinations of ternary relationships found during the experiment.The thickness of the line represents the intensity of the relationship, and the thicker the line, the tighter the relationship.

Based on the analysis of the influence of the triadic configurations on tactics, the following conclusions can be drawn:

1. The forward rush is mainly done by defenders (players 1, 2 and 3) - goalkeepers (players 0) - players 24 (Huskies_F1).
2. There is some center - center - forward and center - guard - forward coordination, but there is no direct coordination between center and forward.
3. There were 6 triples in the first half and the whole game, and there were 6 triples in the second half and the whole game, indicating that the whole team did not change much in tactics during the half-time break.

5 NPC: Probability Transition and Characterization

5.1 The factors in Probability Transition and Characterization

There are many ways to evaluate a team's cooperation. We have summarized the three most important factors: group dynamics, offensive efficiency and cooperation level.

Among them, group dynamics focuses on the effect of individual performance on overall performance. Offensive efficiency is measured by the performance of the team as a whole. Cooperation level focuses on the effect of the 'golden partner' on the team's performance.

5.1.1 Group Dynamics

According to the theory of group dynamics, a person's behavior (B) is the result of the interaction between internal needs (P) and external environmental forces (E), which can be expressed by the formula

$$B = f(P \cdot E). \tag{6}$$

It discusses the effects of various forces in a group on individuals.[3]

We believe that on the football field, intrinsic needs are reflected in the pursuit of individual performance of players, while the environmental factors include the trust of teammates and the influence of home and away.

So, for P, we're going to use the total number of passes per player.

And E, based on markov model, we set up the passing matrix A_g of n by n, to determine the probability of everyone passing to a teammate.

$$g_{ij} = \frac{d_{ij}}{\sum_{k=1}^{n} d_{ik}} \tag{7}$$

with $1 \leq i, j \leq n$. n represents the total number of players on a team. Note, $\sum_{k=1}^{n} g_{i,k} = 1$ Finally, we calculated the team's trust in player i:

$$r_i = \sum_{k=1}^{n} g_{ji} \tag{8}$$

Degree of trust r operates directly on E.

The B on the left-hand side of the equation represents the behavior of each player.So the relationship between B and P and E is exactly

$$B = \frac{P \cdot E}{n} \tag{9}$$

with n represents number of players on the field.

5.1.2 Offensive Efficiency

For a particular game, based on data from *passingevents.csv*, we calculate the number of passes made by players in the game to each other, the number of goals conceded (taking the kick out of bounds and being stolen as an action), and the number of steals per player.

We define the number of passes to each other as c_{ij} to indicate that the player i passes to the player j. We define the number of balls dropped by the player i as l_i and the number of steals by the player i as w_i (number starts from 0).Then we define the pass transition matrix

$$G \in \mathbb{R}^{(n+1)\times(n+1)} \tag{10}$$

with n represents number of players on the field.

$$g_{ij} = \begin{cases} 0 & i = 0, j = n \\ 0 & j = 0, i = n \\ c_{ij} & 0 \leq i < n, 0 \leq j \leq n \\ l_i & 0 \leq i < n, j = n \\ w_j & i = n, 0 \leq j < n \end{cases} \tag{11}$$

Notice that the opponents are treated as a group, not as individuals.

We define the transition probability matrix $P \in \mathbb{R}^{(n+1)\times(n+1)}$

$$p_{ij} = \frac{g_{ij}}{\sum_{k=0}^{n} g_{ik}} \tag{12}$$

Then we do dynamic programming for probability. We define `dp[i]` to represent the expected number of passes from i to the target state. Then we define `dp[i]=0` if i is the target state. The target state in this question is a set of all the forward's player Numbers on the field. From the linear additivity of expectations, we can get

$$\texttt{dp[i]} = \sum_{j=0}^{n} \texttt{dp[j]} * p_{ij} + 1 \tag{13}$$

And let's turn this into an equation:

$$(1 - p_{ii})\texttt{dp[i]} - \sum_{j=0(j \neq i)}^{n} \texttt{dp[j]} * p_{ij} = 1 \tag{14}$$

Now, let's turn this equation into a linear equation and solve it. If the player with the number i is the forward, then $f_i = 1$, otherwise $f_i = 0$. For the newly added node n, we define $f_n = 0$. And then we define the linear equation $A \in \mathbb{R}^{(n+1)\times(n+1)}$, $b \in \mathbb{R}^{n+1}$

$$a_{ij} = \begin{cases} 0 & i \neq j, f_i = 1 \\ 1 & i = j, f_i = 1 \\ 1 - p_{ij} & i = j, f_i = 0 \\ -p_{ij} & i \neq j, f_i = 0 \end{cases} \tag{15}$$

$$b_i = \begin{cases} 0 & f_i = 1 \\ 1 & f_i = 0 \end{cases} \tag{16}$$

Let the solution of gaussian elimination be x, then $\texttt{dp[i]} = x_i$.

From the above calculation process, we can draw a conclusion:

- The lower the value of `dp[i]`, the faster the player can find a forward.So the smaller the `dp[i]`, the more efficient the player is.That is, except for the goalkeeper, the offensive efficiency of a player is inversely proportional to its corresponding `dp` value.
- For a goalkeeper, the lower his offensive efficiency, the better the team's offensive efficiency.

5.1.3 Cooperation level

In the first question we have identified the top 20 dyadic and triadic configurations.In this problem, when analyzing the game data given, we counted the number of appearances of each of the 40 combinations and added up the scores of each combination when they played.

5.2 The performance indicators

We quantified the above three factors and obtained three groups of scores, which were shown as personal score, expected passing score and teamwork score.

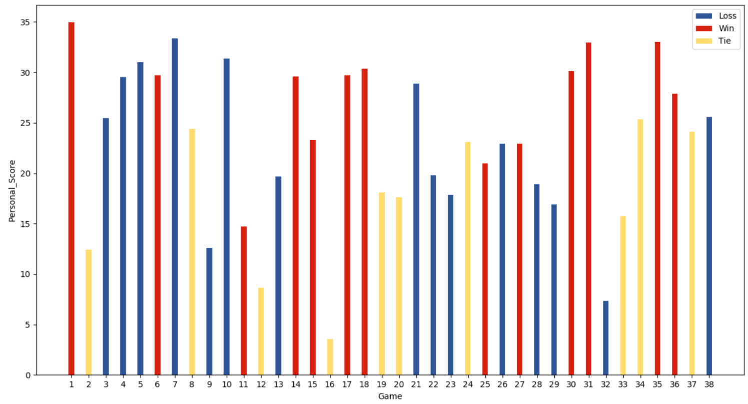

Figure 5: The personal score

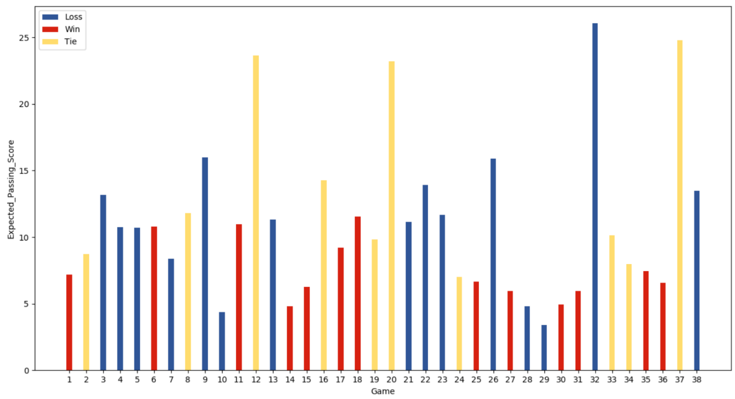

Figure 6: The expected passing score

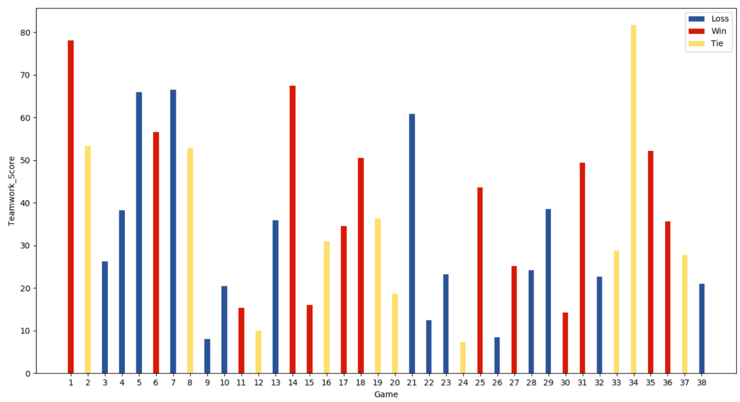

Figure 7: The teamwork score

For the scores of these three groups, we conducted a series of Linear Regression analysis, and obtained the respective weights of the three factors,η_1, η_2, η_3.

	Corresponding relations	Value
η_1	Group Dynamics	0.71
η_2	Offense Efficiency	-0.69
η_3	Cooperation Level	0.2

η_2 is negative because the expected time between a player and a forward on a team calculated by Offensive Efficiency is inversely related to the result of the game.

We defined the constants k_1, k_2. k_1 represents the influence of home and away teams and coaches on the indicators.k_2 is an offset, just to make sure that the end result is not negative.

So the end result is

$$S = \eta_1 \times GroupDynamics + \eta_2 \times OffenseEfficiency + \eta_3 \times CooperationLevel + k_1 + k_2. \tag{17}$$

The corresponding chart is

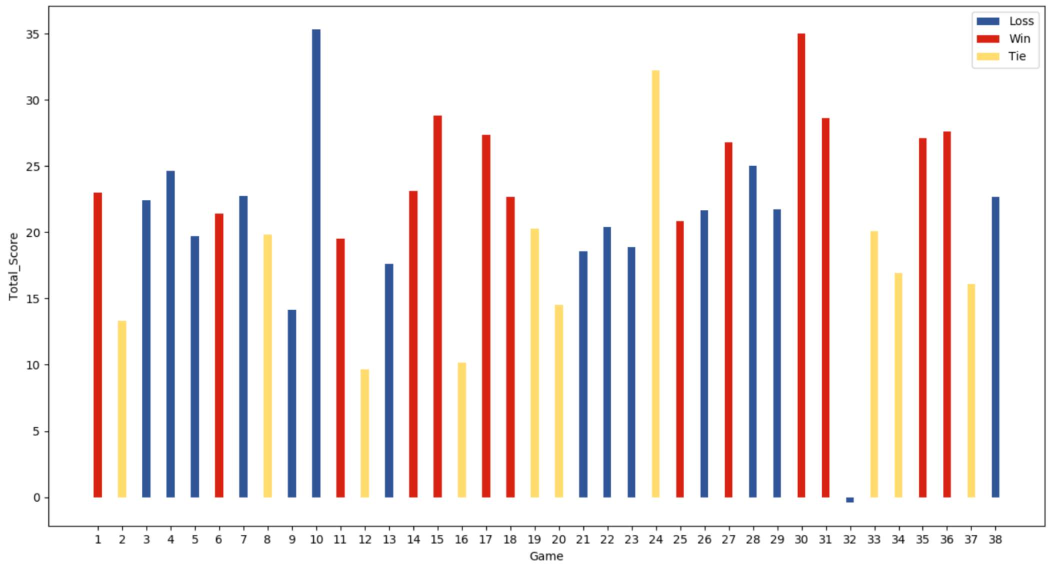

Figure 8: Total performance indicators score

6 Recommendations for better performance

We analyze the conclusion in previous problem and find that part of the data was inconsistent with the intuitive understanding. In theory, for example, a team should perform well in a game when it scores high on all three of the above questions. And vice versa.However, there are two extreme cases in the actual situation. (1) The team scores low in all three aspects, but still wins the game (opponent 11).(2) The team scored well on all three fronts, but still lost the game (opponent 15).

In this case, we consider the effect of the opponent's strength on the final result of the match.Through the analysis of the results of the game, we subjectively divide the opponents into three categories according to their strengths: simple, general and difficult. Without the two extremes of 'simple' and 'difficult', we take opponent 16 as an example to analyze the factors that affect the winning or losing of a match.

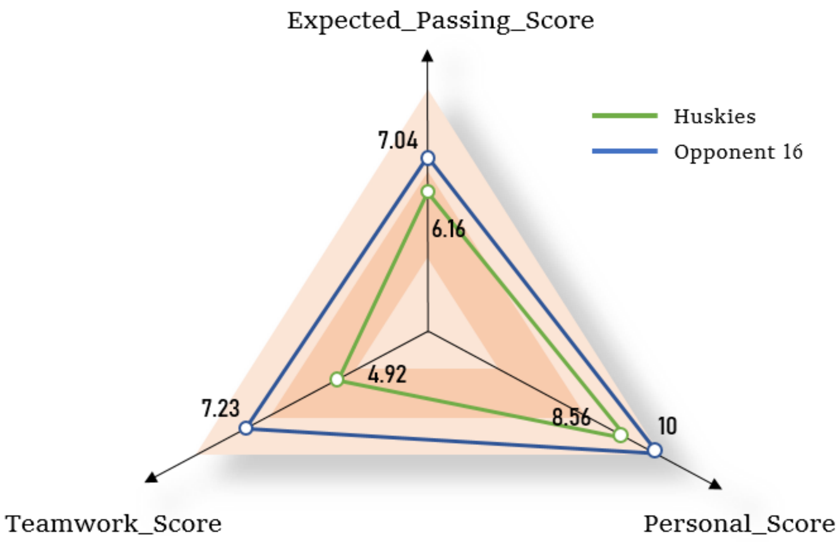

Figure 9: Radar chart of huskies vs Opponent 16

6.1 Efficient teamwork structure strategy

From the data of the match against opponent 16, it can be concluded that:

1. It could be seen from *Personal_Score* that players had a small number of passes, and *Excepted_Passing_Score* could be used to analyze the team's low possession rate, which also affected the cooperation between the teams to some extent, resulting in the poor performance of the whole game.

2. Although the opponent scored higher than Huskies in every aspect, *Excepted_Passing_Score* was still not ideal in the case of full score for *Personal_Score*, indicating that although the team had a high ball control rate and every player played a certain role on the court, the attack rhythm was slow and there was no way to form an effective attack.

3. The analysis shows that the opponent is a defensive team, and better results can be achieved by strengthening the cooperation between offense and players.

The above strategies summarize the strategies used against a team.Effective strategies are not set in stone. For an opponent of equal strength, the team should adjust its strategy according to the opponent's tactics.

6.2 Best team configuration

According to large sample theory, we can use the data of the passing network approximation to get two passing probability matrix between the two players, each based on a certain team asked to choose 11 players, the probability transition matrix between 11 players use their passing between two approximate fitting probability transition matrix, at the same time can also be a similar method approximate passing network, so that we can go to assess the team.

Next, we combine a picture to illustrate:

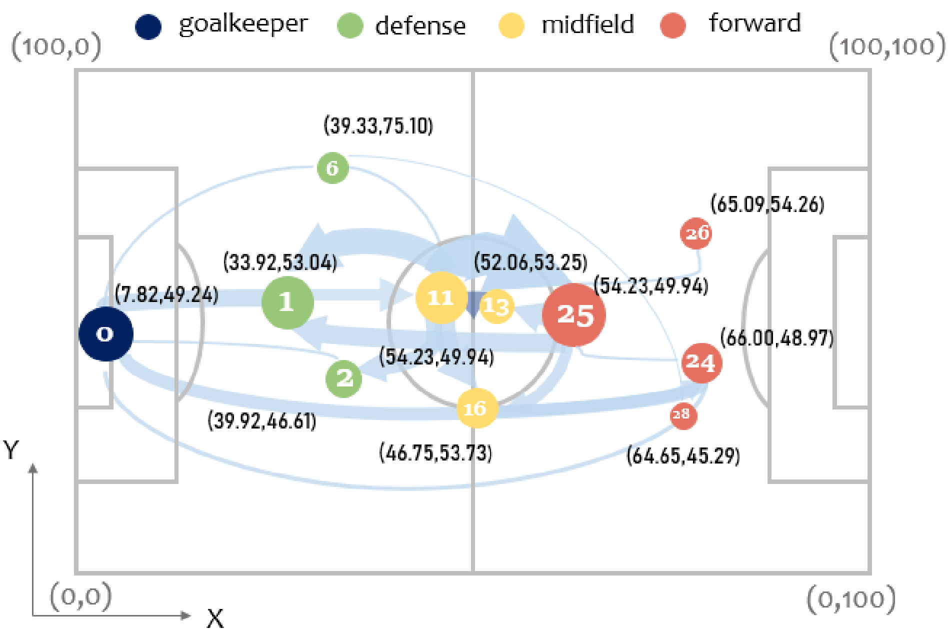

Figure 10: Strategy diagram

The picture shows the personnel of the best team and the distribution map of the team. In the picture, the coordinates are the average position of players based on the existing data. The thickness of the edge between nodes shows the degree of cooperation between players.

6.3 Suggestions for the future

Based on the existing opponent data, we can estimate the approximate strength of the opponent by bringing them into the network model.Here we estimated the opponent's *teamwork_score*.

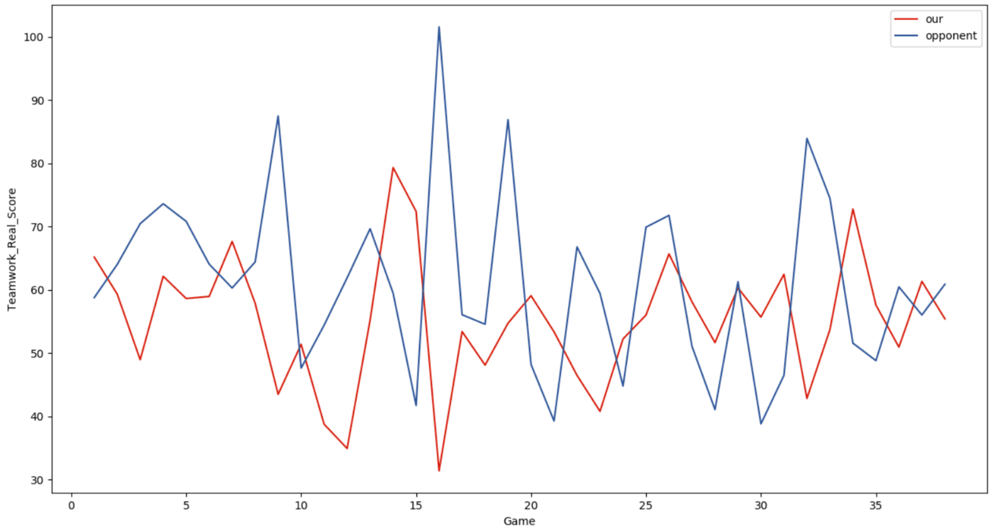

Figure 11: The opponents teamwork score

As can be seen from the figure, Huskies are not as tactically attuned as the other team in 23 of the 38 matches, so try to use more ternary structure to form a significant tactically attuned team later in the match.

All in all, Huskies should consider three dimensions of strength for a comparable opponent and measure what proportion maximizes the value of the team.For strong opponents, the Huskies should focus on more basic skills, such as physical strength.The Huskies cannot afford to be complacent about their weaker opponents, lest they lose the match by underestimating them.

7 More thoughts on the team model

7.1 Model Validation in Group Dynamic view

Group dynamics deals with the attitudes and behavioral patterns of a group. Group dynamics concern how groups are formed, what is their structure and which processes are followed in their functioning. Thus, it is concerned with the interactions and forces operating between groups[5].

The principle of Group Dynamics contributes to the application of social network analysis. Thus, in our paper, we taken into full account the possible factors in the establishment of the evaluation model in this paper.

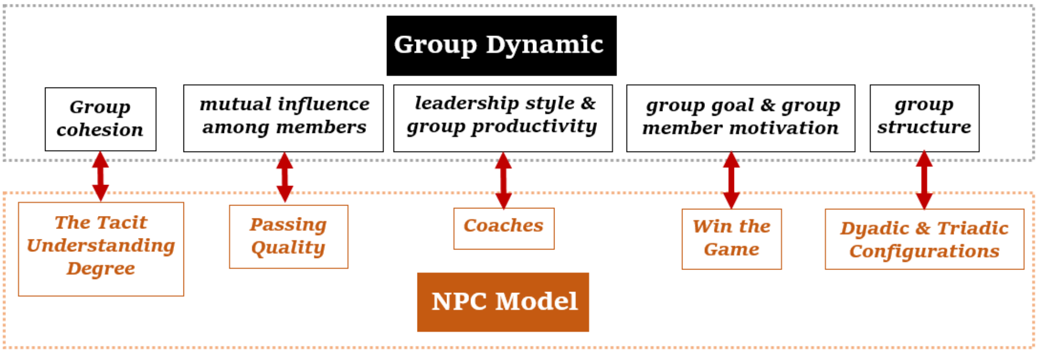

Figure 12: Some of the indicators in the NPC model correspond to the group dynamics

7.2 Restate the factors that influence group performance

We mainly discuss the influencing factors from the perspective of group dynamics.

1. Group decision
   A successful team is far more than the sum of each individual part. The game can usually achieve unexpected results if we analyze the member structure and the cooperation level of the members to reasonably arrange a game.

2. Group Norms
   Norms define the acceptable standard or boundaries of acceptable and unacceptable behavior, shared by group members. Making regulations for the team to exert pressure on the team stimulates members to maximize their performance. Meanwhile, the formulation of rules can also restrain the bad behavior of the team members and encourage them to develop towards the excellent tendency.

3. Leadership level
   When the team lacks a strong leader, the more dominant members of the team can usually take charge of the whole team. This can lead to a lack of direction or a focus on wrong priorities.

7.3 Further Discussion for Model Extension

We tend to explore how to maximize the value of teamwork. Excellence Performance means that the model has a high degree of flexibility and adaptability, and can be well-used in ordinary work situations.

However, in real world, this kind of universal model is often not universal. At the end of the day, the problem is the factors. This is not because the models are not comprehensive, but because these factors are often culturally diverse and difficult to quantify by a universal set of criteria. Therefore, if we want to develop a truly universal model, we should focus on the cultural diversity of various factors. The culture mentioned here can range from national and national culture to enterprise culture and office culture. In different cultural environments, each factor has a different influence on the model. Therefore, a good model should identify the characteristics of each culture and develop corresponding weight algorithms.

8 Conclusions

In our paper, we use the NPC model to evaluate the situation of a football match. First, we set up a passing network to discover the Dyadic Configurations and Triadic Configurations of the whole team, so as to discover the strategic coordination of the whole team. Then, for a given match, we can calculate the Group Dynamics and Cooperation Level of the whole team. Second, we build a pass-probability model, and using the markov property, we can calculate the team's Offensive Efficiency. In the whole process of analysis and solution, a large number of group dynamics analysis was applied, and Lewin's formula $B = f(P \cdot E)$ was used to analyze the influence of individual ability and external factors on individual performance.

9 Strengths and weaknesses

9.1 Strengths

- Our model is versatile and able to adjust to different scenarios based on the real situation.
- The running speed of our programs are fast, so the coach can keep updating the data in the program to get the latest results.

9.2 Weaknesses

- In order to simplify the calculation, we did not take into account the impact of the number of shots on the result. In fact, we know that the number of shots scored has an impact on the outcome of a game, but we believe that the Offensive Efficiency model we calculated will somehow reflect the number of shots scored, even though the correlation is low.

- We didn't take into account the movement of each player throughout the game in the model.

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Appendices

Appendix A The players' information

Team Player Id	Player Id in our Model	Team Player Id	Player Id in our Model
Huskies_G1	0	Huskies_D1	1
Huskies_D2	2	Huskies_D3	3
Huskies_D4	4	Huskies_D5	5
Huskies_D6	6	Huskies_D7	7
Huskies_D8	8	Huskies_D9	9
Huskies_D10	10	Huskies_M1	11
Huskies_M2	12	Huskies_M3	13
Huskies_M4	14	Huskies_M5	15
Huskies_M6	16	Huskies_M7	17
Huskies_M8	18	Huskies_M9	19
Huskies_M10	20	Huskies_M11	21
Huskies_M12	22	Huskies_M13	23
Huskies_F1	24	Huskies_F2	25
Huskies_F3	26	Huskies_F4	27
Huskies_F5	28	Huskies_F6	29