Original Research Article

Tactical Analysis Through Objective Data in Football

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Abstract: Tactical analysis in football has rarely been conducted using a mathematical model with numerical data (although tactical analysis through objective data has been used more often). Therefore, this study establishes principles for tactical analysis in team sports using numerical data, through a mathematical model based on the location of the players and the ball. A competitive match between Sanfrecce Hiroshima (home) and Ehime FC (away) in the third round of the Japanese Emperor's Cup 2011 was filmed and used for the match analysis. Observations were made by a team analyst as well as extracted from official match records. The main procedure in the research flow was to establish a mathematical offence/defence model based on tactical concepts in football, which was applied for the location of players, which, in turn, was quantified from video images in order to categorise a team's tactical performance (in relation to attacking or defending). Furthermore, the authors focused on attacking categories and identified different types of passes during a specific period, as well as comparing these findings with an actual match video. The results obtained from the numerical data derived from applying the offence/defence model led to the same overview as the tactical analysis produced by a team analyst. In addition, the results when categorising types of passes (as extracted through the mathematical model) again mirrored those retrieved from an actual match video. This leads to the conclusion that the offence/defence model could provide relevant insight into types of attacks. The data revealed that football tactical analysis can be successfully performed using a numerical model, which might possibly enable automatic tactical analysis of football games without a match analyst.

Keywords: Football Tactics; Numerical Data; Mathematical Model; Team Sports

1. Introduction

In order to improve a team's performance and results in football, logical and effective training is required to prepare players so that they can perform to the best of their ability[1]. It is important to analyse one's own tactics and

those employed by opposing teams in order to establish logical and effective training. Indeed, this study builds on the premise that tactical analysis of one's own team and opposing teams is an essential element to improve a team's performances and results in football. Particularly in training of team sports, including football, it is crucial for a team to have purposeful and logical criteria in order to gain a mutual understanding of a game's situation[2]. Therefore, using objective data such as numerical location data for players and the ball during a match could be useful as one of the resources to create such criteria and to ensure an objective tactical understanding of a football game.

The adoption of information technology in team sports has increased significantly in recent years, and the use of objective data has become common in sports at the highest levels[3]. Particularly in football, the usage of objective data by professional teams for tactical analysis has expanded in various ways[4,5], which is influenced by business elements[6]. One example entails setting up cameras at a stadium to create a tracking system*[1], which involves capturing the players' movement as location information, for the purpose of improving players' performance[7]. Furthermore, such data is also used to produce valuable information for fans and spectators[8]. The use of such numerical data has an impact on sports analysis and its implications for training and performance[9].

In the analysis of a football game, everything occurring in the play can be translated into numerical data by considering "who" and "where" in terms of three-dimensional spatial coordinates and adding the ball's location[10]. In recent years, a framework has been established to objectively analyse and evaluate players' physical performance[11]. However, the usage of this data can be further developed to improve game analysis[12]. Furthermore, the interpretation of numerical data has been entrusted to analysts with expert football knowledge. This data has, for the most part, been used to analyse players' physical performance, but rarely for the tactical analysis of games[13]. When it has been used for the tactical side of game analysis, such objective data has frequently been used together with the match record and video.

Therefore, the current research aimed to establish the foundations of an analytical method for football tactics using numerical location data and a mathematical model. To achieve this purpose, the authors attempted to establish a method to analyse a football match, attuned to tactical elements, with numerical data on the three-dimensional location coordinates of the players in relation to the ball. The objectives of this research were 1) to develop better-structured tactical concepts in football and 2) to establish a mathematical model based on such concepts and applicable to numerical data.

2. Method

2.1 Participants

The sample match used for this study was the encounter between Sanfrecce Hiroshima (home) and Ehime FC (away) at EDION Stadium, Hiroshima on 11 November 2011, in the third round of the Japanese Emperor's Cup 2011. Ehime FC won the match 1-0 (0-0 at half-time). Only the first half, which lasted 45 minutes and 27 seconds, was subject to analysis.

The Ehime University Research Ethics Committee approved the use of human subjects in this research for the purpose of collecting and statistically analysing data, according to the Declaration of Helsinki. The authors obtained permission from the Hiroshima Prefectural Football Association and the J.League, as well as Sanfrecce Hiroshima and Ehime FC.

2.2 Equipment and instruments

The match was filmed using two SONY DCR-TRV70 video cameras, in full HD (1,920 × 1,080) and at 30 frames per second (fps). The tracking data was obtained at 5fps. The two video cameras were synchronised using an LED-type synchroniser (DKH, PTS-110), and three-dimensional analytical software (MP Japan, Tomoko-VM) was used to obtain the coordinate data of the 22 players and the ball.

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[1] Tracking is a data coding mechanism for players, referees and the ball making use of a special camera and computer software.

2.3 Procedures

The main procedure in this research was to establish a mathematical "offence/defence model" based on tactical concepts in football. This involved conducting basic game analysis with numerical data in order to determine the team's situation (attacking or defending)[14].

First, an interpretation of tactical concepts in football was identified with a view to establishing an appropriate mathematical model. Second, tactical analysis in relation to possession of the ball was considered. Third, an offence/defence model was established. Finally, tactical game analysis using the offence/defence model was compared to the results from manual input completed by an individual observing the match in relation to the following metrics: total attacking time, average duration of attack, number of attacks and maximum and minimum duration of attack. The research flow is detailed in **Figure 1**.
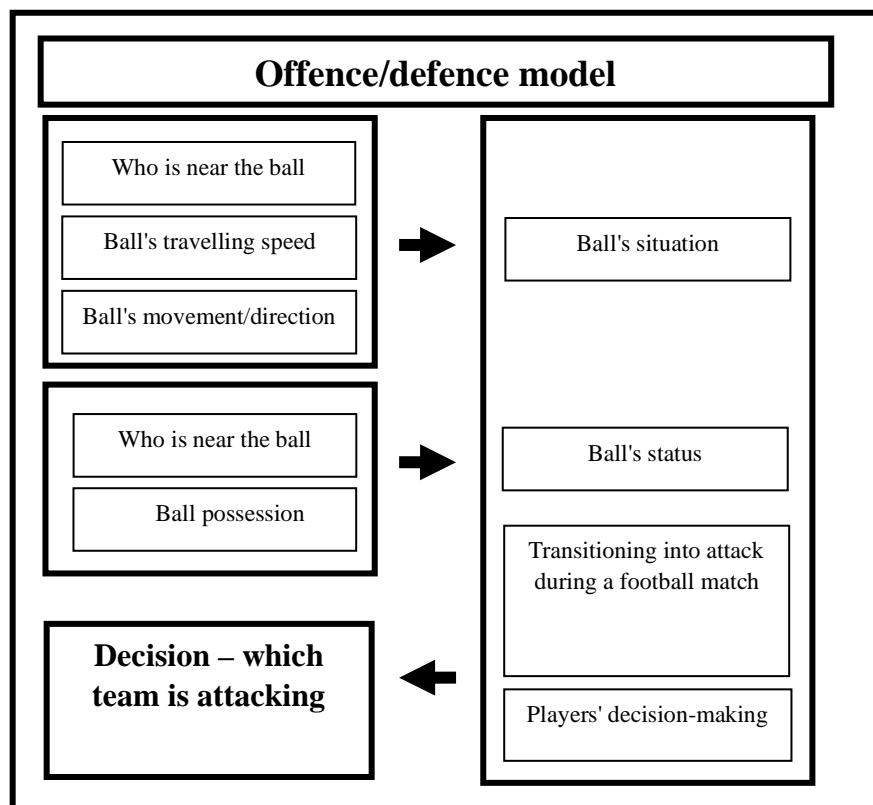

Figure 1. Research flow.

2.3.1 Interpretation and mathematical modelling of tactical concepts in football

This study focused on team tactics in football, covering both the offensive and defensive phases of the game. It explored tactical precepts as logical concepts based on the interpretation below.

In the long history of football tactics, principles of attack and defence have been established through years of analysis and play. In other words, the essence of the game can be said to be the relationship between attacking and defending[15], and it can be considered that tactical concepts in football have developed dialectically through playing experiences[16].

Data is presented numerically and represents the (dynamically changing) locations of players and the ball in the spatial coordinates (configuration space) at certain moments in the match. To structure such data by the team values tactically, tactical concepts must be converted into a mathematical model capable of analysing numerical data. This study aimed to optimise a mathematical way of thinking, such as modelling, to expand logical thinking for tactical concepts, and to provide a framework for the tactical analysis of games.

2.3.2 A framework for tactical game analysis and interpretation of ball possession

Wade[17] showed the team playing principle by capturing the situation in attack and defence on a pitch from a team's tactical point of view (see **Figure 2**).
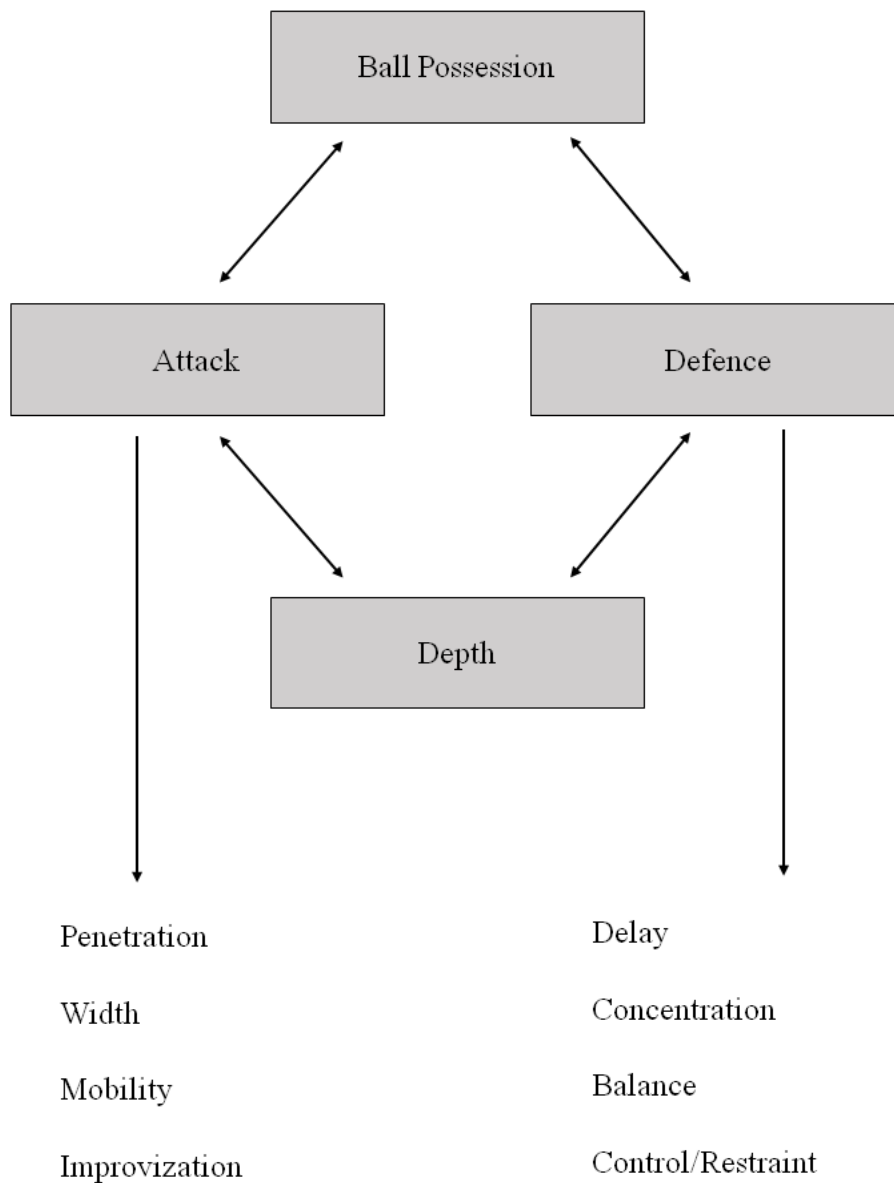

Figure 2. Depth in attack and defence[17].

Worthington[18] provided an overview of the playing principle and players' functions from a collective tactical point of view (see **Figure 3**).
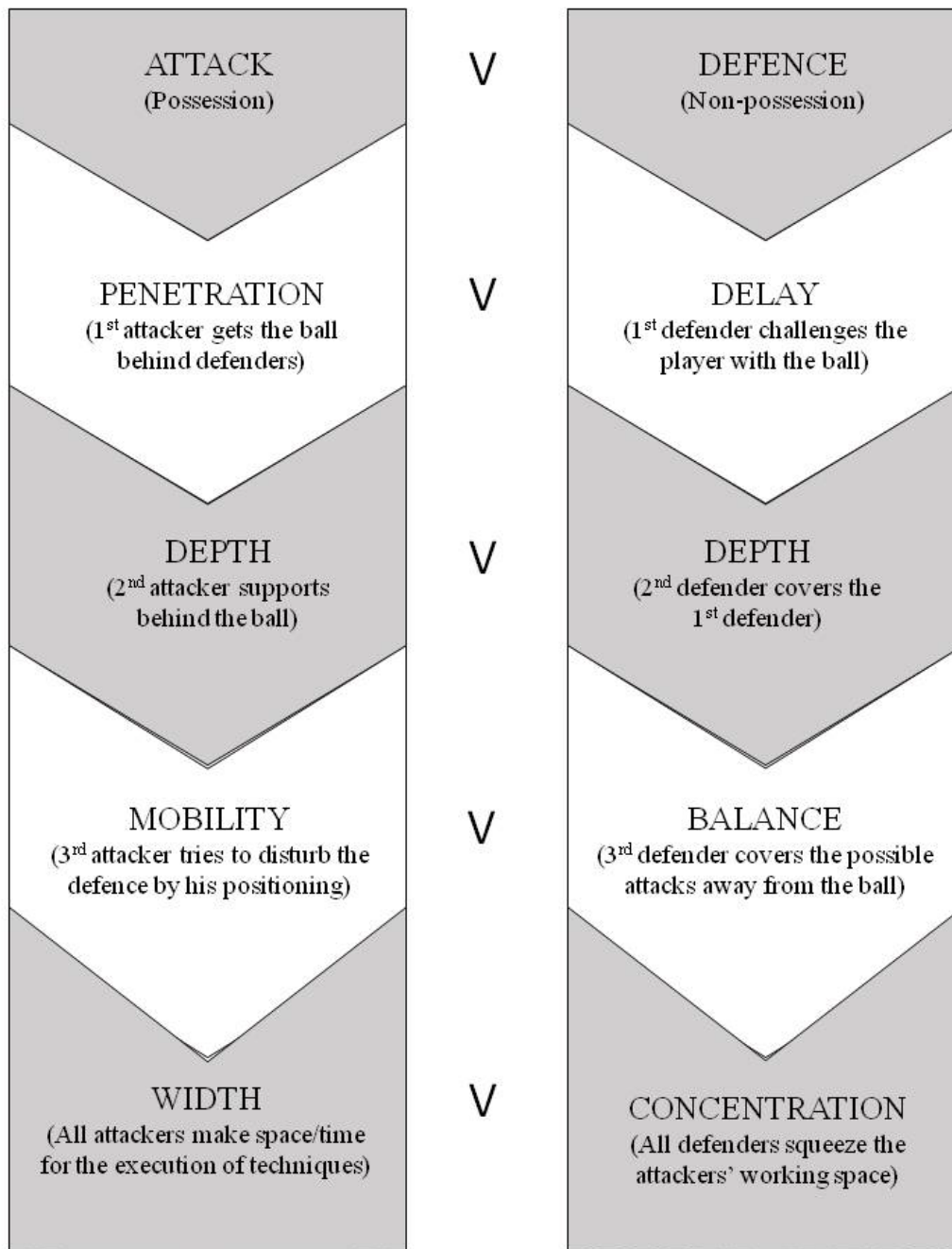
ATTACK (Possession)	V	DEFENCE (Non-possession)
PENETRATION (1st attacker gets the ball behind defenders)	V	DELAY (1st defender challenges the player with the ball)
DEPTH (2nd attacker supports behind the ball)	V	DEPTH (2nd defender covers the 1st defender)
MOBILITY (3rd attacker tries to disturb the defence by his positioning)	V	BALANCE (3rd defender covers the possible attacks away from the ball)
WIDTH (All attackers make space/time for the execution of techniques)	V	CONCENTRATION (All defenders squeeze the attackers' working space)

Figure 3. The principle of play and summary of the main functions of players[18].

Similarly, Takii[15] explained that football can ultimately be boiled down to two situations, attacking or defending, which are defined by possession of the ball. Wade and Worthington concluded, as outlined in the models above, that attacking and defending principles revolve around what players should do once in possession of the ball and what defending players should do after losing the ball, with a tactical decision being made depending on the team in possession.

In other words, in conducting tactical analysis, ball possession could be the basic information to predict players' tactical movement. The main factor determining players' movement is whether a team is attacking or defending, and players should strive to efficiently break the lines or to prevent the opposition from doing so in order to score goals or defend the goal.

When conducting a tactical analysis of a match, a team analyst usually watches the match, judges when a team is attacking or defending, and divides the match into spells of attacking or defending, breaking down the duration of each attack. Moreover, the team analyst often analyses the tactics based on the team's playing style and long-term coaching

plan. A key part of the team analyst's task involves attempting to clearly identify which team is in possession of the ball. Therefore, it could be anticipated that the team analyst intuitively understands the ball's movement and the situation around the ball. This means that the analyst assesses players' tactical movement on the pitch by gauging the ball's movement and the situation around the ball, and judging whether teams are attacking or defending.

Accordingly, the authors attempted to establish a method to analyse game tactics in football, starting by mapping the ball's movement and the situation around the ball, emulating the tactical game analysis conducted by a team analyst intuitively. The authors then proceeded to interpret ball possession from the viewpoint of "which player on which team the ball can be attributed to", rather than "which player on which team is in control of the ball".

2.3.3 Filming methodology

The match was filmed by two cameras using the direct linear transformation (DLT) method to obtain the location information of players and the ball during the match. The two cameras were stationed in the stands of the stadium, with a 70° filming angle, and filmed the whole match at 30Hz. Each camera was positioned so as to be able to film the same reference points, such as the goals and the intersection of the touchline and goal line (see **Figure 4**).
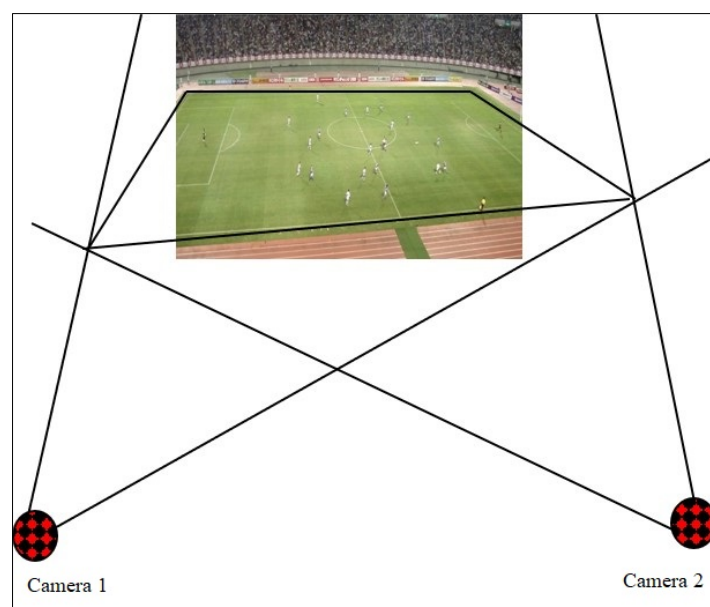

Figure 4. Cameras' angle.

The images were converted from 30fps to 5fps. The tracking data (numerical data) was obtained using video editing software and by manually clicking the location of players and the ball on a screen for each frame. The data is different from usual tracking data, in that it includes the location data of not only players but also the ball. Usually, the location data for the ball involves where the ball is when the players have it under control. However, the data used in this current research could contribute to furthering tactical game analysis using numerical data by making it possible to 1) analyse the locations of the ball when it is in motion and 2) convert the locations of the ball into numerical data, to be applied to tactical analysis.

2.3.4 Capturing objective data (location data)

The images recorded by the two digital cameras were digitalised per 0.25 seconds and transferred to a computer. The coordinated data for 22 players and the ball (x, y, z) was obtained using the three-dimensional analytical software. In the process, a point on players' waist was digitalised. The three-dimensional coordinates were set with the x-axis being parallel to a touchline, the y-axis being parallel to a goal line and the z-axis being the vertical direction. For calibration purposes, the intersection points of the touchlines and goal lines, and 5m-high calibration poles set on the intersection points, were used as the coordinate points. The measurement error for the DLT method was 0.01m on the x-axis,

0.02m on the y-axis and 0.02m on the z-axis.

2.3.5 Data obtained through observation

The same match was observed to manually judge attacking or defending and to calculate the total attacking time, average duration of attack, number of attacks and maximum and minimum duration of attack in the first half of the match. The data in **Table 1** was manually recorded by a team analyst. He determined which team was attacking or defending based on the video of the match. **Table 2** shows a sample of the team analyst's event-tagging notes, with data being recorded on a second-by-second basis in accordance with convention for official matches.

Attacking time	Sanfrecce Hiroshima	Ehime FC
Total	18:21	12:04
Average duration	00:10	00:07
Number of attacks	106	101
Maximum duration	00:48	00:36
Minimum duration	00:00	00:00

Table 1. The data determined manually

		H/A	Start	Time	Close	Time	Outcome	Duration
1		H (Ehime)	KO	00:12		00:18		00:06
2		A (Hiroshima)		00:18		00:20		00:02
3		H (Ehime)		00:20		00:22		00:02
4		A (Hiroshima)		00:22		00:26		00:04
5		H (Ehime)		00:26		00:37		00:11
6		A (Hiroshima)		00:37	Throw	00:41		00:04
7		H (Ehime)	Throw	00:48		00:52		00:04
8		A (Hiroshima)		00:52		00:59		00:07
9		H (Ehime)		00:59	Throw	01:07		00:08
10		A (Hiroshima)	Throw	01:21	Throw	01:28		00:07
11		A (Hiroshima)		01:34		02:01		00:27
12		H (Ehime)		02:01		02:21		00:20
13		A (Hiroshima)		02:21	Throw	02:29		00:08
14		H (Ehime)	Throw	02:42	Throw	02:45		00:03
15		H (Ehime)	Throw	02:52		02:56		00:04
16		A (Hiroshima)		02:56		03:20		00:24
17		H (Ehime)		03:20		03:23		00:03
18		A (Hiroshima)		03:23		03:25		00:02
19		H (Ehime)		03:25		03:27		00:02
20		A (Hiroshima)		03:27	GK	03:33	SH	00:06
21		H (Ehime)	GK	03:58		04:04		00:06
22		A (Hiroshima)		04:04		04:24		00:20
23		H (Ehime)		04:24		04:47		00:23
24		A (Hiroshima)		04:47		05:27		00:40
25		H (Ehime)		05:27		05:29		00:02
26		A (Hiroshima)		05:29		05:33		00:04
27		H (Ehime)		05:33		05:50		00:17
28		A (Hiroshima)		05:50	Throw	05:53		00:03
29		H (Ehime)	Throw	05:53		06:19		00:26
30		A (Hiroshima)		06:19		06:43		00:24

Table 2. Sample of the team analyst's manual tagging notes

The events that triggered the start of an attack (kick-off: KO; throw-in: throw; goal kick: GK; free kick: FK) were labelled ''Start''. The events that finished an attack were labelled ''Close''. The time difference between ''Start'' and ''Close'' was calculated as the duration of the attack. The outcomes of the attacks – a shot (SH) and a goal (GOAL) – were noted in the relevant column.

2.4 Statistical analysis

The offence/defence model was applied to the data obtained, with the objective of determining which team was attacking or defending during the match. The authors attempted to provide an overview of the match with the results from the collected data for the above-mentioned metrics: total attacking time, average duration of attack, number of attacks, maximum duration of attack and minimum duration of attack.

The outcome was analysed using the game summary which was drawn up, along with the official match record and comments from the respective head coaches. Furthermore, the results derived from the offence/defence model were

compared with those yielded through observation in terms of the tactical overview.

2.5 Constants and variables

By applying the offence/defence model to the obtained location data, the total attacking time, average duration of attack, number of attacks, maximum duration of attack and minimum duration of attack were calculated. In the calculation, the constant "$shot_b$" was set as 7.0m/s and the "$angle_b$" was set as 30°. The vicinity of the ball was set as a circle with a radius of 2m because the average height of football players in the Japanese top division (J.League 1) is 1.782m according to the official J.League website[20].

2.5.1 The offence/defence model

Location data was produced at every moment throughout the match, with attacking or defending expressed according to the constantly changing dynamics of the game. Therefore, a model was structured in the following order: 1) first, which team had the ball was determined using location data at a certain moment and 2) next, whether a team was attacking or defending was decided using the information on which team had the ball at a certain moment.

2.5.1.1 Extraction of ball possession at a certain moment

Ball possession was determined based on a combination of 1) the ball's moving speed and changing direction and 2) the number of players within a 2m radius of the ball (*i.e.* in the ball's vicinity) at certain moments. In this research, the ball's situation, $BC(k)$, at the time k was set as follows:

$$
BC(k) = \begin{cases} shot & \left(v_b \geq shot_b \wedge \left| \theta_b \right| \leq angle_b \right) & \rightarrow & \text{Shot and pass} \\ keep & \left(\neg shot \wedge \left| X \right| = 1 \right) & \rightarrow & \text{Dribble} \\ mix\text{--}up & \left(\neg shot \wedge \left| X \right| > 1 \right) & \rightarrow & \text{1v1 situation} \\ others & \left(\neg shot \wedge \left| X \right| = 0 \right) & \rightarrow & \text{Ball free} \end{cases}
$$

Game situation

The radius of 2m, as a constant denoting the vicinity of the ball, was set to reflect the range where a player is able to move within one second while in possession of the ball (*i.e.* dribble). In reality, it will be easier for a player to move in certain directions depending on his/her orientation and the situation around the ball. However, in this study, we did not have data on players' direction, for which reason it was decided to use the aforementioned radius as the vicinity of the ball.

Based on previous research[19], we decided to set the constant for "$shot_b$" at over 7.0m/s and for "$angle_b$" at 30°, taking into consideration the common phenomena occurring on the pitch. X represents a player near the ball, and $|X|$ denotes the actual number of the players around the ball.

$$
BA(k) = \begin{cases} Own(\alpha) & \left(BC(k) \neq shot \wedge \varnothing \neq X \subseteq \alpha \right) \\ Own(\beta) & \left(BC(k) \neq shot \wedge \varnothing \neq X \subseteq \beta \right) \\ Own(\varnothing) & \left(BC(k) \neq shot \wedge o.w. \right) \\ BA(k-1) & \left(BC(k) = shot \right) \end{cases}
$$

Next, possession of the ball, *i.e.* which team (α, β) has possession of the ball at the time k, was defined as $BA(k)$ as follows, including the less clear-cut situations.

Per the above formula, possession was determined when the ball's situation was not "shot". The possession was classified as "own (α)" when the ball's situation was not "shot" and all the players around the ball were from Team α. On the other hand, the possession was "own (β)" if all the players around the ball were from Team β. The possession became "own (∅)" if there were players from both teams, or no players, around the ball.

However, the above definition does not attribute the ball possession when the ball's situation is "shot". Therefore, in such a situation, the possession was determined by going back to the game footage.

In football, attacks can last for sustained periods of time, during which the ball's situation changes through passes between players and through dribbles. Therefore, based on these definitions, we can determine which team is attack-

ing and defending. In the next section, we define the game's situation, attacking or defending, and a team's "attacking scope" in dynamically changing circumstances based on the ball's situation and attribution at every moment.

2.5.1.2 Acquisition of attacking scope amid dynamic action

An attacking transition could be determined based on the ball possession at the moment of a player kicking and receiving the ball. However, it cannot be simply determined from the information at each moment due to possible situations when the ball possession is not clear. Therefore, when the ball possession is clear, it is simply determined that the team with the ball is attacking. In cases when the ball possession is not clear, however, the team that is attacking is determined by looking ahead to the next moment when the ball possession is clear.

$$isOff(k) = \begin{cases} \alpha off & \left(\begin{array}{c} BA(k)=Own(\alpha) \\ \vee \left(\begin{array}{c} BA(k)=Own(\varnothing) \\ \wedge \quad BA(k+m)=Own(\alpha) \end{array} \right) \end{array} \right) \\ \beta off & \left(\begin{array}{c} BA(k)=Own(\beta) \\ \vee \left(\begin{array}{c} BA(k)=Own(\varnothing) \\ \wedge \quad BA(k+n)=Own(\beta) \end{array} \right) \end{array} \right) \end{cases}$$

In the above definition, m and n represent the minimum natural numbers of the future moment when the ball possession could be clear. The relationship between $BA(k)$ and $isOff(k)$ is shown in **Figure 5**.
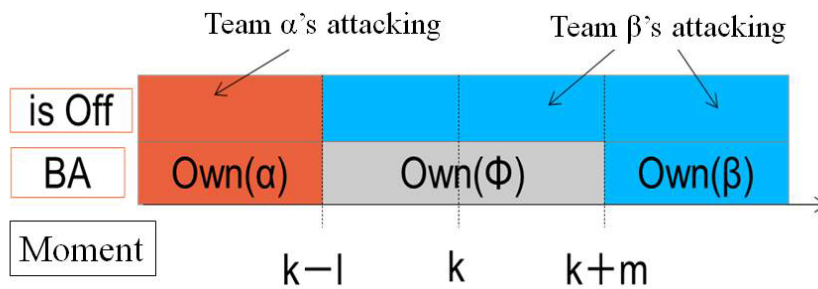

Figure 5. Determination of attacking scope using the offence/defence model.

3. Results and discussion

The offence/defence model yielded the following results for Sanfrecce Hiroshima: 18 minutes 45 seconds for the total attacking time, nine seconds for the average duration of attack, 114 for the number of attacks, 48 seconds for the maximum duration of attack and zero seconds for the minimum duration of attack. The results for Ehime FC were a total attacking time of 12 minutes, an average duration of attack of six seconds, 103 for the number of attacks, a maximum duration of attack of 34 seconds and a minimum duration of attack of zero seconds.

On the other hand, the results that were manually compiled by a team analyst were 18 minutes 21 seconds for the total attacking time, ten seconds for the average duration of attack, 106 for the number of attacks, 48 seconds for the maximum duration of attack and zero seconds for the minimum duration of attack for Sanfrecce Hiroshima. The results for Ehime FC were 12 minutes four seconds for the total attacking time, eight seconds for the average duration of attack, 101 for the number of attacks, 36 seconds for the maximum duration of attack and zero seconds for the minimum duration of attack. These results are shown in **Table 3**.

Attacking time	Sanfrecce Hiroshima		Ehime FC	
	Manual	Model	Manual	Model
Total	18:21	18:45	12:04	12:00
Average duration	00:10	00:09	00:08	00:06
Number of attacks	106	114	101	103
Maximum duration	00:48	00:48	00:36	00:34
Minimum duration	00:00	00:00	00:00	00:00

Table 3. Comparison of the attacking time as determined by the offence/defence model and manually by the team analyst

3.1 Attacking time

In this section, the attacking time obtained using the offence/defence model will be discussed. Sanfrecce Hiroshima's total attacking time was 18 minutes 45 seconds, while Ehime FC's was exactly 12 minutes. The sum of both teams' attacking time was therefore 30 minutes 45 seconds. As the first half lasted 45 minutes 27 seconds, this suggests that about 14 minutes of the half – *i.e.* the difference between the two teams' combined attacking time and the half's duration – involved no attacking action and consisted of what is known in football as ''ball-out-of-play'' situations. These include when the ball is off the pitch and the time until play restarts after a foul or offence is committed. Furthermore, when one team's attacking scope has been established, this confirms that the other team was defending: in other words, one team's attacking time equates to the other team's defending time. The results showed that Sanfrecce Hiroshima attacked for about six minutes more than Ehime FC, which means that the former accounted for 60% of the total attacking time and the latter for 40%. Consistent with the team analyst's findings, the results bore out that Sanfrecce Hiroshima took the initiative and dominated ball possession in the game.

However, Ehime FC won the match by a 1-0 scoreline, demonstrating that having the upper hand when it comes to ball possession during a match does not always lead a team to win. According to the Technical Report for the 2018 FIFA World Cup Russia[21], this point was exemplified by 2018 World Cup winners France, whose average ball possession over the course of the tournament was 48% (20th out of the 32 participating teams).

3.2 Average duration of attack and number of attacks

According to the data obtained through the offence/defence model, Sanfrecce Hiroshima's average duration of attack was nine seconds, while Ehime FC's was six seconds, meaning that, on average, Sanfrecce Hiroshima's attacks lasted three seconds longer.

In terms of number of attacks, Sanfrecce Hiroshima outstripped Ehime FC by 11 (114 to 103). Furthermore, according to the official match record[22], Sanfrecce Hiroshima took 14 shots in the first half, whereas Ehime FC only registered three. This means that Sanfrecce Hiroshima averaged a shot roughly every eight attacks (8.1), compared to Ehime FC's roughly 34 attacks (34.3) per shot. This information supports the conclusion that Sanfrecce Hiroshima took the initiative during the game.

3.3 Comparison with the official match record, coach reactions and other statistics

On the basis of the official match record[22], we can conclude that Sanfrecce Hiroshima took the initiative in the game, having outshot Ehime FC by 23 to 11. Likewise, the Sanfrecce Hiroshima head coach mentioned after the match that his team had taken the initiative and controlled the game, while Ehime FC had focused more on defending and looking to execute their attacking plan by capitalising on their very few opportunities[23].

In addition, the official J.League statistics for 2011 further show that Sanfrecce Hiroshima were successful in taking the initiative in this particular game, having exceeded both their own average number of shots taken per match (13.1)[24] and the average number of shots that Ehime FC faced that season (11.6)[25]. One could therefore consider, without relying on the offence/defence model, that this evidence—the official records and the comments from the Sanfrecce Hiroshima head coach—suggests that Sanfrecce dominated the game.

3.4 Comparison with the results from the observation (manual input)

In the previous sections, the possibility was mooted that the tactical analysis to estimate a game overview could be performed by using data determined by the offence/defence model. In this section, the results respectively obtained using the offence/defence model and manually determined by the team analyst are compared and discussed in terms of attacking time.

Every analyst can hardly be expected to have exactly the same criteria for determining attacking or defending because they make decisions based on football knowledge gained through their own experiences. In other words, each observer interprets football tactics based on his/her distinctive background. Therefore, when comparing the results from the offence/defence model, it was taken into account that the outcomes from the team analyst may be subject to particular trends and a certain amount of bias.

The comparison of the results is shown in **Table 3**. For example, the discrepancy between the total attacking time was 24 seconds for Sanfrecce Hiroshima and four seconds for Ehime FC. Meanwhile, the difference in the average duration of attack was one second for Sanfrecce Hiroshima and two seconds for Ehime FC, and when it comes to the number of attacks, the disparity was eight attacks for Sanfrecce and two for Ehime FC. The results for the maximum duration of attack were the same for Sanfrecce Hiroshima, but there was a difference of two seconds for Ehime FC. There was no divergence for either team in regard to the minimum duration of attack. In sum, there was very little difference in most categories, with the exception of Sanfrecce's total attacking time and number of attacks.

Overall, both game analytic results showed that Sanfrecce Hiroshima took the initiative in the game. Furthermore, the attacking data obtained from the offence/defence model had similar conclusions to those of the team analyst. However, there was a significant difference in the respective figures produced by the team analyst and the offence/defence model for the number of attacks racked up by Sanfrecce Hiroshima.

3.5 Examination of the attacking patterns

As noted, similar numerical data on attacking time was obtained from the offence/defence model and the team analyst. This showed that both methods can potentially provide a similar overview as part of tactical game analysis. However, considering the actual game, we should be able to analyse what shape attacks take at certain times during the game, with reference to the numerical data obtained from the game. Therefore, in this section, the researchers attempted to examine the attacking patterns by picking certain attacks and capturing "Pass" during the periods when a team was clearly in possession of the ball. As explained in the previous section, the situation was defined as "Pass" if the situation during the team's attack was determined as "$shot_b$" (understood as any kick of the ball) by the offence/defence model[26,27]. **Figure 6** shows the movement of the ball during an attack consisting of a string of consecutive passes, to support understanding of the image when comparing the results from the model and the actual video footage.
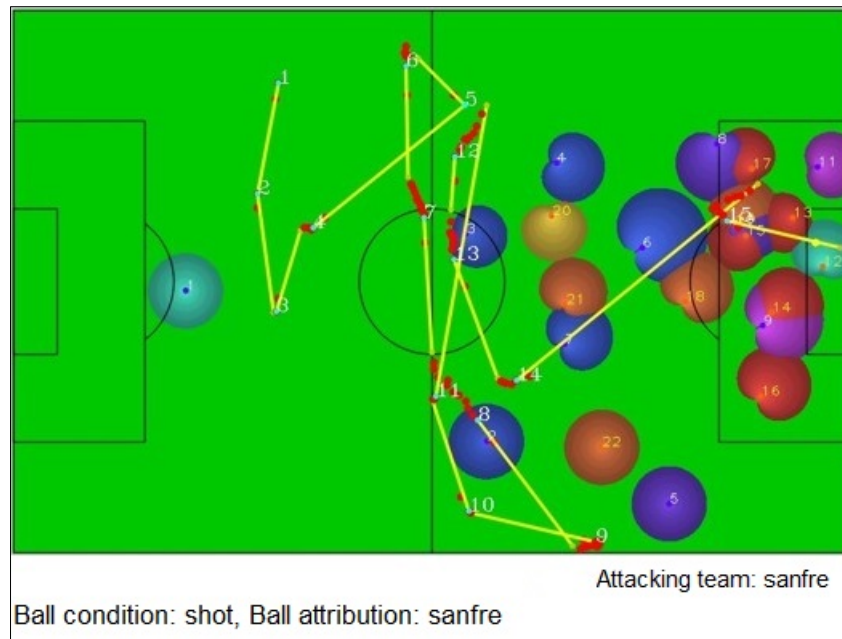
Figure 6. Diagram of passes during 39-second attacking sequence.

Sanfrecce Hiroshima's attack, which lasted 39 seconds, was mapped for the purpose of determining the patterns of "Pass". **Figure 6** shows the sequence of passes put together by Sanfrecce during those 39 seconds. The yellow lines represent the passes, the numbers at the starting point indicate the order of the passes and the red dots denote the movement of the ball that is not considered "Pass". "Which team is attacking", as determined by the offence/defence model, is shown in the top right, and the ball's situation and attribution are displayed in the bottom left-hand corner. Lastly, the players' locations and the predominant area with time limitation[2] evidence the final moment of the attack. Through a comparison between the videos and **Figure 6**, the ball's movement as expressed by the yellow lines was confirmed as "Pass". Therefore, the results suggest that it is possible to apply the offence/defence model to interpret "Pass" as a type of attack.

In conclusion, captured attacks were determined by defining the team in possession of the ball and performing the action "Pass". According to the results, it is reasonable to assert that "which team is attacking" as defined by the offence/defence model could possibly determine the attacking patterns.

4. Conclusion

4.1 Conclusion

From this study, we learned that our mathematical model, the offence/defence model, can produce similar analytical data to the findings of a team analyst. Using numerical data from the location of players and the ball, based on key tactical principles, the authors were able to generate similar information to the team analyst, which also mirrored the official match record. It can therefore be considered that the information obtained using the offence/defence model is sufficient to capture an overview of the tactical analysis of a football game.

It was also found that the numerical data on attacking time respectively obtained by the team analyst and by the offence/defence model showed a similar overview. Furthermore, examining the attacking patterns by capturing "Pass" at a certain moment yielded the same results for the ball's movement in a passing sequence as through observation of a video. "Which team is attacking" can be identified through the offence/defence model and could also be an appropriate

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[2] In football game analysis based on players' location, a predominant area diagram applying the computational geometry concept of the Voronoi diagram is used. Although it is considered that the player's predominant area should be reflected by the territory closer to the player's performance area, rather than the Voronoi area, such an area could be too big to obtain the information on the player's defending area. Therefore, to obtain such information, a time limitation was set for the predominant area.

way to determine attacking patterns.

4.2 Further research

The above-mentioned results show that it is possible to establish a basic framework for tactical game analysis in football by applying the offence/defence model to the objective numerical location data of players and the ball. However, some features of our model could be improved. They include 1) evaluation of entire games by applying the offence/defence model, 2) clarification of the constants in the offence/defence model and 3) incorporation of numerical data from several football games.

On the first front, the evaluation in this study was only conducted for the attacks at certain moments of the game. This needs to be extended throughout a game, and to several games, in the future. As for the constants, or the range of constants, these need to be clarified by applying the model to the data from several games. With regard to the third point, the challenge is that there is currently only a limited amount of publicly available open data, because most of the relevant data is guarded as a proprietary asset for the purpose of sports business.

4.3 Implications for practice

During this research, coaches and researchers worked together to establish a mathematical model based on a concept of football tactics. The researchers who established the mathematical model subsequently attempted to analyse a football match using a sample video. A lack of playing experience would traditionally have been seen as limiting a person's ability to analyse a game. However, the researchers realised that this research led to an opportunity for such people to get involved in the area of tactical game analysis. Indeed, during this research, we discovered that using this kind of model could help people with minimal experience to learn how to analyse the game.

In today's game, game analysis is of the utmost importance for improving and developing better athletes. It is hoped that this study will contribute to the promotion of numerical data as a tool to enhance analysis and potentially help to create a new community.

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