Analysing Team Formations in Football with the Static Qualitative Trajectory Calculus

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Abstract: In this paper, we introduce the Static Qualitative Trajectory Calculus (QTC_S), a qualitative spatiotemporal method based on the Qualitative Trajectory Calculus (QTC), for team formation analysis in football. While methods for team formation analysis are mostly quantitative, QTC_S enables the comparison of team formations by describing the relative positions between players in a qualitative manner, which is much more related to the way players position themselves on the field. To illustrate the method, we present a series of examples based on real football matches of a 2016-2017 European football competition. With QTC_S, team formations of both an entire team as well as a smaller group of players can be described. Analysis of these formations can be done for multiple matches, thereby defining the playing style of a team, or at critical moments during a game, such as set pieces.

1 INTRODUCTION

In this paper, we introduce a new method for analysing team formations in football, based on the Qualitative Trajectory Calculus (QTC; Van de Weghe, Cohn, et al., 2005). We start by giving a brief overview of established methods for analysing team formations in popular team sports and football more in particular. After that, we present the static QTC (QTC_S), an extension of the calculus introduced by Van de Weghe et al. in 2005. After presenting the novel methodology, we illustrate the application of QTC_S for analysing team formations in football by a series of real football examples. In the fifth section, we discuss the applicability of the method, its drawbacks and opportunities, before ending with a conclusion.

2 STATE OF THE ART

Thriving on technological advances in tracking technology and the opening up of different sports branches to data gathering, sports analytics has become a booming business in recent years (D'Orazio and Leo, 2010). Dozens of parameters from players, such as speed, heart beat rate, transpiration level, position, acceleration, jump height, goals scored, attempts, tackles, etc. are being monitored during training and matches of different sports. Even data at team level, called collective variables, such as formation, pass statistics, average positions, number of shots and others are being gathered (Rein and Memmert, 2016). In this overview, we will focus on collective variables and more specifically on the analysis of spatial formations in team sports, which we will refer to as 'team formation analysis' in the remainder of this paper. Since almost all team formation analysis methods, regardless of the sport, use positional data of the players, we start by giving a brief but focused overview of the state of the art of team formation analysis in popular sports, before providing a broader overview of the domain for football. For a more general overview of all different sports analytics methods in football, we refer to the works of Rein and Memmert, 2016 and Memmert et al. (2017).

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2.1 Team Formation Analysis

In American football, Atmosukarto et al. (2013) did efforts for the automatic recognition of offensive team formations, which they defined as "The spatial configuration of a team's players before a play starts" (Atmosukarto et al., 2013, p. 1) Their method automatically detects when one of five reference offensive team formations is achieved during the game. The big difference with football, however, is that a football game is more fluent and dynamic, thus team formations tend to change more during the course of the game (Atmosukarto et al., 2013). Team formation analysis in volleyball has been conducted by Jäger and Shöllhorn (2012). Because of the distinct separation of a volleyball game in separate rallies, Jäger and Shöllhorn used the positions of the players at the start and end of the rallies instead of the average positions during the rallies. Furthermore, they divided the players into attacking and defensive groups, analysing the shape of the two groups separately. On top of that, they discovered that, given a dataset with formations of six teams, an unknown team formation could be correctly classified/assigned to one of the six teams. In basketball, Lucey et al. (2014) analysed defensive team formations of basketball players in the three seconds leading to a three-point shot attempt, finding they were able to predict whether the team was going to give up open shot opportunity or not.

At this point, we would like to stress the difference between team formation analysis, which is the topic of this paper and is a spatial type of analysis, and the analysis to choose the optimal line-up of a team, which can benefit from player-specific data. The latter type of analysis focuses on the selection of actual players for each of the positions on the field and has been investigated more rigorously in, for example, hockey (Colleen Stuart, 2017), football (Barrick et al., 1998; Tierney et al., 2016), volleyball (Boon and Sierksma, 2003), basketball (Dezman et al., 2001) and cricket (Ahmed et al., 2013).

2.2 Team Formation Analysis in Football

In football, teams generally aim to play according to a specific team formation (Kaminka et al., 2003; Kuhlmann et al., 2005), which can be defined as "A specific structure defining the distribution of players based on their positions within the field of play" (Ayanegui-Santiago**,** 2009, p. 1). Advantages of one specific team formation with respect to others, e.g. increased running distances when playing against a 4-2-3-1 instead of a 4-4-2, have been described by Carling (2011). Mapping the advantages of different team formations can be useful when comparing them with the own team strengths and weaknesses in order to choose the most suitable team formation for a game. Team formation analysis in football can be performed in various ways, based on different key performance indicators that are derived from the players' positions (Memmert et al., 2017). For example, Sampaio and Macãs (2012) suggested the team centroid, team entropy, a team stretch index and the surface area of the team as key performance indicators for team formation analytics. Going further on this, Frencken et al. (2012) added the inter-team distance, i.e. the distance between the centroids of both teams, as a key performance indicator to detect goals or attempts in a match. Lemmink and Frencken (2013) demonstrated the possibility to use these key performance indicators not only for the entire team but also for subsets of the team such as players with specific roles, e.g. attackers or defenders.

A method for automatic detection of the type of team formation based on the average position of the players was proposed by Bialkowski et al. (2014). They argue that, because of the players swapping positions during the game, static ordering of the players does not accurately represent the team formation. In order to cope with this, they introduce dynamic ordering of players by the role that they occupy at a given instant in time. Using data from a whole Premiere League season, Lucey et al. (2013) and Biakowski et al. (2014) found no significant difference between formations of different teams, but could detect that English Premier League teams used more offensive team formations during home games.

Various new methods use principles of (artificial) neural networks (McCulloch and Walter, 1943). Visser et al. (2001) used artificial neural network systems to recognize the team formation of the opponent team. Starting with the positions of the opponent players at a certain timestamp, the neural network tried to classify that moment into a set of predefined team formations (Atmosukarto et al., 2013) later used an analogue method in American football) and proposed the appropriate counter team formation for the own team. Going further on this work**,** Ayanegui-Santiago (2009) proposed to include multiple relations between players for the recognition of team formations. He divided the players into three groups (defenders, midfielders and attackers) and used labelled graphs between nodes of adjacent groups to describe and compare team formations.

The methods mentioned above generally aim at calculating frequencies of team formations. This facilitates comparison of different team formations and the temporal evolution of these team formations during the game (Grunz et al., 2012). Furthermore, the occurrence of team formations can be linked to scoring goals and winning games, thus measuring the success of a specific team formation for a team. However, while most methods use quantitative metrics, Perin et al. (2013) argue that quantitative analysis is not sufficient to understand the team formation of a game or a whole season. Unfortunately, qualitative team formation analysis in football is currently mostly performed by human experts and is thus very labour intensive (Bialkowski et al., 2014). The goal of this paper is to contribute to this domain, by introducing QTC_S for (automatic) team formations analysis in football.

3 METHODOLOGY

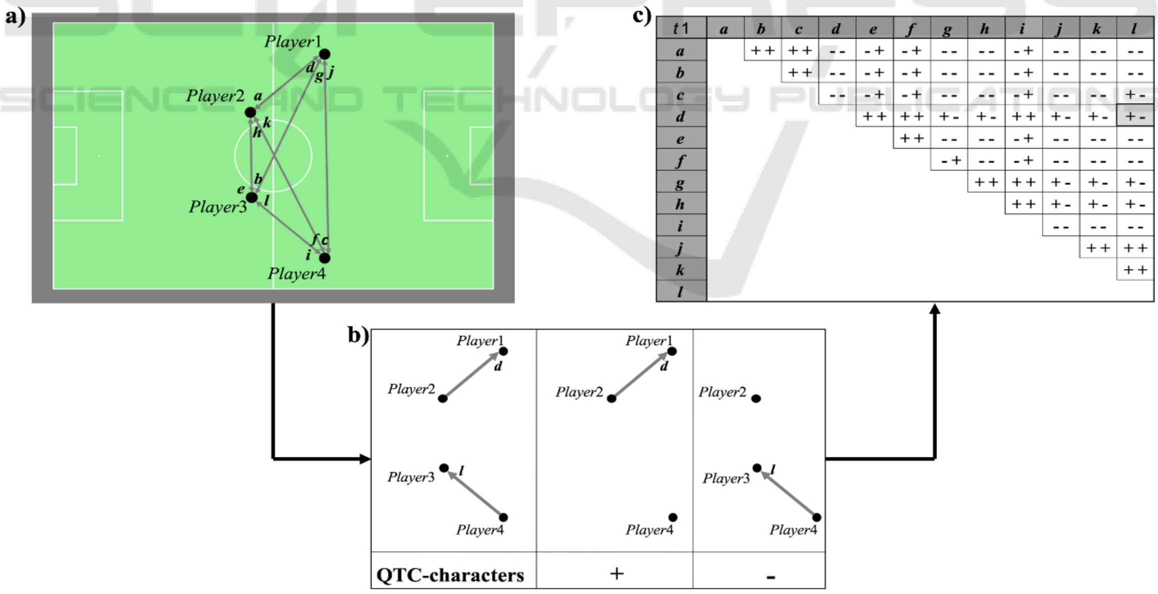
In this section, we introduce the novel methodology for sports team formation analytics. We start by giving a brief overview of QTC, followed by the new variant (QTC_S) that was created for this type of research. Following, we present a series of possible applications for the method in team formation analysis in football.

3.1 The Qualitative Trajectory Calculus

QTC is a qualitative calculus for describing spatiotemporal relations between two or more Moving Point Objects (MPOs). The most basic variant of the calculus, QTC_B, describes the movement of a pair of MPOs during a time interval by means of two QTC-characters (Van de Weghe, Cohn, et al., 2005). Afterwards, multiple variants of QTC were introduced, each named by adding the initial(s) of the variant's name to the abbreviation 'QTC' in subscript (Bogaert et al., 2007; Mavridis et al., 2015).

3.2 QTC_S

While QTC typically describes movement between multiple objects, it can be extended easily to a new variant named QTC_S (Static Qualitative Trajectory Calculus), which describes static formations of point objects (POs), which are players in our case. When describing the formation of POs with QTC_S, the lack of movement is dealt with by constructing all possible vectors between the POs (Figure 1a). Subsequently, QTC_S-relations between each pair of vectors are



t1	a	b	c	d	e	f	g	h	i	j	k	l
a		++	++	--	-+	-+	--	--	-+	--	--	--
b			++	--	-+	-+	--	--	-+	--	--	--
c				--	-+	-+	--	--	-+	--	--	+-
d					++	++	+-	+-	++	+-	+-	+-
e						++	--	--	-+	--	--	--
f							-+	--	-+	--	--	--
g								++	++	+-	+-	+-
h									++	+-	+-	+-
i										--	--	--
j											++	++
k												++
l												

Figure 1: A formation of four players (POs) on a football field at t_1 and the vectors between them (a). The construction of the QTC_S-relations between two vectors *d* and *l*, consisting of the QTC_S-relation of vector *d* with respect to the starting point of vector *l* and of the QTC_S-relation of vector *l* with respect to the starting point of vector *d*. If the vector moves away from the starting point of the other vector, the QTC_S-relation is denoted by '+', if the movement is towards it, the QTC_S-relation is denoted by '-'. If the movement is neither away nor towards the marker (thus perpendicular to the connecting line between the two starting points), the QTC_S-relation is denoted by '0' (b). The QTC_S-matrix describing the full formation of the four players, including all relations between all of the vectors (c).

constructed similar to QTC_B (Van de Weghe, Cohn, et al., 2005), shown in Figure 1b for the vectors d and l. The different QTC_S-relations are stored in a QTC_S-matrix, where the first character in each cell is the QTC_S-relation of the vector in the row header with respect to the vector in the column header, the second character is the QTC-relation of the marker in the column header with respect to the marker in the row header (Figure 1c).

3.3 QTC_S for Team Formation Analysis

By constructing a QTC_S-matrix at different timestamps, QTC_S can be used to describe the team formation at different moments in time. If the number of players in the formation is identical at each of those timestamps, the QTC_S-matrices will have the same dimensions and can be compared by calculating the distance between them. The distance between two QTC_S-matrices is calculated by summing up the pairwise distances between all of its elements (QTC_S-relations), thereby using the conceptual distance between QTC-relations (Van de Weghe and De Maeyer, 2005). By dividing the total distance between two QTC_S-matrices by the maximal possible distance (depending on the matrix dimensions), the relative distance is calculated. For easier understanding, the relative distance is recalculated to a similarity value between 0 and 1. The current implementation of the methodology was done in the Python programming language.

4 APPLICATIONS OF QTC_S FOR TEAM FORMATION ANALYSIS IN FOOTBALL

In this section, we present a series of examples of the QTC_S-methodology for team formation analysis in football. Considering the novelty of the method and the lack of a good ground truth (Feuerhake, 2016), the focus in this section primarily lies on introducing rather than validating the results. All examples are based on real football matches of a 2016-2017 European football competition, but are presented anonymously for privacy reasons.

4.1 Full Team Formation

Often, trainers aim to use one or more predefined team formation(s) for their field players (excluding the goal keeper) according to the situation in the game and the team formation of their opponent. By using QTC_S to describe both the desired team formation(s) as well as the actual performed formation, an evaluation of the team performance can be made. Figure 2, for example, shows compliance (similarity) of an anonymous team with a 4-4-2 team formation during six different matches, analysed with a temporal resolution of five minutes. The higher the similarity in the graph, the more the actual team formation resembled the theoretical 4-4-2 shown on the right side, during the game.

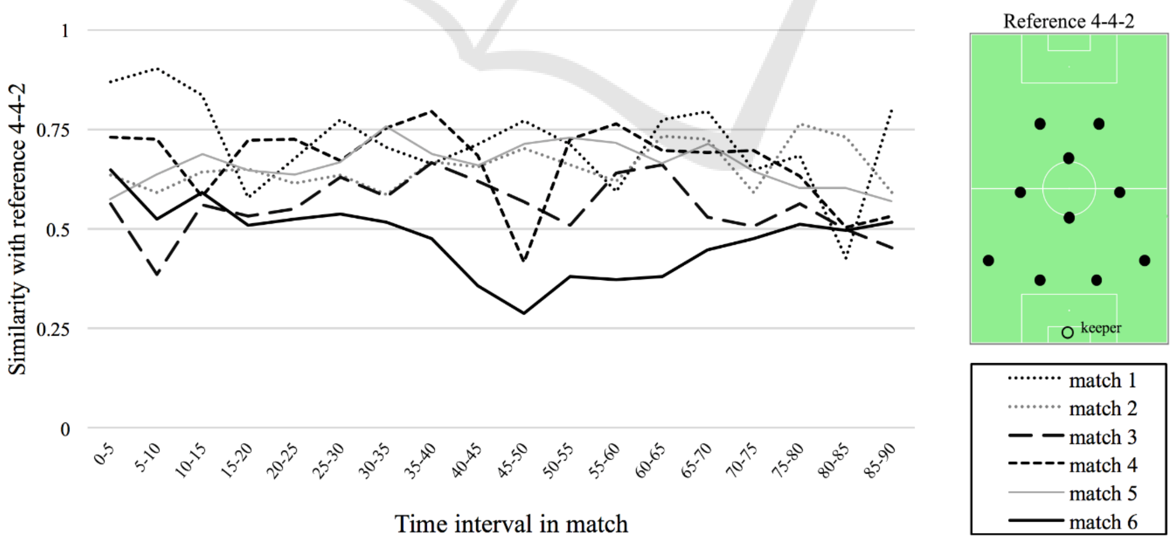


Figure 2: Similarity of an anonymous team with a theoretical 4-4-2 formation during 6 matches, with a temporal resolution of 5 minutes.

4.2 Analysis of a Teams Playing Style

While in Section 4.1 similarity with one reference team formation is calculated, it is also possible to calculate similarities with all of the generally accepted reference team formations (such as those used in popular football simulation games). An example of this can be seen in Figure 3, where for two matches of an anonymous team, frequencies of the most similar reference formation at every second of the game are displayed, illustrating the variety of team formations performed by one team during a game or even between different games. As such, a team's playing style, i.e. a set of regular played team formations by a team, can be defined and compared between teams and matches.

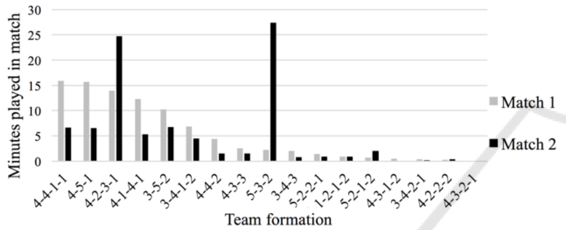


Figure 3: Frequencies of team formations played by an anonymous team during two matches, ordered according to the frequencies of match 1.

4.3 Parts of a Team Formation

Going more in detail, it can be interesting to analyse how different groups of players of a team, e.g. defenders and midfielders, each stick to their theoretical formation during a match. Figure 4 displays the compliance of the midfielders and defenders of an anonymous team with their respective reference formation throughout one match, with a temporal resolution of 5 minutes. It can be seen that the defence much more sticks to its reference formation throughout the game than the midfield, which naturally has a more flexible and interchanging character (Gonçalves et al., 2014). Between minutes 15 and 30 of the match, however, the only period during which the displayed team conceded (multiple) goals, both defenders as well as midfielders had the highest deformations with respect to their reference formations.

4.4 Analysis of a Team Formation at Set Pieces

Team formations at set pieces, i.e. corners and free kicks, are one of the most studied and trained aspects of team formation in football (Sarmento et al., 2014). By transforming both the desired as well as the actual performed formations at set pieces into QTC_S-matrices, coaches can get an overview of whether and to what extent the ideal trained-on formation of their own team was achieved in real matches or get insight into the tactics and regularly performed team formations at set pieces of opponent teams.

5 DISCUSSION

In this paper, we presented QTC_S, a qualitative calculus that can be used for team formation analysis in football. This method can easily be applied to other sports and incorporates both inter-player coordination as well as inter-team coordination (Memmert et al,

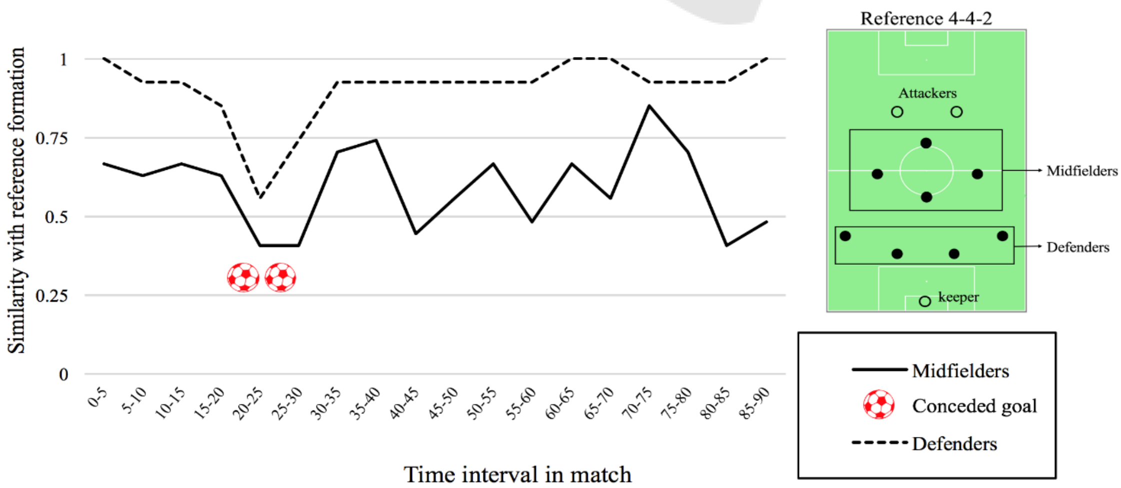


Figure 4: The similarity of midfielders and defenders of an anonymous team with their reference formation throughout one game.

2017). While it has some similarities with already established methods for team formation analysis (see Section 2), we are convinced of its added value by its qualitative character, simplicity and extensibility.

With respect to the qualitative character, we feel that quantitative methods fail to incorporate the perception of the players positioning themselves into the team formation on the field. These perceptions will more likely be qualitative, e.g. “I am too far behind the opponent’s midfielder” or “I am standing too close to my keeper” than quantitative, e.g. “I am currently 21.45 meters away from my team’s left winger”. As such we are convinced that qualitative methods will better grasp the principles players use to position themselves on the field. Although Ayanegui-Santiago (2009) already proposed a similar qualitative method, important differences in this respect can be noticed. First of all, no distinction between the studied players is made with QTC_S, drawing and comparing vectors between all the players and thus using all spatial information for the analysis. Secondly, QTC_S results are standard rotation-invariant, although rotation-sensitivity can be enforced by adding static points (such as the corners of the football field) to the QTC_S description of a team formation. Thirdly, we believe the QTC_S-methodology can calculate distance between different formations more precisely, through the use of conceptual distances (Van de Weghe and De Maeyer, 2005) between QTC_S-characters (instead of the duality between identity and non-identity between characters) and the option to extend the number of QTC_S-characters used, conform the extension of QTC_B to QTC_{B2} and QTC_C (Van de Weghe, De Tré et al., 2005). Moreover, Ayanegui-Santiago argues that his work could be enhanced by the conversion of the numerical orientations between players into symbolical ones, such as the QTC_S-characters.

In Section 4 of this paper, we presented a series of applications of the QTC_S-methodology in football. The applications, however, are not limited to this list, as one could for example analyse how a team gets back into formation in the minutes after conceding a goal or analyse how substitutions affect the quality of the team formation, and so on. Furthermore, by linking the team formation with performance factors such as scored goals, won matches or ball possession, coaches could be supported into making better decisions and ultimately, try to win more games.

We are, however, aware of the lack of concrete validation of the results in this paper, but would like to point out the difficulty of validating methods for (team) formation pattern detection in football due to the lack of a good ground truth, as argued by Feuerhake (2016). Furthermore, because of a huge variety in methodologies, it cannot be assumed that finding the same results as other established methods is desirable nor that it should be the goal. As such, we are convinced that validation should primarily be done by sports professionals (e.g. coaches).

At the moment, the proposed methodology has some computational limitations. Permutations between players, for example, allowing to detect similarities between formations where two or more players switch roles, are possible though require high processing power. As such, when using permutations, the number of players that can be analysed is limited. Furthermore, at the moment it is only possible to compare formations with the same number of players involved.

6 CONCLUSION

In this paper, we presented QTC_S, a novel method for team formation analysis in football. We explained the principles of QTC_S and illustrated its applicability by a series of basic football examples. With QTC_S, team formations of both an entire football team as well as a smaller group of players can be described. Analysis of these formations can be done for multiple matches, thereby defining the playing style of a team, or at critical moments during a game, such as set pieces. Further research could analyse the impact of static points or the extension of QTC_S to include more characters on the team formation detection accuracy. Furthermore, different weights could be allocated to the vectors between players, according to their importance on the field.

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