

# Translating novel collective behaviour measures to concepts and principles of play as understood by football coaches.

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1 **Translating novel collective behavior measures to concepts and principles of play as**  
2 **understood by football coaches.**

3

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8 **Abstract**

9 **Background:** A range of innovative performance analysis metrics have been applied in  
10 recent years to investigate aspects of football using tempo-spatial and network analyses.  
11 These approaches have gained traction within some professional teams to quantify and assess  
12 features of collective behavior. However, metrics employed are rarely created from, or  
13 clearly link to, domain expertise and as a result coaches may be hesitant of their value.  
14 Therefore, the aim of this study was to identify coach perceptions of spatial temporal and  
15 network metrics and identify the feasibility of an iterative and collaborative process to  
16 developing metrics. **Methods:** Two rounds of semi-structured interviews were conducted  
17 with three Scottish youth international UEFA Pro License coaches (age:47.0 ± 2.7 years)  
18 with a focus on aligning metrics with concepts and principles of play. An iterative approach  
19 was used centering around spatial-temporal and network metrics and their adaptation.  
20 Reflexive thematic analyses were conducted with final metrics categorized as *resonant*  
21 (accurately describing concept or principles of play), *relevant* (appropriate but with  
22 limitations that need improvement), or *hesitant* (skeptical of usefulness). **Results:** Across the  
23 ten recognized principles of play, nine metrics were identified and adapted to varying  
24 degrees. Resonant metrics included: network intensity (mobility), distance between defenders  
25 (discipline), triangles (support), team length and distance between deepest defender and goal  
26 line (depth). **Conclusion:** Coaches recognize principles of play within complex collective  
27 behavior metrics and should be encouraged to collaborate with analysts to develop support  
28 systems that may prove to be more valuable and usable.

29 Keywords: Soccer, collaboration, performance analysis, data analysis, decision making

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## 38 **Introduction**

39 With increasing data collection in elite football, more sophisticated approaches are being  
40 developed to derive greater knowledge and insight <sup>1</sup>. Traditional approaches to data analysis  
41 have focused on players physical performance (e.g., information obtained by movement  
42 analyses) or on team performance (e.g., technical, or tactical event frequencies occurring in  
43 matches such as passes or dribbles) <sup>2</sup>. Due to factors such as the low scoring nature of  
44 football and subsequent fine margins to separate winning and losing teams, quantifying  
45 performance in this manner is challenging <sup>3</sup>. Subsequently, individual moments in football  
46 can greatly influence the match outcome and can lead to more frequent victories by teams  
47 who do not perform as well as their losing opponents <sup>3</sup>. Additionally, the continuous nature of  
48 football creates a dynamic environment where each player is constantly moving and adjusting  
49 based on the positions of their teammates and the ball <sup>4</sup>. The complexity can be challenging  
50 to summarize coherently such that performance analysts in football have traditionally  
51 supported coaching staff through video analysis supplemented with basic descriptive statistics  
52 <sup>5</sup>. Indeed, whilst evidence shows increasing use of more complex key performance indicators,  
53 a preference for simpler measures of performance such as shots on target has been  
54 demonstrated <sup>6</sup>. This mixed picture is further evidenced by the recruitment of data scientists  
55 by some elite teams to assist in the development and use of complex performance indicators  
56 that process positional and event data. This posits the question of how performance analysts,  
57 and data scientists can collaborate to create a system that is effective and actively supports  
58 coaching staff.

59 A barrier to achieving buy in from coaching staff is likely to include the mathematical nature  
60 of the complex metrics used in the literature base. Some studies have computed metrics based  
61 within principles of play using a range of techniques including computational measures  
62 relying on the position of player and networks of interactions where sequential order was  
63 integrated into the analysis <sup>7</sup>. Another approach is the FUT-SAT instrument presented by  
64 Costa et al. who created a notational tool based on player actions and underpinned by the 10  
65 principles of play to evaluate tactical performance <sup>8</sup>. Whilst these approaches have  
66 demonstrated progression within football performance analysis, uptake of these tools and  
67 procedures appear limited. In a growing research field, there seems to be little collaboration  
68 with coaches regarding how the metrics used in this field can be applied in coaching.  
69 Gudmundsson and Wolle created tools while in close contact with coaches and analysts to

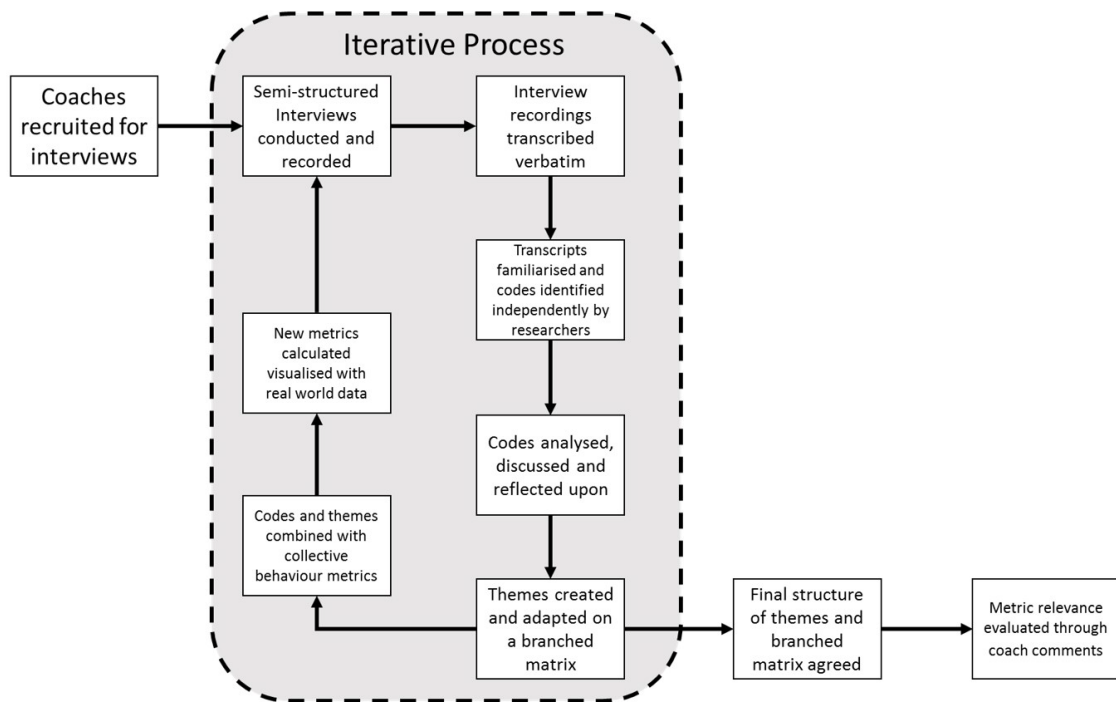
70 help shape analytical systems that were valuable <sup>9</sup>. However, a large section of the literature  
71 base performs research independently and without reporting cooperation with coaches <sup>10</sup>.

72 Considering these issues, a monodisciplinary approach may not be optimal when providing  
73 performance analysis support for coaches. An alternative to this status-quo is co-production.  
74 Co-production is a process for capturing knowledge that is valuable in multidisciplinary  
75 contexts where in the domain of performance analysis, the analyst (the service provider)  
76 collaborates with the coach (the service user) to create higher value output. Whilst this  
77 method has gained popularity in finding solutions to an array of problems, there remains  
78 ambiguity in both the theoretical underpinnings <sup>11</sup> and the terminology with co-creation, co-  
79 design, and co-innovation often being used interchangeably <sup>12</sup>. Despite this, variations of co-  
80 production have been applied in sport and health contexts <sup>13,14</sup>, however, there does not  
81 appear to be any literature that explores co-production in the context of performance analysis.  
82 Considering many coaches do not use more complex key performance indicators <sup>6</sup>,  
83 collaborative approaches offer an avenue to integrate spatial-temporal and network analysis  
84 metrics into analysis provisions. Moreover, there is limited exploration of how coaches even  
85 perceive and use these metrics. Consequently, the purpose of this research was to identify  
86 coach perceptions of novel collective behavior measurements. This was done through  
87 investigating coaches' philosophy and principles of play and identifying how current  
88 measurements of collective behavior can be adapted to achieve buy in from a coach. The  
89 study drew on elements of co-production and comprised an iterative approach working with  
90 elite football coaches to present contemporary collective behavior metrics, explore the coach  
91 interpretations and their own philosophies and principles through qualitative interview and  
92 subsequently refine the metrics used.

## 93 **Methodology**

### 94 *Study design*

95 A framework for creating a tailored system to augment coach decision-making through  
96 performance data analysis and visualization was explored in this study. The framework  
97 comprised of an iterative process <sup>13</sup> (Figure 1), including standard collective spatial temporal  
98 and network metrics as a starting point, with modifications based on interviews with coaches  
99 based on their philosophy. Prior to data collection, institutional ethical approval was granted.



100

101 **Figure 1.** Schematic overview of the iterative interview process.

102 *Participants*

103 Purposive sampling was used to recruit three Scottish international football coaches (average  
 104 age:  $47.0 \pm 2.7$  years) to allow for extensive information to be gathered<sup>15</sup>. Coaches had  
 105 between 8- and 28-years coaching experience (average experience:  $18.3 \pm 10.0$  years) and  
 106 held the UEFA Pro License qualification. Between the initial and follow up interview, one  
 107 coach did not participate in the second interview due to changing jobs, resulting in a total of  
 108 five interviews throughout the iterative research process.

109 *Data Collection*

110 Two separate phases of semi-structured interviews were used to gather the coach perspectives  
 111 and to provide feedback on the initial (phase one) and modified (phase two) spatial-temporal  
 112 and network metrics developed to quantify aspects of collective behavior (Figure 1). Open  
 113 ended questions were integrated throughout interviews to allow for concepts to be explored<sup>16</sup>  
 114 while giving the researcher some control over the process<sup>17</sup>. The interview questions  
 115 (Appendix 2) centered on attacking, defending and transitions as well as spatial temporal  
 116 principles including position, distances, spaces, and numerical relations along with network  
 117 metrics seeking to gain further understanding of passing sequences.

118 Before each data collection phase, a fifteen-minute presentation was provided to the coaches.

119 Phase one presentations provided an outline of common approaches used to describe

120 collective behavior, anchoring the discussions to relevant principles of play<sup>10,18</sup>. Between  
121 interviews, metrics were adapted or created based on coach comments and a second  
122 presentation was constructed. During the second interview, coaches were provided quotes  
123 and interpretations of the initial interview and asked to comment on whether the calculated  
124 and visualized metrics were accurate and relevant or if concepts were incomplete. This  
125 approach has previously been used within coaching<sup>9</sup> and allows for scrutiny of interviewee  
126 quotes, facilitating adaptations to metrics and visualizations to better suit coach  
127 conceptualization<sup>19</sup>. All interviews and presentations were undertaken by the same  
128 researcher (MC). Interviews lasted approximately one hour and were recorded through  
129 Microsoft Teams with participant's permission, for transcription in verbatim.

### 130 *Data Analysis*

131 Reflexive thematic analysis was used to generate themes for both interview phases with a  
132 reflective log (Appendix 1) written to document the process<sup>20</sup>. Both researchers read through  
133 the transcripts multiple times to get a clear understanding of the raw data<sup>20</sup>. Following this,  
134 each researcher individually coded the transcripts prior an open and honest discussion to  
135 finalize coding<sup>20</sup>. Initially, the lead researcher collated and organized these into potential  
136 themes before discussing these with the research team<sup>20</sup>. These themes were reviewed to  
137 ensure they were representative of the coded extracts and fitted with the research question.  
138 Once agreed, themes were then defined prior to the formation of a final thematic  
139 tables/branched matrix<sup>20</sup>. Data were analyzed by two researchers (MC and MM) and both  
140 were involved in the creation of a reflective log to document the process (Appendix 1). Both  
141 have undergone training by their university to conduct thematic analysis and have previous  
142 experience of this process. This allowed for multiple analyst triangulation, ensuring  
143 participant information was interpreted appropriately and allowed for any conflicts or  
144 disagreements to be resolved within the research team<sup>21</sup>. The final thematic tables/branched  
145 matrixes can be seen in Tables 1 and 2. Based on the branched matrix and interviewee quotes,  
146 systems were created to measure the tactical concepts and principles of play highlighted as  
147 important. These were then computed using data from a Euro 2020 qualifying match and  
148 visualized using R and presented back to participating coaches. This step functioned as a  
149 member checking process to ensure credibility and trustworthiness<sup>22</sup>, while forming the  
150 iterative process whereby domain expertise and evidence-based research are combined to  
151 create a robust process to inform practice<sup>19</sup>.

152

153 **Table 1.** Initial thematic analysis identified from the first stage interviews.

<b>Sub-themes</b>	<b>Themes</b>	<b>Main Themes</b>	
Disrupting Opponent Creating Space	Penetration	Attacking	
Diamonds and Triangles Balance Control	Support		
Overloads Attacking Shape	Width		
Speed of Play Movement	Mobility		
Attacking Risk Patterns of Play	Creativity		
Decision Making Counter Attacking	Attacking Transitions		
Defensive Shape Pressure	Delay		Defending
Team Length Lines	Depth		
Cover Adjusting	Balance		
Compactness Distances	Compactness		
Triggers Working as a Team	Discipline		
Reaction Prediction of Transition	Defensive Transition		
Barriers to Development Learning Styles	Player Development	Team Performance	
Learning Experiences Available Coaching Time			
Flexible Tactics Pitch Size	Match Preparation		
Opponent Ability			

154

155

156 **Discussion of Findings**

157 This section provides an overview of the data derived from the iterative interviews along with  
 158 discussions of the initial and adjusted thematic analyses, based on coach comments.

159 Additionally, coach perceptions of proposed metrics and visualizations describing the  
 160 principles of play are discussed, identifying the most promising metrics for tactical  
 161 measurement based on coach opinion. Finally, a discussion on how these metrics can be  
 162 further developed to support the coaching process will conclude this section.

163



164 **Table 2.** Iterated thematic analysis identified from the second stage interviews.

<b>Sub-themes</b>	<b>Themes</b>	<b>Main Themes</b>
Diamonds and Triangles	Support	Penetration
Passing Options		
Angles	Width	
Teammate Distances		
Coordination		
Overloads in Wide Areas		
Creating Space	Mobility	
Disrupting Opponents		
Attacking Shape		
Passing Speed	Creativity	
Contact Time		
Movement		
Risk		
Breaking Lines	Compactness	Delay
Patterns of Play		
Deception		
1v1		
Defensive Shape		
Reaction		
Recovery		
Controlling Opponents		
Decisions	Depth	
Anticipation		
Length		
Lines		
Cover	Balance	
Overloads Near the Ball	Discipline	
Adjusting		
Triggers		
Time		
Distance to Opponent		
Working as a Team		
Pressure		
Barriers to Development		
Learning Styles	Match Preparation	
Learning Experiences		
Available Coaching Time		
Flexible Tactics		
Pitch Size		
Opponent Ability		
Game Context		
Player Strengths		

165

166 *Iterative Thematic Analysis*

167 Questions in the first interview were structured around attacking, transition to defense,  
 168 defense, and transition to attack. These concepts were represented in the main themes from  
 169 the initial thematic analysis: *attacking*, *defending*, and *team performance*. The twelve themes  
 170 that feed into *attacking* and *defending* main themes share strong similarities with traditional

171 principles of play found in football literature <sup>7, 23, 24</sup>. As stated by Prickett these include five  
172 attacking principles: i) penetration, ii) support, iii) width, iv) mobility and v) creativity, and  
173 five defensive principles: i) delay, ii) depth, iii) concentration, iv) balance and v) discipline <sup>23</sup>.  
174 Attacking transition and defending transition were also identified as themes and are  
175 sometimes mentioned alongside the traditional ten principles <sup>7, 24</sup>. These ten principles of play  
176 were identified by participants, despite interview questions being designed without  
177 considering these concepts. The coaches all recognized these principles with coach 1 stating.

178 *“I’m one that very much strives to stick to the principles of the game, you know, those*  
179 *are the constant strains.”*

180 This finding suggests that the principles of play previously identified are robust, however,  
181 the need for elite coaches to undergo education systems featuring these concepts may have  
182 played a role. The traditional principles also suffer from inconsistency in terminology used.  
183 This is demonstrated by coach 1 who lists the attacking principles as.

184 *“depth, width, mobility, improvisation, penetration for your attacking ones.”*

185 The five principles highlighted by the coach align with the previously stated concepts,  
186 however, inconsistent terminology could lead to different interpretations. Other research has  
187 presented different principles of play that do not conform with the ten outlined by Costa <sup>24</sup>.  
188 Moreover, coaches will have differing opinions on how to implement tactical strategies,  
189 underpinned by principles. Establishing a unified framework for principles of play would  
190 help, but this is a challenge due to the varying perspectives of coaches. The initial thematic  
191 analysis can be seen in Table 1.

192 A finding from the initial interviews was that coach 1 stated that they had previously seen  
193 visualizations of team length before, however, did not use it to inform practice. Also, Coach 2  
194 previously used network analysis to identify common passing behaviors of both their own  
195 team and the opponent, however, stopped the use of the analysis due to perceived limited  
196 value and resource required to record the data live. This relates to the final main theme of  
197 *team performance*, which branched into two themes: match preparation and player  
198 development. These factors related to how performance analysis provision can support the  
199 coaching process. Player development focused more on how training can be shaped to  
200 maximize development with sub-themes including learning experiences, available coaching  
201 time and barriers to development. These relate more generally to the holistic improvement of  
202 players and teams. Whereas match preparation identified how changing contexts can impact

203 desirable aspects of team performance from match to match. From the experiences of the  
204 coaches, their previous exposure to these visualizations and data had limited utility in  
205 preparing their team for a match or developing the players.

206 After completing the initial thematic analysis, metrics from the literature were selected and  
207 adjusted based on the coach comments. These were presented back in a second interview to  
208 confirm the interpretation of the coaches' comments were accurate and evaluate how  
209 representative the metrics were. From the transcripts of the 2<sup>nd</sup> interview process, the  
210 thematic analysis was adapted further. The biggest difference was changing the main themes  
211 of attacking and defending to *penetration* and *delay*, respectively. These were changed as  
212 *penetration* describes the main aims of the other themes in *attacking* while every theme of  
213 *defending* was related to *delay*. The transition themes were also removed from the second  
214 iteration of the thematic analysis as they were relevant across many themes. Instead, aspects  
215 of transition were combined as sub-themes within other concepts due to its importance in  
216 tactical organization across both attacking and defending. The changes were not limited to the  
217 removal of transitions from the themes and the promotion of penetration and delay. Of the 33  
218 original sub-themes identified, only 16 (48%) remained unchanged in the second iteration of  
219 the table. Some of these changes were minor and were caused by the removal of the attacking  
220 and defending transition themes whereby sub themes were moved into other relevant themes.  
221 For example, prediction of transition moved from defensive transition to compactness and  
222 was renamed to anticipation to better suit the terminology used by coaches. Only 4 (12%) sub  
223 themes were rephrased and another 4 (12%) were removed completely where words were  
224 either too similar to the themes they were allocated or were too broad and as a result not  
225 informative. For instance, 'decision making', could be perceived as relevant in each theme  
226 and was consequently removed to avoid sub-themes bleeding across the thematic analysis.

227 Such an effect is expected when evaluating tactical principles in a complex dynamical system  
228 such as a football match. Indeed, all these concepts are interconnected, naturally causing  
229 some of the initial sub-themes to bleed into multiple themes. To minimize the impact of this  
230 effect, 3 (12%) of the original codes were split into 6 (14%) of the 41 total sub-themes  
231 identified in the second iteration of the thematic analysis (Table 2). For example, distances  
232 were commonly referenced in the initial interviews. However, after devising the tools and  
233 presenting them to coaches, it appeared that the distances occupied two distinct themes:  
234 discipline and support. Consequently, distance to opponent and distance to teammates were  
235 placed in the themes respectively. Finally, a total of 9 new sub-themes were added to the

236 thematic analysis based on the coaches' comments in the second interviews that related  
 237 distinctly to each principle of play.

238 **Table 3.** Overview of metrics summarizing principles after the iterative interview process and  
 239 feedback from coaches.

Metric	Measurement	principle	Coach perception	Coach quotes
Network intensity	successful passes/time in possession <sup>41,42</sup>	Mobility	Resonant	"I love it, I think it's absolutely brilliant and so critical in terms of player development, team development, winning games."
Distance between defenders	Distance between defenders from identified players in defense position going from the left of the pitch to the right of the pitch <sup>43,44</sup>	Discipline	Resonant	"the whole team needs to get back out. It's, for me really, really important to get those adjustments. And always, you can't... you can't take risks."
Triangles	distances, angles and area of a triangle described by 3 pre-selected players (e.g., midfielders) <sup>43,45-47</sup>	Support	Resonant	"The distances are really important. But I also think it's the players that that need to sort understand that, you know, you don't just move to support the ball, if you're part of the Midfield three like that."
Team length and distance between deepest defender and goal line	Distances calculated in the x-axis only from the deepest defender to the furthest forward attacker (team length) and the goal line <sup>48-50</sup>	Depth	Resonant	"I personally, coach my teams in a similar way. If we were under pressure, then I would want in that scenario, I would want my striker to be back as well"
Surface area	Calculated from the area of a convex hull of the outfield players <sup>29,30</sup> . Differences are measured between 1 second before loss of possession, loss of possession, 2 seconds after loss of possession and time taken until 600m <sup>2</sup> is reached.	Concentration	Relevant	"I think the only thing I would add to that [author] is on the tactical instruction of the coach and the team, knowing whether on those transitions..."
Team width	Distance along the y axis between player furthest right, and player furthest left on the field	Width	Relevant	"at a higher level of the game, they'll start to do things that are very different and much more complex"
Distance dyads, time to contact, and passing lane	Distance pressure calculated through pressure variable from Link <sup>32</sup> . Time pressure calculate	Pressure	Relevant	"I agree with your description of the pressures. What I would add I'm sure you're aware of it is, in my opinion, it's

	through time to contact from player in possession and closest defender <sup>33</sup> . Passing lane identified from available players to pass to who have a passing lane greater than 10° <sup>34</sup> .			the decision from the [Team1] central defenders not to pressure once the transition happens.”
Numerical Advantage	Effective area of pitch described by all outfield players is divided up into 7 areas as shown by Vilar <sup>37</sup> . Difference in the number of players in each team within each section is calculated.	Balance	Hesitant	“I would say probably needs a little bit. A little bit of work.”
Pitch control and number of outplayed opponents	Points on the pitch closest to each player adjusted based on the movement speed and direction of each player <sup>52,53</sup> .	Penetration	Hesitant	“You can show lots of pictures of good examples. But at the end of the day, it comes down to quick time decision making and execution.”

240

241 *Coach Perceptions of Collective Behavior Measurements*

242 The coaches’ perceptions of metric and visualizations presented to them in the second  
 243 interview that were constructed and adapted from approaches in the literature-based on the  
 244 comments made in the first interview. A grading system was used to categorize how coaches  
 245 responded to each metric. If coaches demonstrated enthusiasm towards a visualization or  
 246 identified that the measurement was fully descriptive of a principle in football, then it was  
 247 labelled as *resonant*. If the metric was identified as accurately describing a concept, however,  
 248 the coach identified limitations or aspects that needed improved, then it was labelled as  
 249 *relevant*. Finally, if a coach was skeptical of how useful a metric would be in practical  
 250 settings or identified situations where the model was inaccurate at representing the principle  
 251 then it was labelled as *hesitant*. Table 3 provides an overview of the 9 visualizations  
 252 presented to the coaches, highlighting which metrics show most promise, along with  
 253 summary quotes supporting the categorization of each metric.

254 *Resonant Metrics*

255 *Mobility*

256 The mobility principle was discussed several times in the initial interview phase. Naturally,  
 257 mobility relates to player movement and was suggested as being linked to the concept of  
 258 support, where teammates must move into appropriate positions to provide passing options.

259 However, mobility also relates to actions on the ball and how a team can move the ball at  
260 pace. Coach 3 emphasized the importance of this:

261 *“that's what the top players can do, they can, they can play at speed, they can do*  
262 *everything quickly, control the ball pass the ball, turn.”*

263 This relates closely with the measurement of network intensity, explored by Grund,  
264 measuring the rate that teams pass the ball <sup>32</sup>. This was presented to coaches as a mean across  
265 individual matches, as well as during attacks with comparisons between and within matches.  
266 This measure received a positive reaction with coach 3 stating:

267 *“I love it, I think it's absolutely brilliant and so critical in terms of player*  
268 *development, team development, winning games.”*

269 Evidence from Grund found a link between successful teams and high network intensity.  
270 However, more investigation in this metric is required to inform training <sup>25,26</sup>. Despite  
271 reacting positively, coach 3 provides more detail.

272 *“...it's not just the speed of the pass, it's the contact time in between, you know, the*  
273 *amount of time it takes a player to control the ball and play the ball.”*

274 This suggests that network intensity may not fully describe the team's ability to move the ball  
275 quickly. By splitting passing actions into control-time and pass-time, and incorporating  
276 starting and ending positions of passes, a deeper understanding might be obtained.

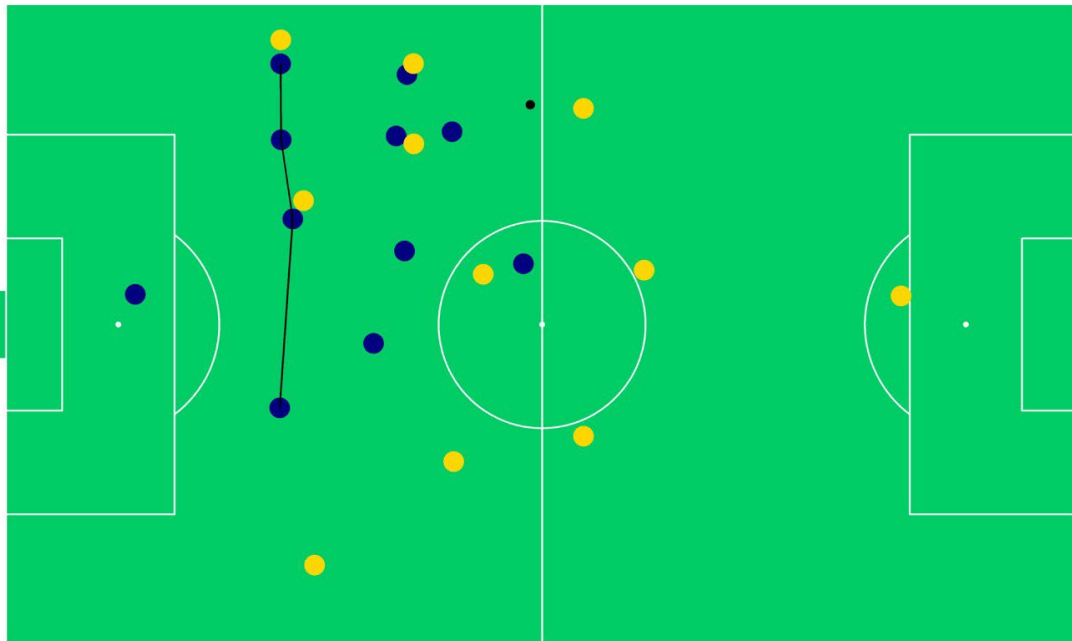
### 277 *Discipline*

278 Another measurement coaches responded positively was the distances between defenders.  
279 This relates to discipline, a principle emphasized by the structure of the defensive unit.  
280 Trigger points were identified as a sub-theme relating to discipline as coach 3 states.

281 *“We speak about where we're going to engage with the opposition, whether it's at the*  
282 *top of the circle, whether it's the halfway line, the distances from side to side, are as*  
283 *important as from front to back and back to front... it comes from, from practice, and players*  
284 *being good enough to do what they've been asked and recognize it. And also disciplined*  
285 *enough to do it.”*

286 Through discussions with a coach, these can act as transition between defensive states of  
287 organization and pressure. However, the measurement presented to coaches focused on

288 defensive structure. In the visualization presented (Figure 2), coach 3 believes players are not  
289 adjusting properly.



290  
291 **Figure 2.** Top-down visualization of players in team 1 (blue) and team 2 (gold). Lines connecting  
292 defenders in team 1 show distance between defenders as they are positioned across the pitch.

293 *“I don't think that's correct. I personally don't think the [Team 1] players are*  
294 *adjusting enough. Like for me, they need to be adjusting more aggressively, especially in the*  
295 *right back.”*

296 Interestingly, there was a difference of opinion between coach 2 and coach 3 in the example  
297 shown. Coach 2 is happy with large gaps appearing based on contextual information.

298 *“we're quite happy for the distance between the centre back and the fullback to be*  
299 *there, because we know that that central midfielder can drop in there as well.”*

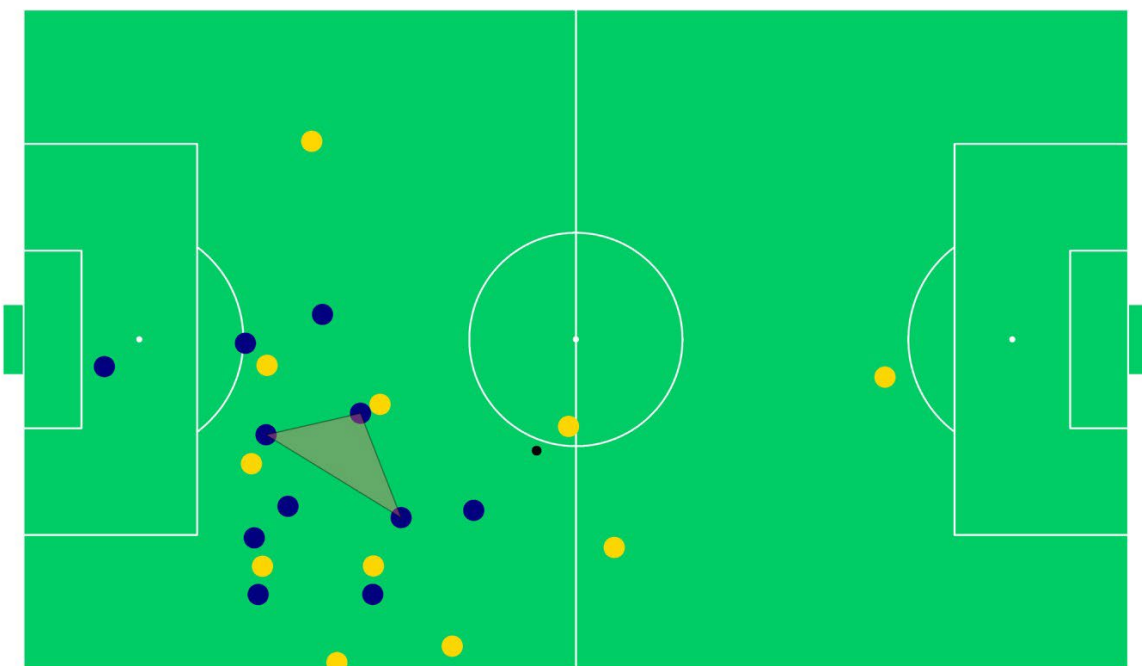
300 Whilst coaches agreed with the importance of this concept, it highlights the need for systems  
301 at clubs to be tailored to individual coaches' principles and philosophies as there is no  
302 universal agreement on nuances held within each concept.

### 303 *Support*

304 The support principle centers around how players organize themselves to provide passing  
305 options. Coach 1 highlighted the importance of angles.

306           *“we play on those sorts of angles, you know, you've got that ability, you know, to see*  
307 *where the balls coming from, if it's coming from a deeper position and also the goal you want*  
308 *to attack so you can make a decision on how to use the ball next.”*

309 This connects to another sub-theme identified as diamonds and triangles. Coaches  
310 emphasized these are important structures created by the players to help teammates. Angles  
311 and distances have been used in multiple investigations, researching the coordination of  
312 player actions<sup>27-31</sup>. Conceptualizing players in groups of 3 and calculating properties of the  
313 triangles they form including distances, angles, areas, and positions on the x-axis can help  
314 quantify team cohesion. These properties are visualized in Figure 3. Whilst measurements of  
315 distances and angles have predominantly been identified through dyadic relationships<sup>28, 31</sup>.  
316 Coaches agreed that triangle formation was an important aspect of team performance with  
317 emphasis on the distances and angles between the players.



318  
319 **Figure 3.** Top-down visualization of players in team 1 (blue) and team 2 (gold). A triangle is annotated  
320 between three central midfield players in team 1, visualizing the distances between the players and  
321 the area.

322 The triangle described by three central midfielders was presented and was identified in the  
323 follow up interviews as the most critical triangle in the formation, however other triangles  
324 were also stated as useful. Coach 3 highlighted the triangular shape in the center midfield is  
325 also important when defending.

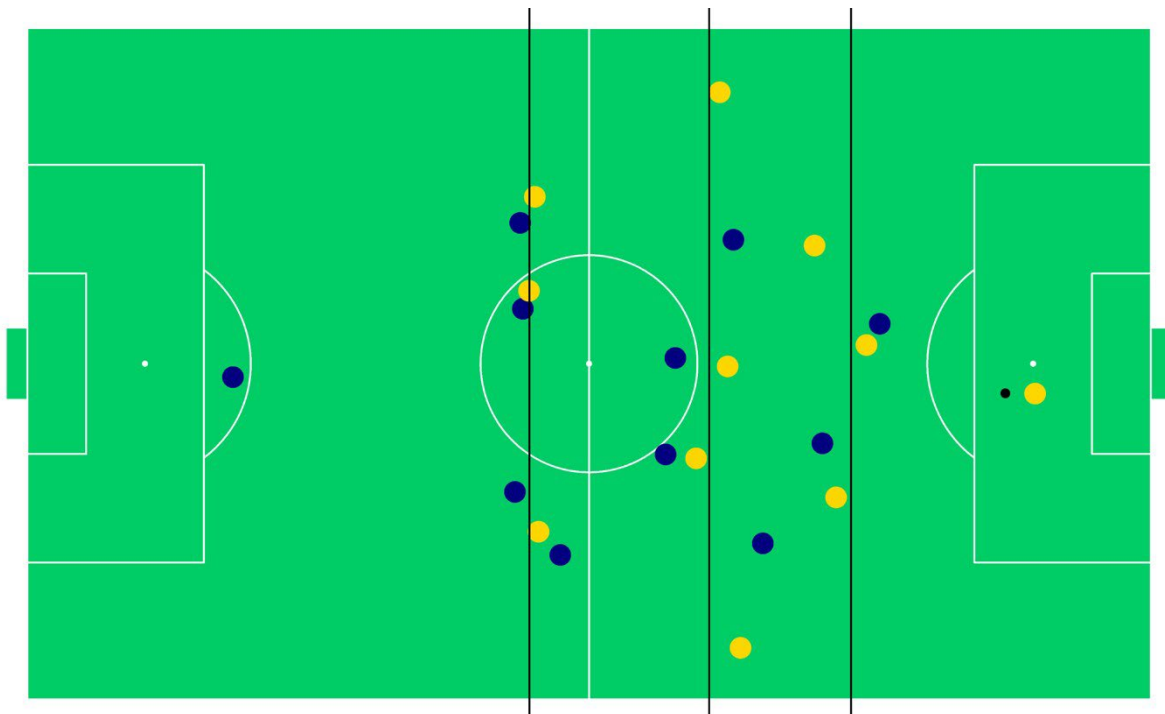


326 “...whether the triangles match, because not sometimes it's just say, my team are  
327 playing two holding midfielders and the number 10. So, in my, the way, I see the game that's  
328 triangle up and the other team might be playing triangle up as well, which means there's not,  
329 it's not man for man, the triangles don't match.”

330 Therefore, triangles, and their relationship between attacking and defending teams may be  
331 important, however, specific measurement for how these relate to each other and what  
332 constitutes successful and unsuccessful organization needs to be identified. Clemente et al  
333 previously investigated defensive triangles, specifically looking at the area<sup>32</sup>. However, these  
334 measures have not been comprehensively explored.

### 335 *Depth*

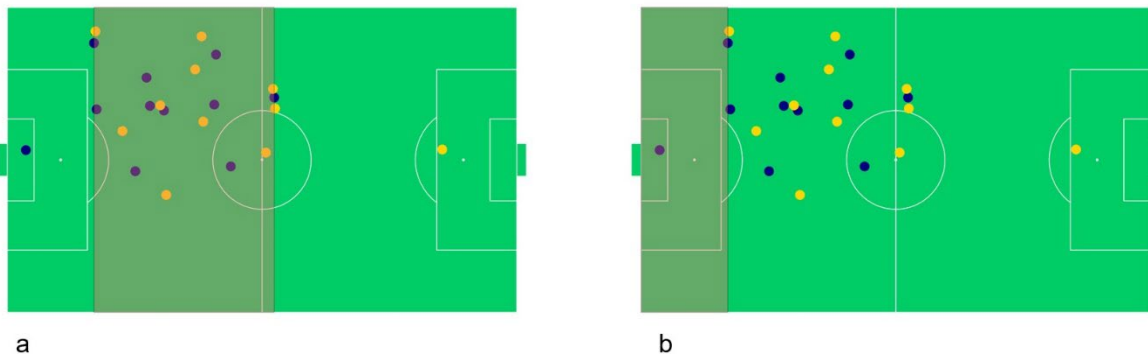
336 The final theme and visualization that resonated with coaches was depth. this relates to the  
337 position of players along the pitch. In this sense, many coaches perceive “*lines*” in their team.  
338 Indeed, this aspect was presented in the initial interviews through group centroids along the  
339 x-axis as shown in Figure 4. This visualization received positive feedback, however, coach 1  
340 mentioned an alternative measurement that appears in the literature often named team length  
341 <sup>33,34</sup>.



342  
343 **Figure 4.** Top-down visualization of players in team 1 (blue) and team 2 (gold). Three lines  
344 demonstrate the average x coordinate on the pitch of the defenders, midfielders and attackers  
345 respectively.

346           *“I’ve seen similar ones where they kind of always have a constant distance from the*  
347 *deepest defender, you know, maybe one of your center backs is behind the rest of the line.*  
348 *And the furthest forward player, you know, is that at 35 or 40 meters.”*

349   The distance between the furthest back and the furthest forward player accompanied by the  
350 distance between the deepest defender and the goal line was measured <sup>34</sup> as shown in Figure  
351 5. In the second round of interviews, coaches stated they actively coached this concept and  
352 that both visualizations aligned with their perception of the principle.



353           **Figure 5.** Top-down visualization of players in team 1 (blue) and team 2 (gold), (a) Team length is  
354 shown by the box that encompasses the width of the pitch and covers the furthest forward and  
355 furthest back outfield players in team 1, (b) Space behind the defence is shown by the box that  
356 encompasses the width of the goal and goes from the deepest defender in team 1 to the goal line.  
357

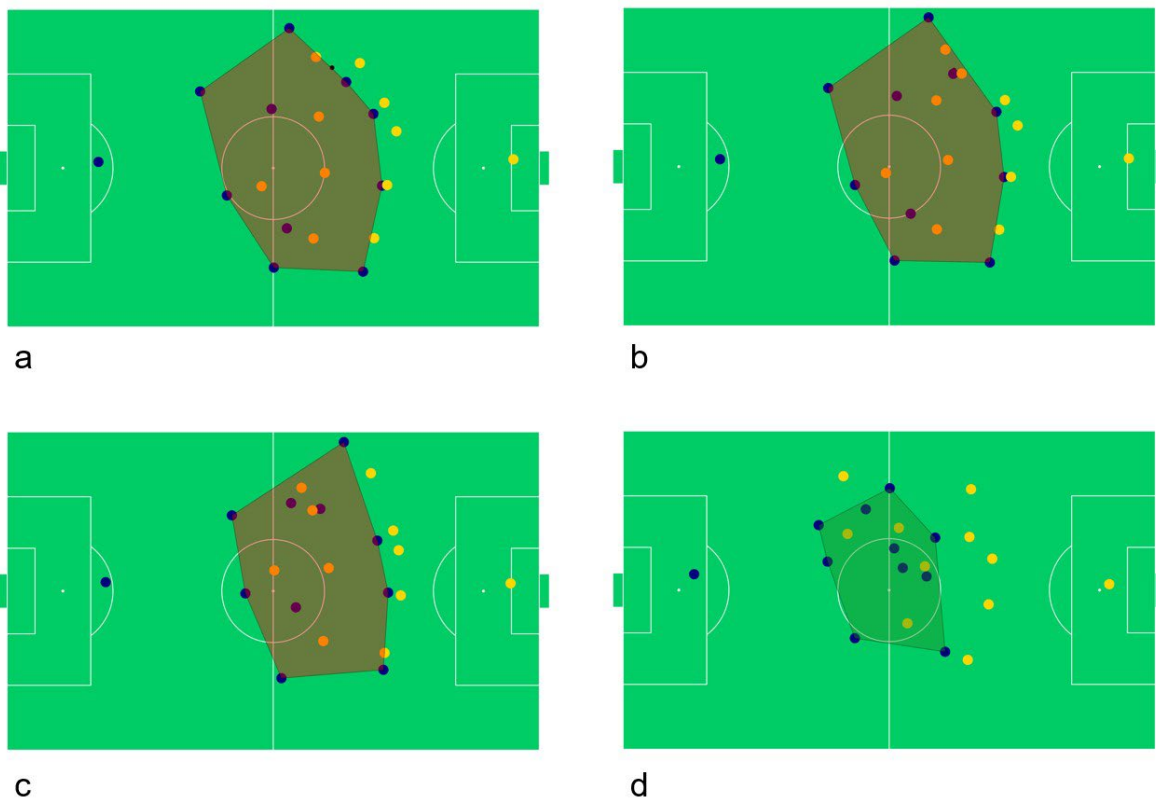
### 358 *Relevant Metrics*

#### 359 *Compactness*

360   Common measures to evaluate the compactness of a team include surface area, stretch index  
361 and team spread <sup>35-40</sup>. These metrics demonstrate similar measurement patterns when  
362 observing intricate attacks <sup>40</sup>. The sub-theme of defensive shape was identified as a  
363 component of compactness; therefore, surface area was selected due to its alignment with this  
364 term (Figure 6). However, simple analyses of surface area along with other measures have  
365 demonstrated they are not sensitive enough to differentiate between successful and  
366 unsuccessful team compactness <sup>40</sup>. To measure this principle in a meaningful way, the  
367 coaches’ conceptualization of it must be understood. Coach 3 highlighted the importance of  
368 speed when returning into defensive shape after transition.

369           *“how quickly you can get back in shape after you lose the ball. And that is something*  
370 *that we coach.”*

371 When discussing these concepts, coaches emphasized the importance of “anticipating” and  
372 “reacting to” the loss of possession. Therefore, these aspects are likely relevant when  
373 evaluating defensive shape through surface area. The output signal of this measurement is the  
374 area encompassed by the outfield players described in figure 6. Anticipation was measured by  
375 the difference between surface area at the loss of possession and 1 second before. Reaction  
376 was measured as the difference between the surface area at the loss of possession and 2  
377 seconds afterwards. Finally, the time to get into a defensive shape was recorded and  
378 measured as the time between losing possession to reaching a surface area of  $600\text{m}^2$ . This  
379 value was selected based on previous data examining other international teams surface area  
380 <sup>40</sup>. Coaches agreed this model made sense; however, this value requires additional contextual  
381 information to be representative as coach 3 highlights that an immediate return into a  
382 defensive shape is not always desired.



383

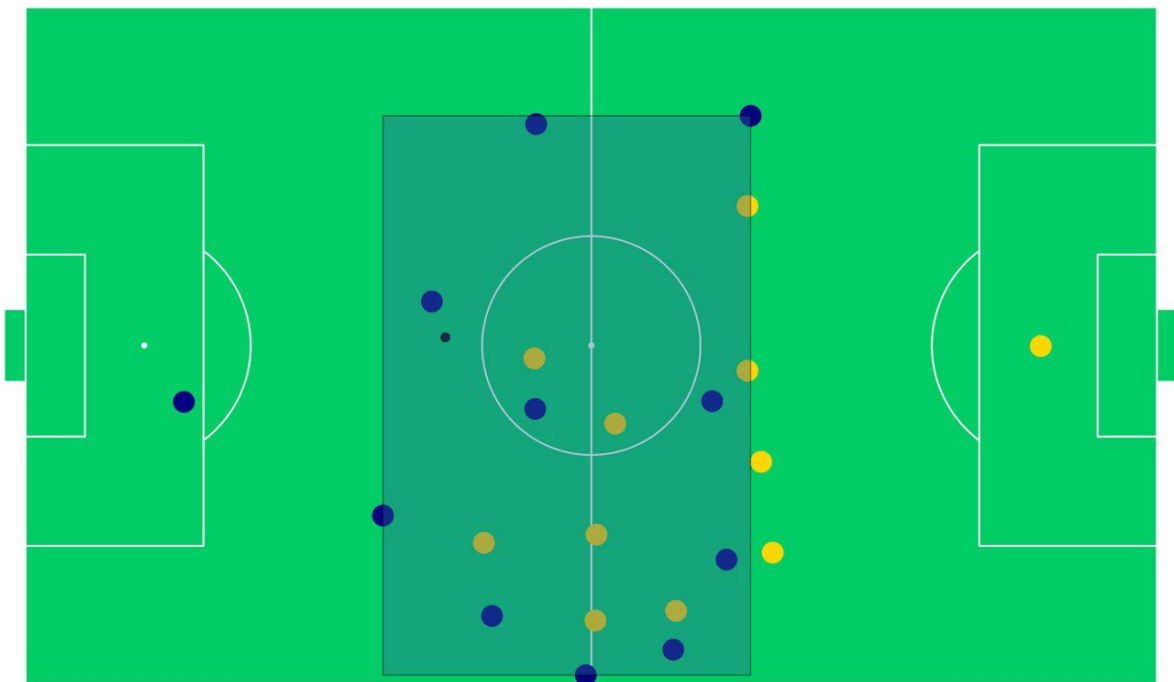
384 **Figure 6.** Top-down visualization of players in team 1 (blue) and team 2 (gold). Surface area is  
385 calculated as the convex hull of the outfield players, visualized through the red polygon. The polygon  
386 describes the surface area of the team (a) 1 s before possession loss, (b) at possession loss, (c) 2 s  
387 after possession loss, and (d) when an area of  $600\text{m}^2$  has been reached with the polygon turning  
388 green.

389            “what is the objective? to get back into shape, and be compact as quickly as possible,  
390 like you're speaking about, or is it to try and win the ball back immediately and to actually  
391 counter press?”

392 *Width*

393 Width is a principle simplistically measured in the literature base<sup>34, 36, 37, 40, 41, 42</sup>. This metric  
394 measures the distance across the y-axis from the player furthest right on the pitch and the  
395 player furthest left. This output is shown in Figure 7 and is often combined with the team  
396 length measurement already discussed.

397 Coaches believed this was an important attacking aspect when presented the visualization.  
398 However, the example provided was specifically chosen to be a situation where the team  
399 were demonstrating low levels of width but were still successful in scoring. Coach 2 believed  
400 that they were performing complex actions due to the tactical set up of the opposition.



401  
402 **Figure 7.** Top-down visualization of players in team 1 (blue) and team 2 (gold). Width is demonstrated  
403 by the box surrounding a box described by the players closest to the touch lines and goal lines.

404            “...you can be really expansive in terms of your width and stuff like that. But if they  
405 sit in and are happy just to defend whatever comes in, then you have to start going in and  
406 trying to manipulate and get movements.”

407 This suggests that applying width directly through players positioning themselves close to the  
408 edge of the pitch was not having the desired effect. One of the sub-themes of width is  
409 creating space and having players in wide areas should facilitate the creation of space in  
410 central areas. Coach 3 highlights that in this situation, the attacking team still have space to  
411 create viable passing options:

412 *“...even though [team 2] are compact, there are still pass options through them*  
413 *available.”*

414 This proposes that width as measured in this example is not comprehensively evaluating the  
415 success of a team in destabilizing the opponent. Considering other sub-themes such as  
416 overloads in wide areas, creating space, and disrupting opponents might help develop this  
417 metric in its evaluation of how teams use width to create space and penetrate defenses.  
418 Alternatively, incorporating overloads in peripheral areas may evaluate a team’s ability to  
419 penetrate opponents out wide.

#### 420 *Delay*

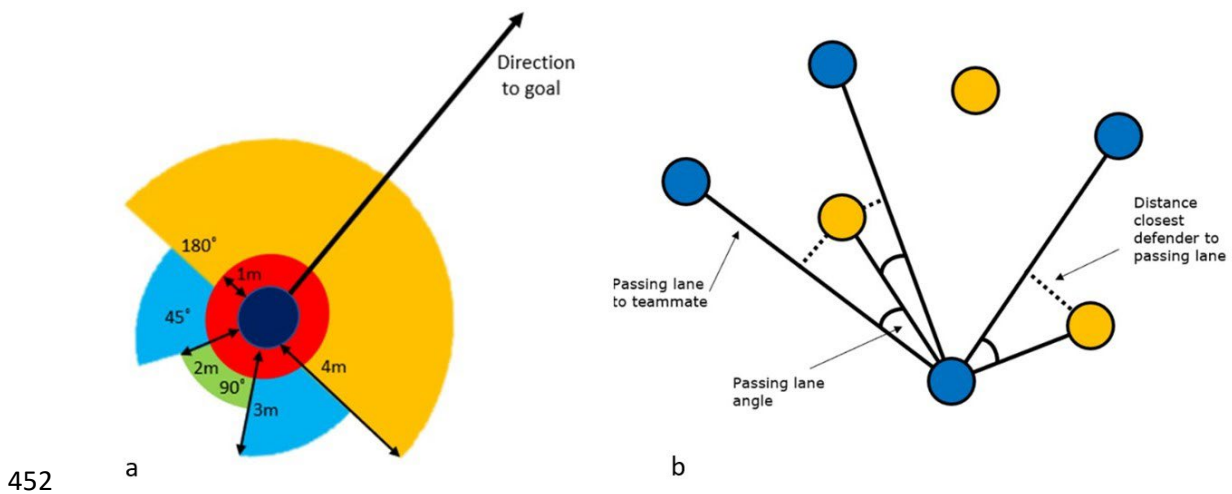
421 After the initial interviews, delay was identified as a theme. However, in the subsequent  
422 interviews it was promoted to a main theme. The following metric is still relevant to  
423 performance and fits closely into the theme of discipline. The metric was initiated based on  
424 comments identifying the role that applying pressure plays in delaying the opponent. Coach 1  
425 states:

426 *“the first thing we have to do is delay the opposition from progressing towards our*  
427 *goal. So again, different applications doing that, you can apply pressure to, you know, the*  
428 *opponent...”*

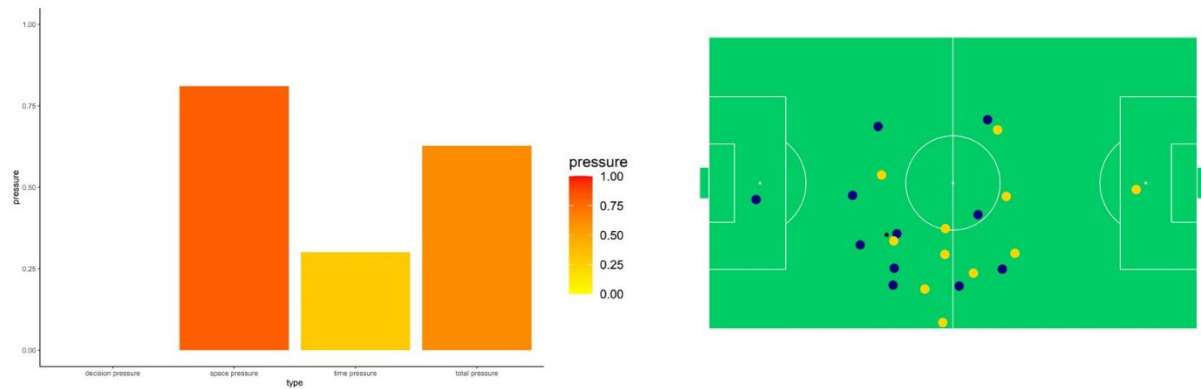
429 Across the three interviews, the coaches highlighted three ways which a player on the ball  
430 can be placed under pressure. Most prominently, the distance between the players was  
431 emphasized as critical in delaying the opponent. However, other factors including the time a  
432 player has on the ball and the number of passing options available. Three models were used  
433 and adapted to evaluate the total pressure being applied to a player. To evaluate the space  
434 pressure, the system devised by Link et al to measure pressure relating to danger was used <sup>43</sup>.  
435 Time pressure was evaluated by the time taken for the closest defender to reach the player on  
436 the ball at their current speed <sup>44</sup>. Finally, decision pressure identified how many simple passes  
437 to teammates were available. This was calculated using passing lanes whereby a simple pass

438 required an angle  $> 10^\circ$  for each player <sup>45</sup>. Diagrams describing calculations for space and  
439 decision pressure can be seen in Figure 8.

440 The three measurements were scaled to represent very high pressure as the value approached  
441 1 and very low pressure as the value approached 0. A weighting procedure was then  
442 intuitively applied where space, time and decision pressure values were multiplied by 0.7, 0.2  
443 and 0.1 respectively before summing together to output the total pressure. Space pressure was  
444 selected as the main component due to previous use as a measurement of pressure <sup>43</sup>. An  
445 animated bar graph was presented to the coaches with the accompanying video footage and  
446 top-down x y coordinates of the players and ball (Figure 9). Coaches stated this made sense  
447 and agreed with the model as accurately describing the pressures on the pitch. However, the  
448 angular threshold of  $10^\circ$  for the decision pressure variable along with the weightings are not  
449 empirically supported and further analysis is required to refine this technique. These concepts  
450 can then be used to accurately understand the pressure that players are under when playing in  
451 matches and consequently tailor training to replicate what they will experience in matches.



453 **Figure 8.** Pressure models, (a) space pressure model, where subzones are created around an  
454 attacker based on the angle to the centre of the goal. Pressure is calculated based on which zone a  
455 defender is in, and their distance to the attacker. The closer a defender is, the higher the pressure, (b)  
456 time pressure measured through passing lanes are identified by the line from the attacker in  
457 possession to their teammates. The angle of a passing lane is calculated between the receiver to the  
458 defender closest to the passing lane.



459

460 **Figure 9.** Top-down visualization of players in team 1 (blue) and team 2 (gold).  
 461 The accompanying graph shows the total pressure calculated from the space, time and  
 462 decision pressure on the player with the ball at each touch. Pressure is interpolated between touches.

463 *Hesitant Metrics*

464 *Penetration*

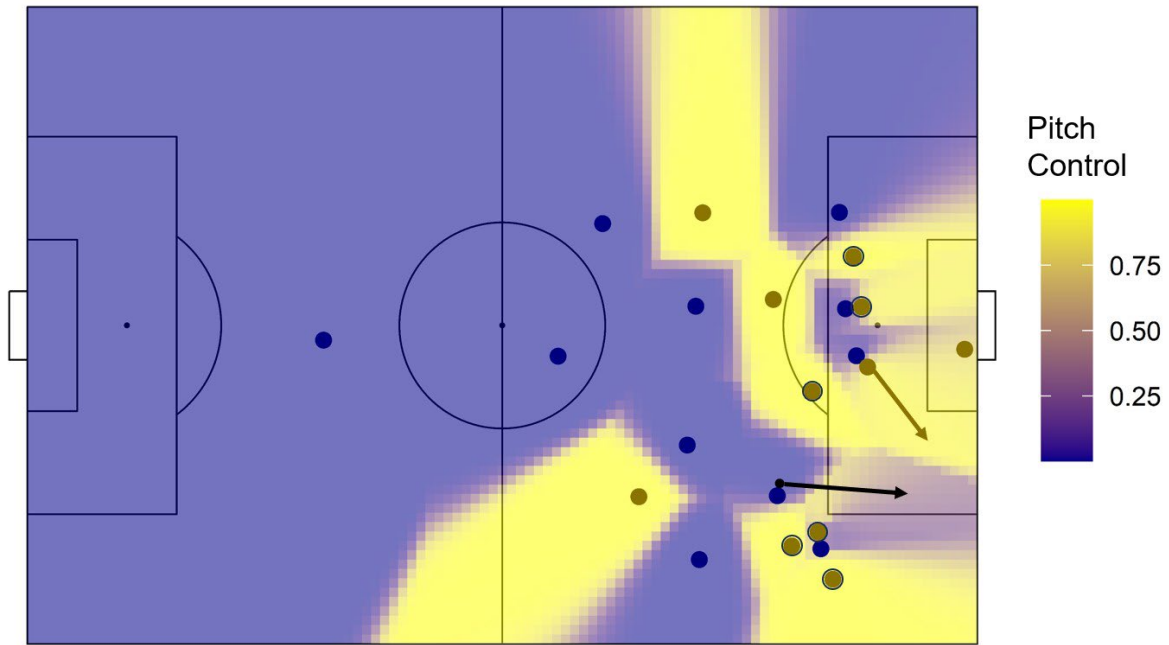
465 Penetration was also changed from a theme to a main theme. Similarly, the proposed metrics  
 466 may still be relevant, although needs adapted further as coaches were skeptical of its use. The  
 467 number of outplayed opponents was used to describe penetrative actions adapted from Rein  
 468 et al <sup>46</sup>. In their analysis, passes were examined to identify the difference in number of  
 469 defenders closer to the goal line at the start and end of a pass. However, this outcome-  
 470 orientated value does not explain how a team successfully progresses through the opposition  
 471 and was used as a guide to identify instances deserving further analysis. Voronoi cell  
 472 computations have been used to examine passing actions and behaviors of high-level teams  
 473 when successfully penetrating opponents through creating space <sup>47</sup>. This mathematical model  
 474 identifies the areas on the pitch closest to each individual and its relevance aligns with a  
 475 comment from coach 1.

476 *“how can we get runs that will, in a sense destabilize, the opposition's organization,*  
 477 *and then use the ball to find those spaces or opportunities to penetrate.”*

478

479 Voronoi cell computations, or variations of the calculation termed as pitch control have been  
 480 suggested to identify likelihood of pass success based on the position a player is in and the  
 481 space they occupy relative to everyone else <sup>47</sup>. Several unique calculations of Voronoi cell  
 482 computations have been implemented across the literature, whereby player movement speed,  
 483 player characteristics, the offside line and the ball trajectory have been implemented to

484 evaluate actions such as passes <sup>46-50</sup>. A simple model was presented to the coaches whereby  
485 player speed was layered on top of positional data to identify areas of the pitch a player can  
486 pass the ball to successfully find a teammate. Figure 10 demonstrates the output of this model  
487 while estimating the probability of a successful penetrative pass that outplayed 6 opponents  
488 with a 55% likelihood.



489  
490 **Figure 10.** Top-down visualization of players in team 1 (blue) and team 2 (gold). Pitch is tiled with  
491 each square and coloured depending on the likelihood of the blue team having possession (values  
492 closer to 0) or the gold team having possession (values closer to 1) when the ball is played into each  
493 area. Outplayed players are highlighted. Movement is shown on one defender to highlight their  
494 movement into a deeper position and not be counted in the outplayed opponents.

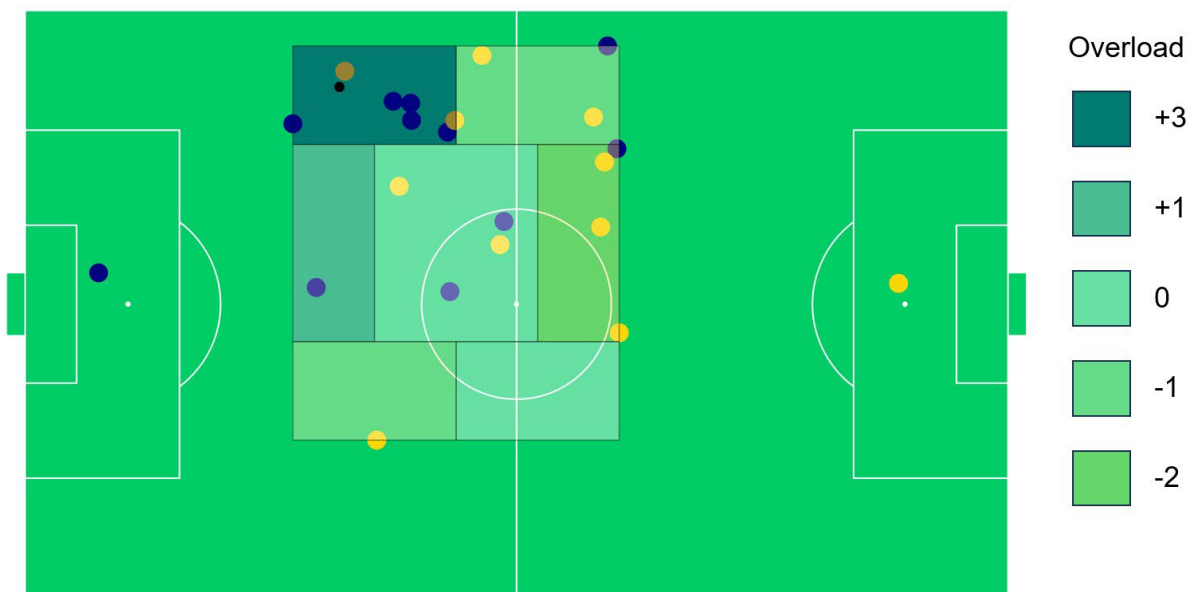
495 When presenting this to the coaches, coach 3 was surprised by how low the success  
496 percentage of the pass was based on the calculation and how they perceived the pass in the  
497 video. That might indicate that a more sophisticated model is required to accurately predict  
498 the success rate of this pass. Moreover, the usefulness of this model for informing training  
499 practices is unclear. Coach 2 emphasizes that identifying and showing previous situations  
500 where this is done effectively or ineffectively does not necessarily translate to players capable  
501 of identifying opportunities and executing penetrative actions successfully.

502 *“You can show lots of pictures of good examples. But at the end of the day, it comes*  
503 *down to quick time decision making and execution.”*



504 *Balance*

505 Coaches frequently discussed “overloads” as a tactically relevant concept. This occurs when  
506 a subgroup of players in a section of the pitch form numerical superiority in a game situation,  
507 for example creating a 2v1 or 3v2. This relates to the defensive principle of balance, where  
508 the defending team seeks to distribute their players so that the opposition is unable to create a  
509 numerical advantage. All coaches highlighted overloads in the wide areas as an effective  
510 tactic to creating dangerous chances. Coaches also identified that overloads in the middle of  
511 the pitch were desirable but more challenging to create. Different models of classifying zones  
512 for numerical advantage have been applied in the research. Clemente et al used 12 static  
513 zones with 4 sections along and 3 sections across the pitch <sup>51</sup>. However, the model selected to  
514 show to coaches used 7 dynamic zones that shifted across the pitch relative to the outfield  
515 players as shown in Figure 11 <sup>52</sup>.



516

517 **Figure 11.** Top-down visualization of players in team 1 (blue) and team 2 (gold). Zones, based on the  
518 length and width of all outfield players are coloured based on the numerical advantage of team 1.

519 Coaches believed this model was not representative of the situation presented to them. In the  
520 example shown in figure 11, the numerical advantage is identified as a 4v2 in favor of the  
521 blue team. However, coaches identified that they perceive this situation to be representative  
522 of a 1v1, as only one defender stands between the highlighted player and goal. Although,  
523 coach 2 suggested that it may be useful with some refinement.

524 *“I like the thought process of it. It's more of an active zone as opposed to static*  
525 *zones”*

526

### 527 *Creativity*

528 Creativity was a recurring theme throughout the interview process. Initially there was no  
529 clear method of quantifying or representing the principle. In the second interviews coaches  
530 were asked to expand on the principle of creativity. In turn, coaches identified that creative  
531 behaviors often lead to penetrative behavior. Coach 2 states.

532 *“I think when something is creative it penetrates a backline or the end result as*  
533 *potentially maybe getting in behind or creating an overload situation.”*

534 This indicates that metrics used for penetration might be helpful in quantifying some aspect  
535 of creativity. However, coaches were hesitant on their value, so would require adaptation.  
536 Based on the sub-themes identified, other measurements could investigate the dynamics of  
537 1v1 situations, as some research has already investigated<sup>27, 53, 54</sup>. Additionally, the sub-theme  
538 of deception, might provide some insight into a team or groups ability to play through the rate  
539 of change in distance between team centroids<sup>54</sup>. Although, such a metric may not align with  
540 how coaches conceptualize such a principle.

### 541 *Future Applications*

542 This methodology identified that novel metrics evaluating collective behavior are  
543 representative of some concepts as understood by coaches. A critical question remains, can  
544 these be used in practice to inform coaching and improve performance? Analysts should look  
545 to establish normative data for metrics that resonate with their coaches. Initially this would  
546 describe team performance within tactical components. This can highlight team  
547 vulnerabilities and inform training design for preparation against specific opponents. An  
548 understanding of how the values and patterns of metric change as constraints are adjusted  
549 could then be used to gain deeper insight in development of an overall performance analysis  
550 tool. Long-term observations could become relevant for developing youth players, creating  
551 pathways, and learning experiences that prepare players for competing at the highest level.  
552 Challenges remain in applying spatial-temporal and network analysis metrics. Considering  
553 the coaches working in the same organization and undergoing similar coach education had  
554 some minor differences in perceptions. This difference has the potential to be greater in

555 coaches with very different educational and cultural backgrounds. Consequently, metrics  
556 tailored to the individual are most likely to achieve buy in from coaches. However, many  
557 coaches may be hesitant to participate in the creation process due to time commitments. In  
558 this investigation, coaches only contributed two hours of their time, but a fully refined set of  
559 metrics would likely require numerous interviews, along with implementation trials.  
560 Moreover, practitioners would be required to continue with their current responsibilities  
561 whilst creating these tools. Based on this investigation, the time requirement for each  
562 iteration was approximately 80-100 hours of work, making the development a slow process.  
563 Future refinements, however, may be less time consuming and once the system is created,  
564 valuable metrics can be fed back immediately after a session.

565 From the interviews, many principles and concepts are measurable using spatial-temporal and  
566 network analysis metrics and as such further study is recommended. A collaborative  
567 approach might be valuable for analysts to consider, helping to achieve buy in from the coach  
568 and develop metrics informing the decision-making processes. A limitation of this research is  
569 that the application of these novel metrics was not tested, limiting the evaluation of a  
570 comprehensive co-creation process. Whilst this research presents evidence that should  
571 encourage analysts to co-create collective behavior metrics through positional and network  
572 data, more research is required to fully evaluate the utility of this process, especially  
573 considering the small sample of coaches used in this investigation. A range of analysis  
574 approaches including approximate entropy<sup>55</sup>, relative phase<sup>56</sup>, and vector coding<sup>57</sup> have  
575 been explored in the literature. Practitioners should remain cautious when applying more  
576 advanced mathematical procedures, however, this research suggests that understanding coach  
577 perceptions might be a valuable approach to start a collaborative process and create  
578 individualized metrics that the coach will find value in.

## 579 **Conclusion**

580 This investigation demonstrates a methodology for collaborating with coaches to create a  
581 unique and tailored performance analysis system that integrates novel metrics applying social  
582 network and spatial temporal analyses to quantify principles of play. Coaches suggested that  
583 network intensity, distance between defenders, team length, space behind the defense and  
584 triads were the most promising metrics. From the interviews coaches highlighted these  
585 models can be useful for improving team performance with emphasis on enhancing training  
586 sessions. Further iteration and practical application of the systems being used are required to

587 maximize the utility of applying novel collective behavior systems. The models require  
588 integration with contextual variables to comprehensively describe and explain the decision-  
589 making processes in football.

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