GIS-Based Football Game Analysis – A Brief Introduction to the Applied Data Base and a Guideline on How to Utilise It

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Abstract. The acquisition of a vast amount of spatial referenced data in professional association football cannot be disregarded any longer in the field of cartography and geo information science. GIS-appropriate data is being captured on a regular basis with sufficient accuracy. The project *"GIS-based Football Game Analysis"* can be regarded as a contribution and effort in order to share our spatial knowledge and accomplishments in GIS-technology within an interdisciplinary field. The objective of this article is to present the applied data base in as much detail as possible in order to draw our colleagues' attention to this interesting data source which facilitates manifold GIS-based analysis opportunities. In this context, tracking and event data are described as well as classified from a geospatial analyst's perspective. Furthermore, unconsidered parameters, which doubtlessly have a certain impact on the game, but cannot be taken into account, are reviewed. Moreover, our approach in the case of the GIS-appropriate data preparation and integration is provided as a guideline on how to utilise football-specific geo data.

Keywords: GIS-based football game analysis, GIS, geographical information systems, sports analytics, football-specific geo data, tracking data, event data, association football, ProzoneSports

1. Prologue and Introduction

"GIS-based Football Game Analysis" is a PhD project at the University of Vienna, Austria. In this sense, association football (soccer) is meant. In the course of this project, analysis of the football's gameplay, based on football-specific geo data utilising GIS-technology, is intended. By taking the spatio-temporal character of football games adequately into account, we are highly confident that this measure could pave the way to a more appropriate and deeper understanding of the gameplay. Thereby, we focus on both, single

player and team analysis in order to explore the complex spatio-temporal interactions and relationships which occur between the players on the field during the entire game. Since football can be described as a union of space and time (Kotzbek & Kainz 2014), game analysis cannot disregard these two essential components any longer. Unfortunately this is often the case (Kim et al. 2011).

Not only in football, but also in almost all sports, analysing games without any spatio-temporal relation produces statistics only (Demaj 2013, Goldsberry 2012). This must be considered insufficient because the only information provided is *what* and *how often* it happened?

Recently, so called *"heat maps"* appeared in the domain of the football game analysis. This term refers to density maps with spectral colours. Certainly, this kind of representation can be regarded as an improvement in respect of its consideration of space and time, especially if it is interactive, because the questions *where* and *when* something occurred are answered. However, the question *why* something happened at a particular time and place remains unacknowledged. From that perspective, heat maps have to be considered a mere eye catcher, as its meaningfulness is finite.

In general, sports analytics are highly valuable for professional football clubs (Di Salvo et al. 2007). Despite this, a deficiency in terms of consideration of space and time can be observed (Kim et al. 2011), leading to less meaningful analysis results. Since a vast amount of geo data is being captured, the usage of GIS-technology can significantly enhance the game analysis by taking the spatio-temporal nature of football sufficiently into account. An overview of the portrayed project is provided in Kotzbek & Kainz (2014).

The purpose of this article is to present and characterise football-specific geo data thoroughly. It is decidedly intended to familiarise our colleagues with this unique kind of data in order to encourage them to participate in the field of GIS-based sports analytics in general. In this course, we set out to focus on both, tracking and event data which represents football games in great detail. The primary objective of this paper is to provide a broad overview of the data employed in our research project. Regarding this, we attempt first: to illustrate that this kind of data conforms to all prerequisites of a geographical information system (GIS), and second: to highlight the inherent high potential of this data which facilitates manifold analysis possibilities.

The rest of this paper is organised as follows: First, the intended comprehensive description of the introduced data comprises not only a definition, but also information about the initial local coordinate system. Furthermore, we will outline the data capturing methods, including the quality of the outcome and the spatio-temporal resolution, respectively. Moreover, we attempt to classify the data from a geospatial analyst's perspective. Besides, parameters which doubtlessly have a certain influence on the game but cannot be measured are reviewed. In addition, we present our approach on how we conducted the GIS-appropriate data integration process. Finally, this article will be concluded in its last section.

2. Overview of the Applied Football-Specific Geo Data

Since almost two decades, acquisition of football-specific geo data by several companies can be observed (Di Salvo et al. 2007). Although geo data can be considered as a core component of any GIS application (Longley et al. 2005), this particular data has been widely unknown for a long time in the field of cartography and geo information science. There is a deficiency on a generally accepted definition about what *"football-specific geo data"* may be. This term was first introduced by Kotzbek & Kainz (2014) and refers to a special kind of geo data that encompass all spatio-temporal data which directly represent the entire gameplay of a football game.

However, not only in football but also in a number of other sports disciplines, acquisition of a vast amount of spatial referenced data is a significant part of sports analytics' everyday business. Regarding football, over time two different types of geo data have evolved. They are commonly referred to as tracking and event data.

Our research project is kindly supported by *ProzoneSports*[1] which is one of the world's leading companies for performance analysis in sports. The data, which was provided as xml files (extensible markup language), is introduced in the subsequent three sections. The following statements relate exclusively to our own experience with handling those data as well as supporting facts provided by employees of *ProzoneSports*, except where otherwise specified.

2.1. Building the Bridge to GIS: Tracking and Event Data

The term *"tracking data"* is widely employed within several different GIS applications, such as tracking transport fleets in the course of network analyses. Comparable to that, tracking data in football corresponds to tracks gathered as consecutive point data linked with a certain timestamp provided as an attribute to the spatial data. Instead of *"tracking data"*, the term *"physical data"* is also common. However, there is no preferred term. Based on this spatio-temporal information, speed is calculated at each single point and also provided as an attribute. All this information is separately available for each player as well as the ball. Occasionally, data representing the match officials

[1] http://www.prozonesports.com

is also provided. The provision of the z-coordinate is also common for the ball's path in order to reconstruct its trajectory.

Whereas tracking data is directly linked to the game's protagonists and the ball, *event data* represents connected dynamic interactions between the players. These comprise all ball specific events, such as passes, tackles, shots, etc. Furthermore, any other events which occur during the course of the game, for example, injuries or substitutions are also captured and provided.

ProzoneSports has roughly 200 employees around the globe, including three main offices in Leeds, UK, Nice in France and Düsseldorf in Germany as well as several regional offices on each continent, except for South America. *ProzoneSports* clientele consists of professional football clubs, national leagues and football organisations as well as media partners. At this point, it would be very interesting to share details about how much one game dataset actually costs. However, the price is in dependence upon the individually negotiated agreements between *ProzoneSports* and its clients. In this particular case, several factors are essential, for example, the contract duration, the agreed competitions as well as the systems scope. Therefore, general statements cannot be given. Nevertheless, it is acknowledged that professional football clubs invest heavily in appropriate data and analysis programs in order to remain competitive (Ohno et al. 2000).

Since all datasets features spatial information within a local coordinate system the basic requirement of data integration into a GIS is accomplished (Longley et al. 2005). Therefore, the following technical description of this data is intended to provide detailed insights into our data base.

2.2. Data Capturing Methods and Technical Description

Both, tracking and event data are based on the same local coordinate system which refers to the international standardised football field. The total pitch size is determined to 105 m x 68 m by the *FIFA's*[2] *laws of the game*[3]. The origin of the local coordinate system is positioned at the field's centre.

Within this spatial framework, all tracks and events are defined. However, not all football fields are standardised. In the course of international competitions, for instance, there is a range of 10 m and 11 m for the length and the width, respectively. Nevertheless, the standardised dimensions are employed throughout whereby the data is scaled where necessary. Indeed, this fact leads to inaccuracies which are widely negligible, though.

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[2] Féderation Internationale de Football Association: http://www.fifa.com

[3] http://www.fifa.com/mm/document/footballdevelopment/refereeing/02/36/01/11/27_06_2014_new--lawsofthegameweben_neutral.pdf

The acquisition of *tracking data* is conducted with a number of high speed cameras. Its total amount depends on the system applied. However, a decrease in the total number of cameras has been observed, owing to progressive technological development in recent years. However, 6 to 8 cameras are presently common, even if its placement along only one side line is sufficient today. Requirements applying to the stadium are relatively low. First, an online connection is demanded. Furthermore, the automated referencing process is based on the field's lines. Therefore, marking the lines well is essential and the cameras have to be installed at a certain height. Although there is no predetermined limitation regarding the camera's height, a minimum height of at least 15 m is recommended to gain reliable data. In general, an increase of the cameras' height has a positive influence on the data accuracy. Unfortunately, details about the applied tracking algorithm cannot be provided at this point.

The data points' acquisition is conducted with 25 fps which leads to a vast amount of geo data. Considering all 22 players, the ball as well as the referee team, if applicable, about 3.5 million tracking data points are being captured in the course of one game only. This vast amount of data leads to xml-file data sizes of about 50 MB. The acquisition of tracking data is conducted entirely automatically. In addition, permanently installed systems can be remotely controlled, whereas mobile systems have to be operated by an assistant on the spot.

The collection of *event data* is entirely conducted manually after the game by employees of *ProzoneSports*, who received a special training in advance to cope with the required tasks. In dependence upon each individual's previous experience the duration of the employees' formal training varies. Based on the tracking data's spatio-temporal information, event datasets are recorded by repeatedly watching every game scene. Simultaneously, the occurred events are matched with predefined game events which are collected in a catalogue. In this case, common TV recordings are applied, since they are considered more suitable than the recordings of the tracking cameras because on TV enlargements of controversial situations are embedded. Although human beings have to decide whether, for instance, this particular event is a cross or a simple pass, this kind of data capturing can be regarded as mostly impartial.

Along that process, on average more than 2.600 different events are being captured for one single game. In addition, about 30 event classes are distinguished which are subdivided into sub classes. For example, a cross is regarded as a sub class because it is a special kind within the pass class. In contrast to tracking data, the file size of event data is comparatively low and amount to approximately 1.5 MB. To ensure maximum quality, a supervisor controls the output. The duration of this process predominantly depends on how many employees are working on it concurrently. Furthermore, the video's quality also has a certain impact on the working time. At *Prozone-Sports*, the staff's total number for processing one game varies from one to five, in dependence upon the current workload distribution. However, an empirical value indicates that an average duration of five to ten hours per one game is common. Analysing this kind of data makes it possible to examine the spatio-temporal distribution of certain events during the game. Beyond that, it is of particular interest, if tracking and event data are being combined by an attributive join via the available timestamp. This measure facilitates manifold analysis opportunities.

In both cases, the data structure is clear. For instance, within the xml-file the information is well-organised in several parent-child relationships which entails a particular and legible hierarchy.

Although both, tracking and event data were provided as xml files, other formats are also available. Since the analysis software *Prozone3/AmiscoPro*[4] for tracking data and *Prozone MatchViewer*[5] for event data are based on unique data formats, all others have to be considered as exchange formats only.

2.3. Data Accuracy

According to an employee of *ProzoneSports* a spatial accuracy of at least 20 – 30 cm regarding tracking data can be guaranteed, in dependence upon different factors, such as lighting conditions, etc. In this case Di Salvo et al. (2006) examined the spatial accuracy at different speeds and observed a range of average errors between 1 cm and 23 cm for dissimilar runs and speeds. Indeed, this is not sufficient to determine if the ball crossed the line or not. However, combined with a high resolution of 25 fps it is more than satisfactory, if single movements and movement patterns are analysed in order to gain insights into the dynamic spatio-temporal structure of the game.

Carling et al. (2008) contended that no standardised test for the tracking data's validity, reliability and objectivity exists. Nevertheless have several studies, including Di Salvo et al. (2006), Di Salvo et al. (2009) and O'Donoghue & Robinson (2009) attempted to fill the gap by conducting various analyses. All three surveys demonstrated that the tracking data of *Prozone-Sports* are satisfactorily accurate. For example, Di Salvo et al. (2006) stated: *"The results [...] show that Prozone represents a valid motion analysis system for analysing movement patterns of footballers on a football pitch."* In

[4] For more information: http://www.prozonesports.com/product/prozone3/
[5] For more information: http://www.prozonesports.com/product/matchviewer/

accordance to that, O'Donoghue & Robinson (2009) concluded: *"…the current investigation found that the location of player movement recorded by the ProZone3 player tracking system […] is sufficiently accurate for scientific research and coaching applications."*

Since event data are captured manually, reliability is a key factor. Regarding this Bradley et al. (2007) found evidence that event data are sufficiently reliable for scientific purposes as well as in the coaching context. In terms of spatial accuracy an average error of 3.6 m was observed. However, a join between tracking and event data overcomes this comparatively high spatial error. Bradley et al. (2007) finally concluded their study as follows: *"… since this system provides acceptable levels of error for event time and position, this gives the coach the opportunity to provide detailed analysis of technical elements that occur in games and therefore improve the quality of feedback provided to the players."*

3. Data Classification from a Geospatial Analyst's Point of View

Having described the applied football-specific geo data in the previous chapter, we now attempt to classify it from a geospatial analyst's point of view. First, both, tracking and event data can be regarded as *vector data* in form of *point features*. According to Mitchell (2012) such data is defined by a single pair of coordinates which determine the features' position. In this case, Zeiler & Murphy (2010) indicate that *point features* refer to *"small features and locations where measurements are made"*, a definition which is precisely applicable to the characteristics of football-specific geo data.

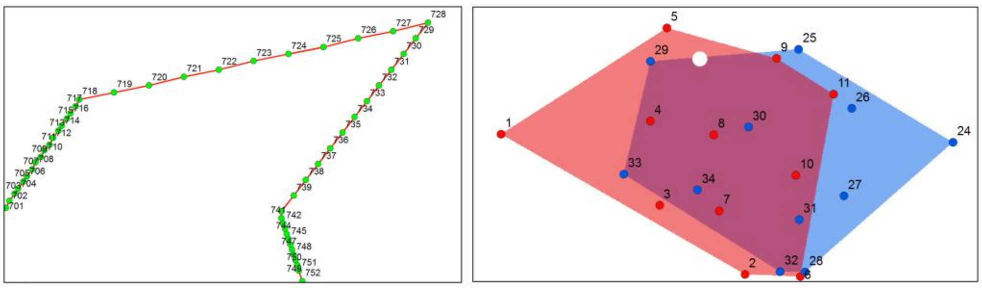

Figure 1. Derivation of line and polygon features from tracking data points

In further consequence, line and polygon features can be created based on the existing point data, as shown in *Figure 1*. For example, a conversion from point features representing a movement's vertices to a line feature, depicting the entire path, would be conceivable. In this case, the created lines between the points can function as edges of a network which can be considered as a *"specific type of vector data"* (Mitchell 2012). Moreover, the players' points of one team can be interpolated to a polygon feature in order to obtain the teams' covered space on the football field at a particular time. This could serve as an input to further intersection analysis, for instance.

Tracking and event data do not only comprise of coordinates, but also of attribute data which are *"… descriptive information about geographic features"* (Mitchell 2012). The provided timestamp refers to a ratio scale, owing to its absolute zero. Besides, event data contains additional attributes. Contrary to the timestamp, other attributes may have other scales. For example, the vast majority of attributes, such as the "*event name"* and the involved "*body part",* refer to nominal values. Ordinal and interval scales do not appear in general. Furthermore, almost all attributes features text data types.

4. Unconsidered Parameters

The game of football is significantly influenced by external impacts and parameters which predominantly cannot be taken into account in the course of the GIS-based game analysis. Although the following parameters doubtlessly have a certain impact on the game, they are not or cannot be captured, neither quantitative, nor in a qualitative manner.

In general, two specific kinds of parameters can be distinguished, *internal and external factors*. Although real-time performance analysis is presented by several companies, such as *ProzoneSports*, signs of *fatigue* as well as *mental and physical conditions* are not captured. Furthermore, the measurement of the external factors' impact on the players is almost impossible. *Atmospheric conditions* such as *temperature*, *humidity* as well as *wind* and *lighting conditions* undeniably have a certain impact on the players' performance. Moreover, *altitude* may be also crucial. For instance, playing football at sea level is much easier than playing at high altitude. In addition, the *ground's condition* is changing continuously, especially due to dynamic *atmospheric conditions*.

Between these internal and external factors, *cross connections* can be traced. For example, playing on a muddy ground can be considered more debilitating than playing under dry circumstances. Besides, the *stadium atmosphere* may affect the players mentally, etc.

5. GIS Data Integration

Football-specific geo data is not exclusively provided by *ProzoneSports* but also by other data gathering companies, such as *Opta*[6] and *Deltatre*[7] as well as their subsidiaries. The data not only can be distinguished by its content and its extent but also primarily regarding its structure. The latter aspect leads to the demand of customised solutions in the case of GIS-appropriate data preparation and integration. Despite the numerous different possibilities of coping with the required tasks, our adopted approach is portrayed in the following two sub-sections.

5.1. The Systems Applied

In the case of the proposed analyses, which are described in Kotzbek & Kainz (2014), *ArcGIS for Desktop*[8] 10.2 and higher, developed by *ESRI*[9], is utilised. Based on years of practical experience, we assume that this software provides a well-established, well-documented and robust GIS-platform.

Since *Python*[10] is the preferred programming language of *ArcGIS* software (Zandbergen 2013) it is reasonable to apply it for the necessary data preparation and integration tasks. However, initially it is essential to examine the raw data in order to understand its structure.

While reading event data with common text editors no considerable problems have been observed, whereas almost all programs crashed when opening tracking data, due to its immense data size. In this case, *firstobject XML editor*[11] was applied to solve this problem as it enables the user to load multi-megabyte xml-files fast.

5.2. Our Approach

Although *Python* is a programming language (Zandbergen 2013), it was applied as a scripting language only. The created scripts' main tasks are briefly outlined to portray our approach. Previously, the entire data preparation and integration process is illustrated in a simplified way in *Figure 2*.

The created script is in the centre of the entire data preparation process and can be run as a custom tool within *ArcGIS*. Executing a script as a tool yields to several advantages, such as providing the user with additional information

[6] http://www.optasports.com/
[7] http://www.deltatre.com/
[8] http://www.esri.com/software/arcgis/arcgis-for-desktop
[9] http://www.esri.com/
[10] https://www.python.org/
[11] http://www.firstobject.com/

via the *ArcGIS Help panel* (Zandbergen 2013). In this case it is primarily intended to provide a straightforward GIS tool to users even without any *Python* but *ArcGIS* knowledge. However, the script itself is only one particular part of a comprising script package which consists of additional tool data and layer files.

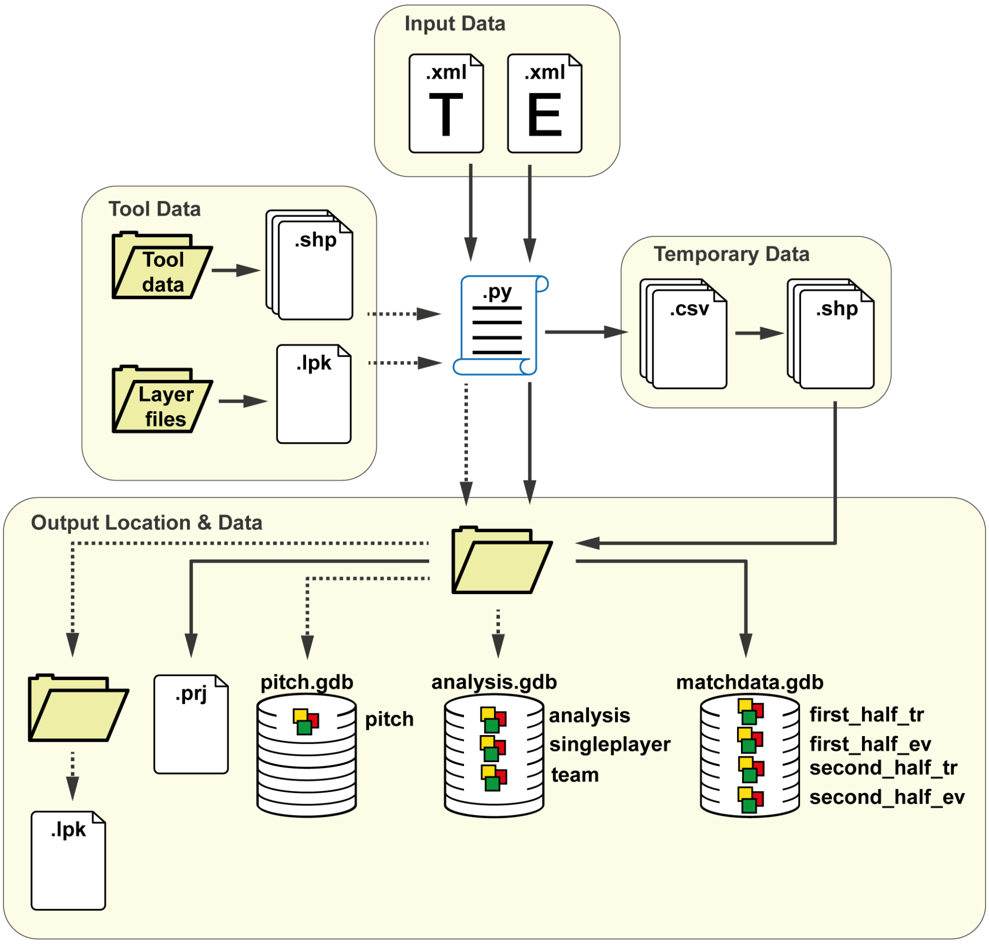

Figure 2. Illustration of the major steps of the GIS-appropriate data preparation and integration process (Kotzbek & Kainz, 2015)

The script comprises five input parameters: 1) *Select Tracking Input Data*, 2) *Select Event Input Data*, 3) *Set Output Workspace*, 4) *Create pitch.gdb* (optional) and 5) *Create analysis.gdb* (optional). Running the tool creates an output folder and therein a geodatabase named *"matchdata"*. According to Zeiler & Murphy (2010) *"... in ArcGIS, the geodatabase is the native data* *structure for storage and analysis of geographic information"*. This geodatabase contains four feature datasets separating the origin input data in halftimes and data type. If the two optional parameters (4 and 5) are also selected, two more geodatabases will be created. First, *pitch.gdb* which contains pitch related point, line and polygon feature classes stored in a feature dataset. In this case, a proper *layerpackage file* (.lpk) is also copied from the supplied tool data, in order to provide the user with an adequate graphic analysis environment. Second, *analysis.gdb*, wherein two empty feature datasets provide output locations for further single player and team analysis, respectively. Moreover, three different spatial zoning variations are stored as polygon feature classes within an appropriate feature dataset.

The successful execution of the tool demands the import of the following modules and sitepackages, respectively: *arcpy*, *os*, *sys*, *csv*, *xml.etree.ElementTree* and *shutil*. After the definition of the input parameters a spatial reference file as well as the geodatabases described above, are created. Basically, the xml trees of the input data files are parsed, whereby *parents* and *child nodes* are defined. This measure enables the programmer to browse through the file and select specific information via determined xml-tags.

Once the entire output location is created, the event data file is parsed in order to receive additional player information, such as "*Jersey Number"*, "*Tactical Position"*, etc. This information are going to be appended later to the output tracking data. Three lists are created subsequently to separate the data into superior tracking objects, representing the teams and the ball. Furthermore, the lists are populated with necessary column headers. In this process the x/y-information are of greatest importance. Since the measurement units of the original coordinate system differs from that of the applied local coordinate system a modification of the x/y-information is essential. Whereas the ball object is described with basic attributes only, such as *"Half_ID"*, *"O_ID"*, *"Frame"*, *"Min"*, *"Sec"*, *"GameMin"*, the players are provided with further fields, such as *"Team_ID"*, *"Player_ID"*, *"Jersey_No"*, *"Position"* and *"Starter"*, in order to facilitate further data classifications and special queries. The script passes through several iteration processes to populate the created lists with required information from the xml input file. As a result specific tracking lists representing each player and the ball, are created, which are further exported into intermediate csv (comma-separated values) text files. For this purpose, a csv writer, which is a part of the csv-module, is required. Based on the single csv files, intermediate *ESRI* shape files (.shp) are generated and finally copied to the corresponding feature datasets as feature classes. Regarding this, the allocation is conducted by the fields *"Half_ID"* and *"O_ID"*/*"Team_ID"*. After that all intermediate data are deleted.

In the case of *event data*, the process of data preparation and integration is almost identical to that described above. However, only one list has to be created in advance, which is also populated with basic attribute headers, such as *"Half_ID"*, *"Frame"*, *"Sec"*, *"Min"*, *"GameMin"*, *"X_cal"*, *"Y_cal"* and *"Event_Name"*, as well as all specific event fields, such as *"Bodypart"*, *"Duel_Type"*, *"Blocked"*, etc. During the tool's execution the script passes through the input data file and creates lists for each single event based on its *"Event_Name"*. Moreover, the lists are separated in halftimes in regard to its *"Half_ID"*. In dependence upon the very particular event type, all unnecessary attributes are deleted. For example, a foul event does not contain any information if the ball hits the posts, which is why this field is not essential. Besides the creation of event specific feature classes, two feature classes containing all events of one halftime each are also compiled in order to provide a chronological order of all events. In this particular case, basic attributes are given only.

In conclusion, the tool creates GIS-appropriate match data, alongside the optional output. In general, the match data is separated in halftimes and further categorised in tracking as well as event data. Furthermore, each tracking object and every event type is represented by a single point feature class. This fragmented data management structure facilitate manifold analysis opportunities due to abundant connection possibilities.

The script package for the data preparation and integration described above has to be considered as a prototype. Therefore, further improvements are scheduled. Especially the creation of the intermediate data files should be avoided. However, bugs were observed where feature classes were directly derived from the lists. Due to this, the described process makes a circuit admittedly, though it is robust.

Visualising football-specific geo data requires an appropriate analysis environment, in form of a football field. In this case, the modelling process was already described in Kotzbek & Kainz (2014) and can reread there. The following figures (3-5) are provided as evidence in order to demonstrate that it is possible to integrate football-specific geo data within a GIS environment.

Figure 3 displays first, the goalkeeper's and a forward's path, depicted as single tracking point features. If the tracks of all players would be presented, a differentiation would be definitely impossible. However, this figure highlights the vast amount of available football-specific geo data. Second, the ball's track is demonstrated. In comparison with the players' tracks, the straight movements of the ball are conspicuous.

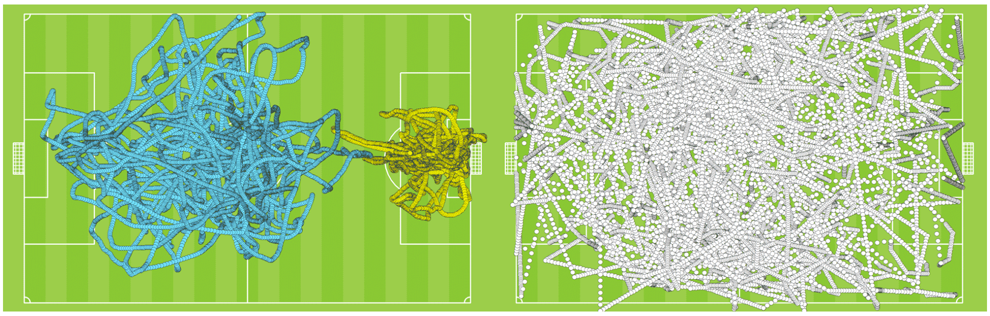

Figure 3. Representation of tracking data points for the duration of one halftime. Left: the goalkeeper's (yellow) and a forward's (light blue) tracking data points. Right: the ball's tracking data points (data source: ProzoneSports)

Whereas *Figure 3* illustrates the full amount of raw data, *Figure 4* shows the locations of all players and the ball at a particular time. Applying tracking analysis tools, covered paths can be displayed as lines. Furthermore, it is possible to animate the entire data based on the available timestamp to reconstruct the dynamic spatio-temporal structure of the game, either in the course of single scenarios or the complete halftime. Such measures can assist to understand the course of the game in retrospect.

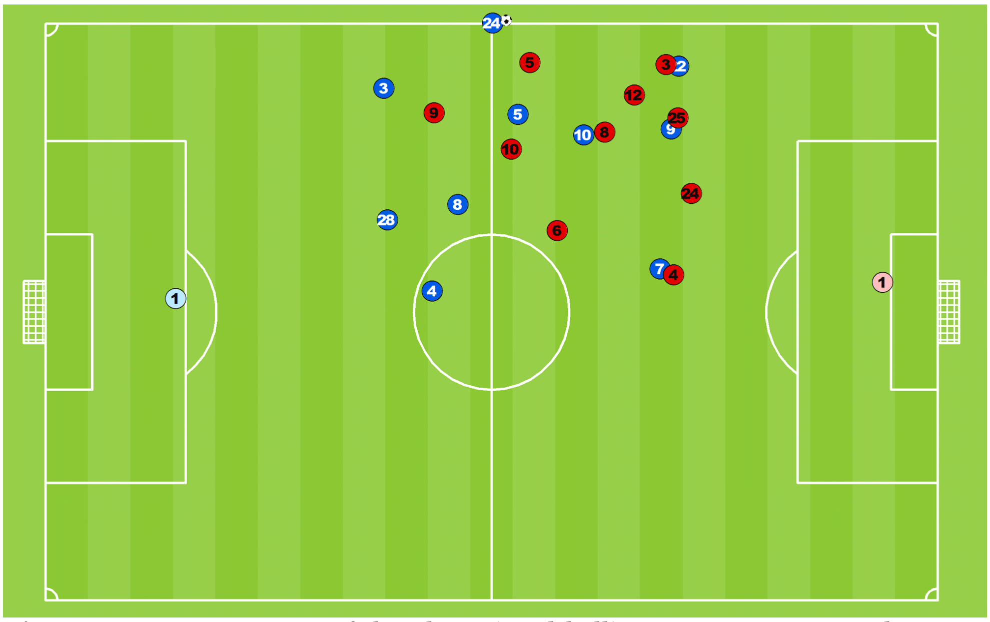

Figure 4. Representation of the players' and ball's position at a particular time, based on tracking data points (data source: ProzoneSports)

Finally, *Figure 5* provides an overview of the diversity of event data. Although a selection is demonstrated only, its comprehensiveness is obvious.

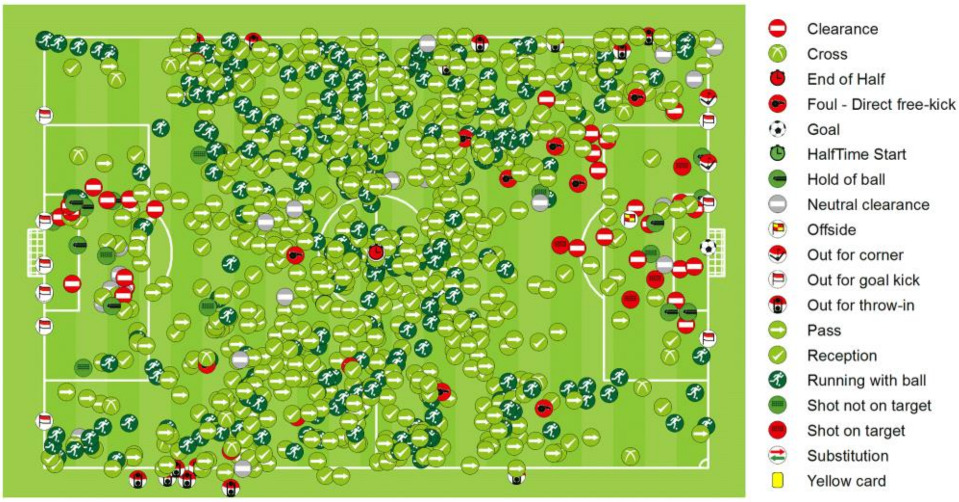

Figure 5. Representation of a selection of events which occur for the duration of one halftime (data source: ProzoneSports)

6. Conclusion and Outlook

The description about football-specific geo data above indicates that this data source is interesting because of its inherent manifold analysis opportunities. This is particular the case if tracking and event data are combined and analysed. As a consequence, further contributions and efforts are highly demanded to establish a new field of application within our scientific discipline and beyond.

The primary aim of this paper was to introduce this special kind of data in as much detail as possible in order to draw our colleagues' attention to GIS-based game analysis. Not only in football, but also in other comparable (team) sports disciplines, geo data is being captured on a regular basis. Most notably, the data fulfil all requirements of a GIS. Hence, as cartographers and GI-experts, we should be aware of this data and analyse them scientifically.

Research at our department will continue. After one year of investigation and negotiations with data providing companies the development of a GIS-appropriate data base can be considered as completed. In the next months we will focus on the theory in more detail in order to determine the analytical procedure thoroughly. Following this, first spatio-temporal analyses, which were already outlined by Kotzbek & Kainz (2014), are scheduled, whereby first results can hopefully be shared soon.

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