A CUSUM tool for retrospectively evaluating team performance: the case of the English Premier League

Abstract

Purpose

Despite being a widely used management technique, cumulative sum (CUSUM) analysis remains almost unheard of in professional sport. To address this, CUSUM analysis of soccer match data from the English Premier League (EPL) was performed. The primary objective of the study was to evaluate CUSUM as a tool for assessing 'on-field' team performance. As a secondary objective, the association between managerial change and team performance was evaluated.

Design/methodology/approach

CUSUM was applied retrospectively to goal difference data for six EPL teams (Arsenal, Chelsea, Everton, Liverpool, Manchester United, and Tottenham) over 23 consecutive seasons from 1995-2018. This was supplemented with change point analysis to identify structural changes in mean goal difference. Succession was evaluated by mapping historical managerial changes onto the CUSUM plots for the respective clubs.

Findings

CUSUM analysis revealed the presence of structural changes in four clubs. Two structural change points were identified for both Chelsea and Everton, one for Manchester United and Tottenham, and none for Arsenal and Liverpool. Relatively few managerial changes coincided temporally with structural changes in 'on-field' performance, with most appointments having minimal impact on long-term team performance. Other factors (e.g. changes in ownership) appear to have been influential.

Research limitations/implications

The study was limited by the fact that only successful teams were investigated.

Practical implications

CUSUM analysis appears to have potential as a tool for executive decision-makers to evaluate performance outcomes in professional soccer.

Originality/value

The study is the first of its kind to use CUSUM analysis to evaluate team performance in professional soccer.

(250 words)

Keywords

OR in sports; CUSUM; managerial succession; soccer; English Premier League.

Funding

The study was self-funded.

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1. Introduction

Cumulative sum (CUSUM) analysis is a well-known statistical process control technique (Bissell, 1969, Woodall and Adams, 1993, Montgomery, 2007) that enables users to readily identify points in time where 'performance' has substantially deviated from the norm. First developed in the 1950s (Page, 1954), CUSUM is widely used in the production engineering (Woodall and Adams, 1993, Stapenhurst, 2013, Vera do Carmo et al., 2004, Davies and Hanchard, 1980, Bissell, 1969) and energy management (Beggs, 2010, Puranik, 2007, Barney et al., 2008) sectors as a tool for analysing time-series data and detecting when structural changes have occurred, or when performance has deviated (either positively or negatively) from some agreed target. CUSUM has also been used successfully to assess clinical performance in the healthcare sector (Noyez, 2009, Neuburger et al., 2017). As such, CUSUM has proven to be a useful technique for assessing success or failure when strategic decisions are made (Gove et al., 2013, Neuburger et al., 2017, Scandol, 2003), and also for minimising damage when things go wrong (Bissell, 1969, Chang and McLean, 2006, Li et al., 2017). Yet, despite its widespread use in other sectors, CUSUM remains almost unheard of in sport in general, and professional soccer in particular.

That CUSUM is largely unknown in sport is somewhat surprising, given that the literature base relating to CUSUM is vast, with thousands of academic papers and textbooks devoted to the subject. This omission may, in part, be because sport management scholars prefer the use of multivariate explanatory models when analysing performance. These models generally utilize linear and other regression techniques (e.g. ordinary least squares (Lago-Penas, 2011),

generalised least squares (Fizel and D'Itri, 1999), logit models (d'Addona and Kind, 2014), ordered probit models (Audas et al., 2002, de Dios Tena and Forrest, 2007), multiple models (Koning, 2003), and mixed logit models (Frick et al., 2010)), together with large numbers of predictor variables, to explain the variance observed in any given response variable. While these models can have high explanatory power, they often perform less well when used to make predictions (Shmueli, 2010), something which, together with their inherent complexity, makes them of only limited applicability to practitioners working in sport business management (Beatty and Zajac, 1987, Frick et al., 2010). Furthermore, it is not possible with these approaches to identify temporally when structural changes have occurred, something that is particularly important to practitioners who need to know when performance has deviated from target so that remedial action can be taken. In order to identify the presence of structural changes in performance, it is necessary to use a time-series analysis approach. However, time-series data can be difficult to interpret because it is often 'noisy' and may contain multiple periodic cycles (Kammler, 2007, Walker, 2017) that can obscure underlying trends. Consequently, there is a need for practical diagnostic tools, such as CUSUM, that can easily be applied to sport related time-series data to identify when changes in performance have occurred. Once identified, further detailed investigations, using more sophisticated multivariate techniques, can be initiated to determine the causes of any changes identified.

Despite its widespread use in other contexts (Gove et al., 2013, Li et al., 2017, Neuburger et al., 2017, Scandol, 2003), to the best of our knowledge, no published work has been done on the use of CUSUM in sport business management. So in order to address this knowledge gap and to assist practitioners, we designed the study reported here to illustrate how CUSUM analysis might be applied retrospectively to univariate time-series soccer data in order to gain new insights into team performance that might otherwise be obscured. As such, we applied CUSUM analysis to match goal difference data collected from the English Premier League

between 1995 and 2018 (i.e. the period in which the Premier League has comprised 20 teams). Specifically, we applied CUSUM analysis in a retrospective longitudinal study to identify structural changes in the match performance in the six teams (i.e. Arsenal, Chelsea, Everton, Liverpool, Manchester United, and Tottenham Hotspur) who remained in the league throughout the entire study period. Although our primary objective was to evaluate whether or not CUSUM analysis could detect the presence of structural changes in mean match goal difference, we also wanted to show how CUSUM might be used in practice to gain insights into the success or failure of past decisions. To this end, we mapped onto the CUSUM plots the various managerial changes that occurred during the study period for the respective teams, in order to evaluate whether or not the managerial changes coincided temporally with the structural changes in mean goal difference. In so doing, we aimed to demonstrate the potential of CUSUM as a management tool within professional soccer.

Because CUSUM is unfamiliar in sport, we have restricted ourselves in the present study to the simplest form of CUSUM, namely the 'off-line' retrospective application of CUSUM (Stapenhurst, 2013, Montgomery, 2007). Many other 'on-line' operational adaptations of CUSUM also exist (Cheifetz et al., 2012, Chen, 2016, Oskiper and Poor, 2002, Sibanda and Sibanda, 2007) that can be used in real-time to monitor processes. However, these are beyond the scope of the present study, which restricts itself to the analysis of historical match data. Likewise, although some advanced multivariate adaptations of CUSUM have been developed (Pignatiello Jr and Runger, 1990, Woodall and Ncube, 1985, Healy, 1987), these are not widely used in practice, and so we restrict ourselves here to the application of CUSUM to univariate data (Stapenhurst, 2013, Montgomery, 2007), which is by far the most common application of the technique. In doing so we aim to introduce the reader to the fundamental concepts underpinning CUSUM and show how these might be applied in professional soccer.

2. Literature Review

In order to familiarise the reader with the concepts underpinning our study, we present below a brief review of the literature relating both to the theory associated with managerial succession and CUSUM analysis. As alluded to in the introduction above, although CUSUM analysis is well known in other fields, it is noticeably absent from the sport management-performance literature. This is primarily because much emphasis has been placed in this field on explanatory regression models (e.g. (Lago-Penas, 2011, Fizel and D'Itri, 1999, d'Addona and Kind, 2014, Frick et al., 2010)), rather than on time-series analysis techniques such as CUSUM. Time-series techniques can be used either to predict future performance, or alternatively, to identify points in time where structural changes in performance have occurred. While in recent years a number of papers have been published in sport journals on the former (e.g. (Camps and Pappous, 2016, Miller et al., 2017, Yiannakis et al., 2006)), the latter issue, which CUSUM addresses, has been largely overlooked in the sport management literature. It is this gap in the research knowledge base that we address here.

2.1 Managerial succession in sport

Sport, in particular professional sport, provides a unique arena to test management theories and concepts, mainly due to the publicly available performance data. However, the extent to which team managers matter is an issue that management scholars and executive decision-makers have constantly wrestled with over time (Flores et al., 2012). This question has dominated sport management literature ever since Grusky's (Grusky, 1960, Grusky, 1961, Grusky, 1963, Grusky, 1969) well-known work on managerial succession. Such has been the interest in this subject that managerial succession – the forced dismissal or voluntary exit of an executive leader (Zhang, 2008) – has become one of the most debated and researched sport management topics (Allen and Panian, 1982, Allen et al., 1979, Ferris et al., 2015, Fredrickson et al., 1988, Mobbs and Raheja, 2012, Zhang and Qu, 2016, Zhu and Shen, 2016,

Cannella Jr and Shen, 2001). While earlier work undertaken in this field has focussed predominantly on American sports (Cannella Jr and Rowe, 1995, Fabianic, 1994, Fizel and D'Itri, 1999, Giambatista et al., 2005, McTeer et al., 1995, Rowe et al., 2005), European sports, especially soccer, have received considerable attention in recent years (Audas et al., 2002, Dawson et al., 2000, de Dios Tena and Forrest, 2007, Desai et al., 2018, Flores et al., 2012, Frick et al., 2010, Hughes et al., 2010, Trequattrini et al., 2018, Audas et al., 1997). However, regardless of context, the theories underpinning the study of managerial change remain the same and can be broadly classified as the: *common-sense*; *vicious-circle*; and *ritual scapegoating theories*. The *common-sense theory* proposed by Gamson & Scotch (1964) asserts that managerial change provides enough stimulus to break the cycle of poor performance regardless of the successor's attributes, whereas the *vicious-circle theory* (Grusky, 1963) postulates the opposite view, that managerial change disrupts internal operations and capabilities leading a further decline in performance. Conversely, the *ritual scapegoating theory* suggests that succession has no impact on performance, and serves only as a means to appease stakeholders (Audas et al., 2002, Frick et al., 2010, Hughes et al., 2010, Lago-Penas, 2011). The contradiction in the positions held by these respective theories only serves to highlight the inconsistencies in the evidence base and suggests that much still remains unknown about the impact of managerial changes in professional sport.

While a large body academic work has investigated management succession, there is nonetheless a considerable gap between the research and operational practice (Beatty and Zajac, 1987, Frick et al., 2010), making it difficult for executive level decision-makers to make effective and informed decisions. This may be because the findings of the various studies have been somewhat inconsistent (Giambatista et al., 2005, Hughes et al., 2010, Lago-Penas, 2011). For example, Grusky (1963) found a negative relationship between performance and managerial change within Major League Baseball (MLB), which led to a

constant vicious-circle (hence the *vicious-circle theory*), whereas McTeer et al. (1995) discovered an immediate performance increase, but no improvement over the season for all major North American sports, thus supporting the *scapegoating theory*. Interestingly, Rowe et al. (2005) found support for all three theories, concluding that enough time for a new team leader to 'take charge' was key to successful managerial succession. However, in professional soccer, 'enough time' is something that managers and boards do not always have, especially when under pressure from fans and the media (Koning, 2003).

Concerning soccer, the research findings have been equally inconsistent as those for other sports. For example, Bruinshoofd & ter Weel (2003), investigating Dutch soccer, found that performance decreased in the four games after a manager was dismissed. Conversely, Van Ours and Van Tuijl (2016) demonstrated positive effects for managerial change also within Dutch soccer. However, they concluded that no impact had occurred as their control group of non-dismals also demonstrated positive effects. de Dios Tena & Forrest (2007) found support for the *common- sense theory* when analysing Spanish soccer, albeit that the positive effects of replacing a manager were only observed for home games. Madum (2016) also observed a positive impact within Danish soccer, similar to Muehlheusser, Schneemann and Sliwka (2016) who identified positive effects following managerial change in German soccer, but only for specific homogenous teams. Whereas, Besters, van Ours and van Tuijl (2016) reported both positive and negative effects for individual case studies of managerial change in the English Premier League, but concluded no positive effects overall.

Many researchers have observed a 'regression to the mean' when investigating managerial succession in soccer, namely that after the initial positive or negative perturbation due to the appointment of a new manager, performance levels soon revert back to the status quo (Audas et al., 2002, Bruinshoofd and Ter Weel, 2003, Koning, 2003, Trequattrini et al., 2018, Heuer

et al., 2011). Therefore, it is essential to clearly distinguish between situations where a dip in performance is not exceptional and out of context, and those where a structural change has occurred. With the latter, it may be folly to delay appointing a new manager, whereas with the former, acting too soon might result in a costly and unnecessary exercise. Given that the average tenure of a soccer manager in the English leagues in 2016-17 was just 1.16 years (LMA, 2017), this suggests that many managerial sackings occur as a result of an oscillation that would otherwise regress back to the mean (Heuer et al., 2011).

It is important for executive decision-makers within professional soccer to make effective and informed decisions, as getting managerial succession wrong can result not only in a significant loss of revenue and opportunity (Khurana, 2001) but also in considerable compensation and restructuring costs associated with the dismissal process. For example in England, Liverpool FC paid £6 million in compensation to Rafael Benítez in 2010 and Chelsea paid £12.6 million to Luiz Felipe Scolari in 2009, after paying £18 million only two years earlier to Jose Mourinho following his dismissal (Flint et al., 2014). The voluminous turnover of managers (e.g. 44 managers dismissed in the English leagues in 2016-17 season (LMA, 2017)) coupled with high compensation payments and vast media attention (Brady et al., 2008) means there is a pressing need for objective management tools to aid decision-making associated with managerial succession in professional soccer. Therefore, any tool that can help clubs be more objective when making difficult decisions is to be welcomed. We argue here, that CUSUM appears to have considerable potential in this respect because it removes superficial noise from the signal to reveal the underlying trends in time-series data, thus enabling structural changes in performance to be clearly distinguished from mere fluctuations. When used retrospectively, as we have done in the present study, CUSUM also has the potential to help clubs executives evaluate whether or not strategic interventions, such as purchasing high profile players or appointing a new manager have been successful.

2.2 CUSUM analysis

Although a relatively simple univariate technique, CUSUM has nonetheless proven to be a useful management tool for evaluating performance and identifying when problems occur in complex systems. In such systems, performance may be influenced by multiple contributory factors, many of which may be stochastic. However, by identifying one key output metric that captures the overall performance of the system, for example, the number of cars produced per day by an assembly line, it is possible to use CUSUM analysis to evaluate the performance of the line over time with respect to some arbitrary target (Stapenhurst, 2013, Montgomery, 2007). By simply cumulating the deviation of the output metric from the target value over time, it is possible to identify whether or not the process has 'drifted' away from the target and to pinpoint exactly when this deviation may have occurred (Beggs, 2010). To illustrate this, consider the example data set shown in Table 1, which represents 30 weeks of production for a factory that has a weekly target output of 100 arbitrary units (AU). If we plot the data as a time-series on a Shewhart control chart (Figure 1a) we can see that the signal tends to oscillate around the target value, with all the data points lying within the range ±2 standard deviations (SD) (i.e. ±14.13 AU). Although the actual mean output over the 30-week period is 98.33 AU, slightly lower than the target value, the 'reasons' for this apparent under-performance are not immediately obvious from the Shewhart chart. However, by computing the cumulative sum of the weekly deviation from the target value (Table 1) we can produce the CUSUM plot shown in Figure 1b. From this, it can be seen that the performance of the factory suddenly deteriorated at about week 21 for some unknown reason. For weeks 1 to 20 the mean output was indeed 100 AU, although some variation around this target value was exhibited from week to week, as evidenced by the CUSUM plot, which oscillates about zero over this period. However, after week 20 the CUSUM plot alters markedly and slopes steeply downwards, indicating that at this point in time something happened to reduce the

output of the factory. Furthermore, because the slope of the CUSUM plot continues in the same trajectory from this point on, it suggests that the drop in output was maintained from week 21 through to week 30. In fact, the mean weekly output from week 21 onwards dropped to 95 AU, a 5% reduction, something that is not immediately obvious from the time-series in the Shewhart chart, but is instantly recognisable from the CUSUM plot.

[Insert Table 1 here.]

[Insert Figure 1 here.]

From the simple example above, it can be seen that it is much easier to spot the change in performance that occurred around week 21 using the CUSUM plot (Figure 1b) than it is with the Shewhart chart (Figure 1a). The reason for this is that for any point in time, the Shewhart chart uses only the information in the last sample observation, ignoring the information contained in the entire sequence of data points, whereas the CUSUM plot makes use of the information embodied in the whole signal (Montgomery, 2007). Indeed, it has been shown that Shewhart time-series charts are insensitive to small process shifts of the order <1.5 SD (Montgomery, 2007), unlike CUSUM plots which tend to outperform Shewhart charts, especially when sample sizes are small (e.g. when n = 1) (Nenes and Tagaras, 2007). Being much more sensitive, CUSUM is generally a superior alternative when small changes in performance are important (Neuburger et al., 2017, Nenes and Tagaras, 2007). As illustrated in Figure 1a, when faced with even a small time-series data set, it can become difficult to spot the presence of adverse changes in performance, let alone identify when the adverse events occurred. So when faced with larger time-series data sets the task of identifying problematic

adverse events can be very challenging if CUSUM is not used, particularly when the data is noisy.

CUSUM charts produce an historical record that captures the underlying trend in performance while removing signal noise. This can be particularly useful when investigating complex systems, such as those found in the healthcare sector, where extraneous factors and signal noise can often obscure performance. In such situations, CUSUM can be a useful tool, when applied retrospectively (off-line), for evaluating whether or not interventions have worked (Leandro et al., 2005, McLaren et al., 2017). With respect to this, because CUSUM is an objective tool, which quantifies the cumulative change in the observed target metric arising from any intervention, it can be particularly useful in sectors such as healthcare where emotive and political pressures can often obscure the evidence and potentially lead to poor decision-making. CUSUM can also be used in real-time (on-line) mode (Cheifetz et al., 2012, Chen, 2016, Oskiper and Poor, 2002, Sibanda and Sibanda, 2007) to monitor performance closely and limit any potential damage or loss arising from an adverse event (Sibanda and Sibanda, 2007, Neuburger et al., 2017). Specifically, when used operationally in on-line mode, CUSUM allows adverse (out-of-control) changes in the performance to be quickly identified, thus enabling prompt remedial action to be taken to minimize any damages that might occur. Many on-line CUSUM techniques have been developed (Cheifetz et al., 2012, Chen, 2016, Oskiper and Poor, 2002, Sibanda and Sibanda, 2007), discussion of which is beyond the scope of the present study. While these on-line techniques vary in the specific methodology used, they generally involve the setting of thresholds, which when crossed by the CUSUM plot trigger remedial action (Lucas, 1976, Edwards, 1980, Schmidt et al., 2015, Montgomery, 2007, Lucas, 1973). Although CUSUM analysis performs well with many time-series data sets, it can however be compromised if the data is strongly autocorrelated (Tseng and Adams, 1994, Lu and Reynolds Jr, 2001, Atienza et al., 2002). Consequently, several

adaptations to CUSUM have been developed which are explicitly designed to overcome the adverse effects of autocorrelation (Atienza et al., 2002, Tseng and Adams, 1994, Kim et al., 2007).

When applying CUSUM one of the challenges is to identify suitable metrics (variables) that capture the aspect of 'performance' that is considered to be of importance. Being a univariate technique, CUSUM is generally only applied to one performance variable at a time, with typical metrics used being for example: the number of items manufactured per unit of time; the number of units of electricity consumed per unit of time; the number of hours a machine is out of action for maintenance, etc. Given that team sports like soccer produce performance metrics, such as points accrued or goal difference that are equally easy to measure, this would suggest that CUSUM may have potential as a management tool for executive decision-makers in professional soccer. Indeed, it is arguably more important to measure and monitor 'on-field' performance effectively in professional soccer than in some other industries, given the magnitude of the rewards and costs associated with success and failure. For example, qualification to the UEFA (Union of European Football Associations) Champions League competition garners a starting income of £15 million, with an extra £30 million payment for reaching the play-off's (2018 data) (UEFA, 2018), while relegation from the English Premier League has an estimated cost of £50 million in the first year and £70 million in the second year (Deloitte, 2019). With such large financial pressures, clubs tend to demand instant success when making decisions, for example, about the appointment and retention of players and team managers. This short-term mindset has, however, an inherent weakness, because it is difficult to distinguish simple fluctuations about the mean, which generally should be ignored, from structural changes in performance, where swift intervention is needed. CUSUM however, as can be seen from the example above, can distinguish the underlying trend from the noise, and as such may be useful as a simple tool to assist decision-making and

objective setting in professional soccer.

3. Methods

In order to assess team performance, we utilised Premier League match data from 'Football-data.co.uk' (http://www.football-data.co.uk) for the 23 seasons from 1995-96 (when the Premier League was reduced to twenty teams) to 2017-18 and computed the game-by-game goal difference for 874 consecutive matches for each of the six teams that remained in the 'top flight' over this period. Match goal difference, as opposed to points awarded, was selected as the performance metric because it encapsulated both the offensive and defensive characteristics of the respective teams in a single indicator and also has been shown to be a mathematically superior metric (Heuer and Rubner, 2009). Additionally, match goal difference has been a popular output metric when analyzing efficiency and performance in soccer (Bosca et al., 2009, Beck and Meyer, 2012). The resulting stochastic goal difference signals were analyzed using the appropriate algorithms in 'R' (R Development Core Team; version 3.4.3) and tested for: (i) autocorrelation using the 'acf' function in 'R' and the Box-Ljung test ('Box.test' function); (ii) approximation to white noise ('whitenoise.test' function); (iii) unit root stationarity using the Augmented Dickey-Fuller (ADF) test ('adf.test' function); and (iv) trend stationarity using the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test ('kpss.test' function).

Following the methodology outlined by Stapenhurst (2013), for each team we calculated the mean goal difference per match (i.e. over the 874 consecutive matches) and subtracted this from the goal difference for each match to give the game-by-game deviation from the long-term mean, otherwise known as the 'target value'. We then produced retrospective CUSUM

plots for the respective teams by cumulatively summating the deviations from the target value, as follows:

$$C_i = \sum_{j=1}^{i} \left(x_j - \bar{x} \right) \quad (1)$$

Where: $\bar{x}$ is the mean match goal difference over the 874 matches (i.e. the target value); x_j is the goal difference for each match in the sequence j = (1 to i) matches; and C_i is the CUSUM score for the i^{th} match. The statistical significance of the CUSUM range was tested using a permutation test involving 1000 random permutations (without replacement) taken from the observed goal difference signals. Statistically significant changes in the CUSUM plots were deemed to have occurred when $p<0.05$.

In order to validate the CUSUM plots and identify significant changes in team performance, we adopted the unsupervised change point analysis approach outlined by James and Matteson (James and Matteson, 2015). This involved using the 'e.divisive' function in the 'ecp' package in 'R' to identify change points in the mean value of the respective signals through a hierarchical bisection approach (James and Matteson, 2015). The change points identified were tested for significance using a permutation test involving 1000 random permutations. In order not to exclude change points that might be relevant but not strictly 'significant', a relaxed significance threshold of $p<0.1$ was used in this analysis. The 'ecp' package was used to perform the change point analysis because unlike alternative approaches (Killick and Eckley, 2014, Kleiber et al., 2002, Sen and Srivastava, 1975) it required minimal *a priori* knowledge and was therefore largely an unsupervised process.

In addition to identifying the structural changes in the goal difference data, we also mapped historical changes in team management onto the respective CUSUM charts, in order to assess

whether or not these interventions were associated temporally with changes in team performance.

4. Results

The results of the various signal analysis tests are presented in Table 2. From these, it can be seen that the Box-Ljung test found significant evidence of non-zero autocorrelations in the goal difference signals for Chelsea and Tottenham, whereas no autocorrelation was observed for the other teams. However, further examination revealed that although significant autocorrelations were present in the cases of Chelsea and Tottenham (Figure 2), these were weak and approximated to white noise – something confirmed by the white noise test results, which found none of the team goal difference signals to be significantly different from white noise. The results of the ADF test found the goal difference signals for all the teams to be 'unit root' stationary (i.e. no evidence of a unit root), whereas the KPSS test found only the signals for Arsenal, Everton and Liverpool to be 'trend' stationary. This implies that the signals for Chelsea, Manchester United and Tottenham were not 'trend' stationary, suggesting the presence of change points in the goal difference performance profiles of these clubs, something that was confirmed by the CUSUM significance test results in Table 3, which also suggested the presence of significant change points in the signal for Everton.

[Insert Table 2 here.]

[Insert Figure 2 here.]

The results of the change point analysis are presented in Table 3, which shows the points in time where significant changes occurred in the mean of the goal difference signals for the respective clubs. From this, it can be seen that two change points were identified for Chelsea and Everton, with one identified for Manchester United and Tottenham, while no change points were found for Arsenal and Liverpool.

[Insert Table 3 here.]

The results of the combined CUSUM and change point analyses are presented in figures 3 to 8. These figures show sequential goal difference and CUSUM plots for the respective teams over 874 matches from season 1995-96 to season 2017-18. In each figure, the identified significant change points are shown as solid red lines, with the final end-of-season league positions indicated on the CUSUM plots. The blue circles indicate changes of team management on the respective CUSUM plots.

In broad terms, when the CUSUM plots in figures 3 to 8 slope upward, it indicates a period in which goal differences tended to be above the overall average for the 23 seasons. Conversely, when the plots slope downwards this indicates a period of time where values tended to be below the overall average. Where the plots are relatively horizontal, it indicates a period in which goal difference was similar to the 23-season averages for the respective teams. Any sudden change in slope gradient in a CUSUM plot, be it upward or downward, is indicative of a change in performance and worthy of further investigation.

4.1 *Arsenal*

CUSUM analysis of the goal difference data for Arsenal produced a plot (Figure 3b) that resembled a flattened sine wave, in which the CUSUM score deviated relatively little from zero. As such, this indicates a considerable amount of consistency in team performance over the 23-season period. Although the overall range of the CUSUM plot did not reach significance ($p = 0.251$), several clear changes in slope direction were observed, each of which was followed by a long period in which the gradient of the plot was relatively constant. This suggests that subtle changes did occur which were sustained over many seasons.

Confirming the results of the CUSUM significance test, the change point analysis (Figure 3a) revealed that no significant breakpoints occurred during the 23-season study period. Average match goal difference (mu) during this period was 0.89.

[Insert Figure 3 here.]

4.2 *Chelsea*

The CUSUM plot for Chelsea (Figure 4b) deviated from zero much more markedly than that for Arsenal, with the overall CUSUM range being strongly significant ($p<0.001$). It was characterised by an initial period from 1995-96 to the start of the 2003-04 season when Roman Abramovich became the owner of the club, in which average match goal difference was well below the long-term mean of 0.87. After the Abramovich takeover, particularly when José Mourinho was appointed team manager in June 2004, goal difference dramatically improved and remained consistently high until the start of the 2010-11 season. Thereafter, it plateaued and remained at a similar level to the 23-season average.

The change point analysis (Figure 4a) confirmed the above interpretation of the CUSUM plot, with two significant change points identified. The first ($p<0.001$) occurred in round 30 of the 2002-03 season, shortly before Abramovich took over the club in June 2003, and the second ($p=0.084$) occurred in round 6 of the 2010-11 season when the CUSUM plot changed slope and flattened out. This was a few weeks before Ray Wilkins, the assistant first-team coach, was dismissed in November 2010. Average match goal differences (mu) for the periods between the change points were 0.51, 1.31 and 0.80 respectively.

[Insert Figure 4 here.]

4.3 *Everton*

CUSUM analysis of the Everton goal difference data produced a 'V' shaped plot (Figure 5b) with a range that was strongly significant ($p<0.001$). The CUSUM chart was characterised by a long downward slope (mu = 0.26) that lasted from round 14 in the 1996-97 season to round 19 in the 2005-06 season (almost four years after David Moyes was appointed manager), which was immediately followed by an equally long upward slope (mu = 0.38), which lasted until just after Roberto Martínez was appointed manager in June 2013. Thereafter, the CUSUM score remained close to the zero baseline.

The change point analysis (Figure 5a) broadly confirmed the CUSUM plot, with two significant change points identified. The first ($p = 0.010$) occurred in round 15 of the 1996-97 season, coinciding with the beginning of the long downward slope in the CUSUM plot, and the second ($p = 0.099$) occurred in round 20 of the 2005-06 season when the CUSUM plot started to rise. Average match goal differences (mu) for the periods between the change points were 0.47, -0.25 and 0.27, respectively. Average match goal difference over the 23 seasons was 0.08.

[Insert Figure 5 here.]

4.4 *Liverpool*

Like Arsenal the range of the CUSUM chart for Liverpool (Figure 6b) did not reach significance ($p = 0.561$), indicating that the plot 'hugged' closely the zero baseline over the 23-season period. This is supported by the change point analysis (Figure 6a), which found no significant break points during this period. Average match goal difference over the 23 seasons was 0.71.

[Insert Figure 6 here.]

4.5 *Manchester United*

Of the six teams included in the study, Manchester United is notable for being the only team which exhibited a largely positive CUSUM chart (Figure 7b) ($p = 0.023$), due mainly to on-field success during the Alex Ferguson era which lasted until July 2013 when David Moyes was appointed team manager. This managerial change is clearly identified by both the CUSUM plot and the change point analysis ($p = 0.024$) (Figure 7a), and stands out as the point in time when Manchester United fortunes were reversed. Prior to this change point, mu = 1.17, whereas after it mu = 0.65. Also clearly identified by the CUSUM analysis, but not by the change point analysis, was the point in July 2006 at which the Malcolm Glazer, who took control of the Manchester United in May 2005, refinanced the clubs debts (RTE, 18 July 2006). Average match goal difference over the 23 seasons was 1.06.

[Insert Figure 7 here.]

4.6 *Tottenham Hotspur*

CUSUM analysis of the Tottenham goal difference data produced a 'U' shaped plot (Figure 8b) with a range that was strongly significant ($p<0.001$). Three phases characterised the CUSUM chart: (i) a long downward slope (mu = 0.18) that lasted from round 13 in the 1996-97 season to round 14 in the 2004-05 season, when Martin Jol was appointed manager; (ii) an approximately horizontal phase (mu = 0.30), which lasted until the start of Mauricio Pochettino's second season in charge (round 5 of the 2015-16). Thereafter, the CUSUM score rose dramatically (mu = 1.21). Noticeably, the change point analysis identified only one significant change point ($p<0.001$), which occurred in round 5 of season 2015-16 and coincided with the start of the steep upward slope on the CUSUM plot. Prior to this change point mu = 0.11, whereas after it mu = 1.21. Average match goal difference over the 23 seasons was 0.25.

[Insert Figure 8 here.]

5. Discussion

The principal aim of the study was to evaluate the extent to which CUSUM analysis might be useful as a tool for assessing on-field team performance in professional soccer using time-series data. With respect to this, our findings suggest that CUSUM is well suited to retrospectively analysing time-series data in sport, and in particular, identifying points in time where the observed target metric, in this case, match goal difference, changed markedly. As such, our findings mirror those of the many researchers who have investigated the application of CUSUM in other sectors (e.g. (Woodall and Adams, 1993, Davies and Hanchard, 1980, Bissell, 1969), etc.), suggesting that CUSUM is equally applicable to the analysis of time-

series data in sport as it is, for example, in manufacturing (Bissell, 1969, Davies and Hanchard, 1980, Stapenhurst, 2013, Vera do Carmo et al., 2004, Woodall and Adams, 1993). Time-series data can be difficult to analyse because it is frequently noisy and can be influenced by multiple underlying periodic cycles (Kammler, 2007, Walker, 2017). Consequently, practitioners often have difficulty spotting when important changes in performance occur. This is especially the case if the changes are relatively small in magnitude (Montgomery, 2007), as is generally the case with mean match goal difference. However, as we have shown, by applying a CUSUM function it is possible to transform the complex match goal difference signals into CUSUM plots, which are much easier to interpret. Comparison of the respective goal difference (a) and CUSUM (b) plots in figures 3-8 illustrates this very clearly. The goal difference signals are noisy and difficult to interpret, whereas their CUSUM counterparts are much less noisy and reveal the underlying trends in the data. As such, CUSUM would appear to have considerable potential as a management tool in professional soccer, primarily because it is easy to use and that naturally lends itself to visual communication.

Unlike competing time-series techniques such as Shewhart charts (Montgomery, 2007) and change point analysis (James and Matteson, 2015, Killick and Eckley, 2014, Kleiber et al., 2002, Sen and Srivastava, 1975), which tend only to respond to extreme 'statistically significant' events, CUSUM responds rapidly to more subtle changes in performance, which nonetheless may be important (Neuburger et al., 2017, Nenes and Tagaras, 2007), to produce an 'historical' chart which is easy to understand and interpret. While in the present study both CUSUM and change point analysis identified major changes in team performance, it can be seen from figures 3-8 that the CUSUM analysis also identified other more subtle changes that, although not statistically significant, were nonetheless important. For example, the CUSUM analysis identified the steady improvement in team performance that occurred after

the Glazer family refinanced the debts of Manchester United in June 2006, something that was not identified by the change point analysis. Furthermore, CUSUM identified the marked improvement in team performance that occurred when José Mourinho became manager of Manchester United in May 2016 – again, something not revealed by the change point analysis. This latter event was all the more noticeable because his direct predecessor, Louis van Gaal, had failed to halt the steep downward slope in the CUSUM plot, which commenced when David Moyes was appointed. This highlights one of the major limitations of many statistical techniques, namely their failure to detect subtle changes that although not statistically significant may nonetheless still be important (Montgomery, 2007).

When applied retrospectively (as we have done in the present study), CUSUM can be used to assist in evaluating the success or failure of past strategic interventions (Leandro et al., 2005, McLaren et al., 2017). By mapping the interventions onto the CUSUM plot, it is possible to see whether or not they affected the slope to the target metric. For example, if on the appointment of a new team manager, the goal difference CUSUM plot-line which may have been sloping in a continuous downward direction for the past two seasons, suddenly changes direction and flattens out to the horizontal at approximately the same point in time as the new appointment, then this suggests that the intervention, *in toto*, has had a positive impact on team performance. Of course, because CUSUM is not an explanatory analysis technique, it is not possible using CUSUM alone to tell whether or not the observed improvement is due to the new manager or simply the 'shock' associated with the decision to change a manager, or indeed some other reason, such as an injection of new 'cash' by the club's owners to purchase high profile players. In order to determine why the observed improvement actually occurred, it would be necessary to employ a more sophisticated analysis technique than CUSUM. Having acknowledged this, it is nonetheless true that CUSUM can give an indication as to whether or not a given intervention, *in toto*, resulted in the desired effect. With respect to this,

by mapping all the managerial changes onto the CUSUM plots of the six clubs, we were able to assess the overall impact of these various managerial changes on the on-field performance of the respective teams. Our findings revealed that for the six clubs in the present study most of the managerial changes resulted in little or no change in average goal difference. For example, it can be observed from the CUSUM plot for Chelsea (Figure 4b) that out of the fourteen managerial changes that occurred, arguably only one, José Mourinho's appointment in June 2004, produced a marked change in the direction of the CUSUM slope that was sustained. All the other managers, with the possible exception of Carlo Ancelotti, for whom there was a marked change in trend after one season in charge, simply continued trends that were already established, no matter how long their tenure. As such, our findings largely confirm those of others who have investigated this issue (Heuer et al., 2011, Lago-Penas, 2011, ter Weel, 2011), and broadly support the *ritual scapegoating theory* that managerial succession has no impact on long-term team performance (Audas et al., 2002, Frick et al., 2010, Hughes et al., 2010, Lago-Penas, 2011). For example, Lago-Peñas (Lago-Penas, 2011), who investigated Spanish soccer, found that other than a short-term shock effect, coach turnover had no impact on team performance in the long term. Likewise, ter Weel (ter Weel, 2011) investigating Dutch soccer, found no statistically significant improvements in performance after manager turnover, and Heuer et al (Heuer et al., 2011) found that changing coach, either mid-season or at the end of the season in the German soccer league, did not affect the subsequent performance of a team. Importantly, ter Weel (ter Weel, 2011) found team performance to be time-invariant, with the average points won per game remaining relatively constant over time, despite multiple player and managerial changes. Collectively, this suggests that successful soccer clubs that consistently play in the English Premier League have a built-in inertia, which tends to inhibit change. This inertia to change is exemplified by the CUSUM plot for Liverpool (Figure 6b) which exhibited only small deviations from the baseline average, despite eight managerial changes occurring during the study period.

As to why soccer clubs should be so resistant to change, is not fully understood. ter Weel suggested that clubs tend to recruit managers with similar styles to those recently departed, with the result that long term trends are established which can last for many seasons (ter Weel, 2011). There are a plethora of other potential reasons, for example, but not limited to; the overall organisational culture and structure within clubs; the recruitment and selection strategies as well as squad investment strategies – giving larger budgets to new managers could show initial improvement or providing similar/smaller budgets may lead to similar/worse results; owners commitments and ethos – their overall club investment strategies; club infrastructure and development plan – focussing on player development through academy systems over purchasing talent. However, no matter the reasons for this inertia, the fact that observed goal difference tends to regress to the mean despite the presence of numerous managerial changes is evidence of its existence (Heuer et al., 2011). In our study, regression to the mean is evident by the fact all the CUSUM plots exhibited long periods in which the slope of the plot remained relatively constant, implying that during these periods goal difference tended to fluctuate around a constant mean. Furthermore, we found no evidence of unit roots in any of the goal difference signals, suggesting an overall tendency for the signals to regress to the mean following any perturbation, as others have reported (Heuer et al., 2011, Lago-Penas, 2011). Notwithstanding this, both the CUSUM analysis and the change point analysis suggest that structural changes did occur in some of the goal difference signals. The CUSUM statistics revealed the presence of statistically significant breaks in performance for Chelsea, Everton, Manchester United and Tottenham, something that was confirmed by the change point analysis. These structural change points are instances in time where the statistical properties before and after this time point differ significantly. The presence of change points implies that although the tendency to regress to the mean is always there, sometimes structural changes occur which cause the mean to shift either upwards or

downwards. It is noticeable however, that these major change points are few and far between. After analysing a total of 5244 match results, we were only able to identify six statistically significant change points. Having said this, the CUSUM plots suggest that other change points (e.g. when the Glazer family refinanced the Manchester United debts in July 2006) may well exist and that these would have become apparent if the selection criteria had been relaxed.

Irrespective of the selection criteria used, the fact remains that, for the six clubs in the present study, structural change points were relatively rare and were not always easy to explain when they did occur. While the breaks that occurred in Manchester United's signal at the end of the 2012-13 season (Figure 7b), and in Chelsea's signal at the end of the 2002-03 season (Figure 4b), can probably be attributed to changes in team manager (David Moyes' appointment at Manchester United in July 2013) and club owner (Roman Abramovich became the owner of Chelsea in June 2003) respectively, other change points are more difficult to explain. For example, the marked improvement in Everton's performance that occurred in the middle of the 2005-06 season (Figure 4b) does not appear to have been associated with either a change in manager or club ownership. Likewise, the reasons for Chelsea's sudden and prolonged deterioration in form early in the 2010-11 season is a mystery, although this may have been linked to the departure of the assistant first-team coach, Ray Wilkins, which occurred at approximately the same time. Interestingly, very few managerial appointments coincided with marked changes in the gradient of the CUSUM plots. Indeed, only one, when David Moyes took over from Alex Ferguson at Manchester United in July 2013 (Figure 7b), coincided temporally with a change point (in that case resulting in a sudden drop in average goal difference) that was identified as being significant, although it is arguable that José Mourinho's appointment at Chelsea in June 2004 (Figure 4b) was also associated with an 'instant' marked change (i.e. a substantial improvement) in team performance. Mauricio

Pochettino's appointment as manager of Tottenham in May 2014 was also interesting because it preceded a dramatic improvement in the clubs on-field performance, although this did not occur during his first season in charge as the CUSUM plot shows in Figure 8b. The change point actually occurred at the start of season 2015-16. So although we can say that a positive change in performance (which was unlikely to have occurred by chance) happened during Pochettino's tenure, it is unclear why it took over a year to come into effect. One reason may however be that in his second season in charge, Pochettino remodelled his squad and deliberately chose to promote young players, with the result that Tottenham had the youngest team in the Premier League that season (Riach, 2015) – a talented young squad that presumably matured and performed consistently well in the subsequent seasons. Clearly, if this is the case, then Pochettino's appointment would appear to conform more to the *common-sense* model (Gamson and Scotch, 1964) than the *ritual scapegoating* model (Audas et al., 2002, Frick et al., 2010, Hughes et al., 2010, Lago-Penas, 2011).

Historically, professional soccer has been viewed as a cultural institution (Giulianotti and Robertson, 2004), with fans traditionally supporting their local team. However, due to 'commodification' and exponential commercial growth, professional soccer is now seen very much as 'big business', with the Premier League, for example, generating €5.3 billion in 2016-17 alone (Deloitte, 2018). Nevertheless, running a professional soccer club remains an emotive business, with strategic investment decisions heavily scrutinized by fans, the media, and shareholders alike. Under such scrutiny and pressure, as the *ritual scapegoating theory* suggests, decisions can all too easily be made primarily to appease stakeholders, something that can potentially lead to poor decision-making. Therefore, executive decision-makers in soccer need tools such as CUSUM, which can provide an objective view of the target performance metric under consideration. With respect to the selection of suitable performance metrics to use in a CUSUM analysis, match goal difference and match points awarded would

appear likely candidates. However, of the two, match goal difference appears more suitable because it encapsulates both the offensive and defensive characteristics of the respective teams in a single indicator and has been shown to be the mathematically superior metric (Heuer and Rubner, 2009). Furthermore, as we have shown in Table 2 and Figure 2, because the match goal difference signals approximate to white noise, it means that they exhibit minimal or no autocorrelation, making this performance metric an ideal target to use in CUSUM analysis. Notwithstanding this, it is important to note that while match goal difference is an objective measure of 'on-the-pitch' team performance, it does not take into account the competitive balance of the league in which a team plays, or its position within the league throughout the season. In other words, a CUSUM analysis, which utilizes match goal difference as the target metric, cannot take into account the performance of the team relative to its competitors, something that can be important in the latter part of the season, particularly if the team is fighting relegation or seeking promotion. CUSUM should therefore be viewed as just one of many tools that can be used to monitor and assess team performance. So while CUSUM might yield an objective indication of, for example, structural changes in average goal difference, it is important to evaluate the results of any CUSUM analysis in context, by also considering the performance of the team relative to its competitors in the league.

The canon of work relating to CUSUM is both extensive and mature, with many variants of CUSUM developed over the years for a wide variety of applications. Yet this body of work remains largely unknown in sports analytics. Therefore, in this study we have attempted to bring CUSUM to the attention of the sport business management community by demonstrating its applicability to professional soccer. Because of the introductory nature of this paper, we felt that it was appropriate to restrict the study to the 'off-line' retrospective version of CUSUM, which is the oldest form of the technique and the basis of the many advanced variants of CUSUM that have subsequently been developed. Although restricted to

historical applications, off-line CUSUM analysis is nonetheless a useful management tool, which is primarily used to review past historical performance data in order to: (i) establish realistic performance targets for future use; (ii) evaluate the success or failure of past strategic interventions; and (iii) assess the 'cost' of past mistakes. However, CUSUM can also be used operationally in an on-line mode to monitor performance in real-time (Cheifetz et al., 2012, Chen, 2016, Oskiper and Poor, 2002, Sibanda and Sibanda, 2007). While a full discussion of on-line CUSUM analysis is beyond the scope of the present study, it is perhaps worth noting that it involves plotting CUSUM charts, which evolve in real-time as each new data point is added. With on-line CUSUM analysis, in order to construct a CUSUM plot it is necessary to use an *a priori* performance target value, similar to that used to construct Figure 1b. This target value is generally determined from historical data and can be: the historical mean value of the performance metric (Montgomery, 2007); some agreed arbitrary value; or even a value determined using a performance equation (Beggs, 2010). When used operationally in on-line mode, CUSUM allows adverse changes in the performance to be quickly identified, enabling prompt remedial action to be taken if so required. Conversely, if the perceived dip in performance is simply due to regression to the mean, then on-line CUSUM should identify this as being the case and indicate that no remedial action is necessary. With respect to managerial succession this is a particularly important point, because as we and others (Audas et al., 2002, Bruinshoofd and Ter Weel, 2003, Koning, 2003, Trequattrini et al., 2018, Heuer et al., 2011) have shown, after an initial positive or negative perturbation due to the appointment of a new manager, performance generally reverts back to the status quo. Given that managerial change can be a very expensive exercise, often costing many millions in compensation payment (Flint et al., 2014), it is essential that executive decision-makers clearly distinguish between situations where a dip in performance is not exceptional from those where substantial change has occurred, requiring remedial action to be taken.

Given that the margin between success and failure in professional sport can be very fine, small changes in team performance can have a big effect on league position, particularly when relegation or promotion is a possibility. Therefore it is important in professional sport that management be aware of any negative change in performance as soon as possible so that remedial action can be taken, even though such changes may not be statistically significant. This fact is well recognised in other industries and is one of the reasons why on-line CUSUM analysis is so popular, because it enables managers to quickly identify in real-time when processes are straying from the norm (Celano et al., 2012, Schmidt et al., 2015, Yang et al., 2010). However, before CUSUM can effectively be utilized on-line in professional sport it will be necessary to identify and validate the optimum CUSUM methodology for the particular sporting application. Therefore, it is recommended that future work be undertaken to: (i) identify robust CUSUM performance metrics for a variety of sporting applications; (ii) develop a methodology for establishing target performance values in sport; and (iii) develop an on-line methodology for identifying when it is appropriate to take remedial action. It is also recommended that future work be undertaken to investigate how CUSUM might be adapted to take into account the evolution in the competitive balance that often occurs in sporting leagues both within and between seasons (Bond and Addesa, 2019, Caruso et al., 2019). In short, there is a need to investigate how CUSUM might be adapted to accommodate changes in the difficulty/competitiveness of the league, something that is particularly prescient when teams are either relegated or promoted. This is important because a team might be perceived to being outstanding, when in reality it is just competing against weaker opposition. Therefore, it would be helpful if a CUSUM methodology could be developed which automatically adjusts for the relative strength of the opposition, as this would yield a more informative output.

6. Conclusions

6.1 Summary

Through analysis of historical (1995 to 2018) match goal difference data from the English Premier League, we have been able to show that CUSUM can be used to identify the moments in time when structural changes occurred in the on-field performance of the six professional soccer teams included in the study. By mapping historical managerial appointments onto the CUSUM plots for the respective teams, we were also able to show that the vast majority of the managerial changes were associated with little or no change in long-term match goal difference. However, a few managerial appointments, notably David Moyes' appointment at Manchester United in July 2013; José Mourinho's appointment at Chelsea in June 2004; and Mauricio Pochettino's appointment at Tottenham in May 2014, were associated with marked changes in the slope of the CUSUM plots, suggesting that these particular appointments may have had an effect on the performance of their respective clubs.

6.2 Implications

Collectively, our findings suggest that CUSUM appears to be well suited to the retrospective analysis of time-series data in professional sport. Time-series data can be complex and difficult to interpret. However, by using CUSUM it is possible to identify when changes in any underlying trends occur, something that might be useful when evaluating the success or failure of strategic events, such as: appointing a new team manager; changes in club ownership; the signing of expensive players; injuries to key players; or indeed, moving the club to a new stadium.

Although CUSUM analysis is a widely used statistical process control technique with a proven track record in the manufacturing, energy and clinical sectors, it is largely unknown in sport business management. In these other sectors, CUSUM is often used operationally in

real-time to initiate remedial action when adverse events occur. As such, CUSUM would appear to have great potential in professional soccer as a tool for monitoring team performance and initiating remedial action when necessary. Importantly, CUSUM can distinguish situations where perturbations in performance are likely to regress back to the mean from those where structural changes have occurred. Consequently, CUSUM has the potential to minimize the number of 'false positives', something that should help to prevent costly mistakes.

6.3 Limitations

While the CUSUM analysis presented here revealed useful insights into managerial changes in the Premier League, it should be noted that in the present study we only investigated successful teams that were not relegated. Our findings concerning managerial succession should therefore be treated with caution, especially regarding their applicability to less successful teams, who may experience promotion and relegation relatively frequently. With these so-called 'yo-yo' teams, the inertia that we observed in the successful teams may not be as strong. Furthermore, in the present study, we only investigated goal difference and did not take into account league position, which is a strong driver for managerial change. We therefore recommend that further work involving CUSUM analysis be undertaken specifically on teams facing relegation to evaluate the outcome of managerial change in teams struggling to survive in the Premier League.

6.4 Future research

While CUSUM appears to have potential as an executive decision-making tool in professional soccer, the technique has not yet been adapted for use in this context. Consequently, it is recommended that further work be undertaken to investigate how CUSUM might be used in professional soccer to achieve optimum results. In particular, there

is a need to develop a bespoke methodology so that CUSUM can be used operationally to monitor team performance. In addition, there is a need to develop CUSUM performance metrics that can control for the relative strength of the competition within leagues.

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