

OR Analysis of Sporting Rules – a survey
by
Mike Wright
Department of Management Science
Lancaster University
LA1 4YX
UK
tel. +44 1524 593846
email m.wright@lancaster.ac.uk

Abstract

This paper surveys the academic OR/analytics literature describing research into the laws and rules of sports and sporting competitions. The literature is divided into post hoc analyses and proposals for future changes, and is also divided into laws/rules of sports themselves and rules/organisation of tournaments or competitions.

The survey outlines a large number of studies covering 21 sports in many parts of the world. The analytical approaches most commonly used are found to be various forms of regression analysis and simulation. Issues highlighted by this survey include the different views of what constitutes fairness and the frequency with which changes produce unintended consequences.

Key Words: OR in Sport; Review; Survey; Analytics; Rules; Tournaments

1. Introduction

Sporting applications of Operational Research are now commonplace in the academic world. A recent overview (Coleman, 2012) of papers in the field of "Sports Analytics" – a term consistent with a broad definition of OR – found over 1000 such articles. Many published papers feature recurring themes such as sports scheduling, tactics and strategy. Such papers have been recently surveyed by Rasmussen and Trick (2008), Wright (2009) and Kendall *et al.* (2010).

OR in Sports has in the past been ridiculed at times for being frivolous: the accusation is that it consists merely of people researching into their hobbies rather than into serious matters. However, given that sports are of great interest to a high percentage of the world's population, it could be counter-argued that there is little that could be researched into that is more important. Sometimes, however, one is forced to wonder about the purity of researchers' motivations, as with a paper on beach volleyball which states: "Videos from 18 games including 1645 action sequences consisting of 10918 actions from female World Tour athletes were analyzed" (Koch and Tilp, 2009)!

There is one area which appears to be growing fast where there has as yet been no comprehensive review paper. This is in the area of analysis of sporting rules, whether analysis of what happens now, analysis of the results of changes made or analysis leading to proposals for future changes. These may be rules of the sports themselves or rules which apply to particular tournaments and the ways in which they are organised. This paper therefore aims to fill this gap.

Note that we are here just looking at OR/Analytics. There has been a recent survey (Arias and Argudo, 2011) mainly considering the medical and physiological effects of such changes, but we are not considering such matters in this paper.

First it is necessary to distinguish between rules of sports (sometimes called *laws*) and rules of tournaments. The rules or laws of a sport apply wherever it is played. Thus it is a law of cricket that if the wicket is broken while the runner is out of his crease and the ball is in play, then he is out. The offside rule in football is thus also a law. Tournament rules, on the other hand, apply to a particular competition. Thus a rule of most tennis tournaments is that the top four seeds are all placed in different quarters of the draw, and a rule of the Olympic long jump competition is that the eight competitors who jump the furthest plus anyone else achieving a prespecified distance make up the finalists.

This distinction is not always absolutely clear-cut; for example, the football offside rule was experimentally varied for the Football Conference in England during the 1987-8 season (see [http://en.wikipedia.org/wiki/Offside_\(association_football\)](http://en.wikipedia.org/wiki/Offside_(association_football))), and the definition of a wide is not the same for all cricket tournaments (see [http://en.wikipedia.org/wiki/Wide_\(cricket\)](http://en.wikipedia.org/wiki/Wide_(cricket))). Moreover, some rules which started as specific tournament rules have since become so widespread – e.g. the three-substitute rule in football, or the Duckworth-Lewis rule in professional cricket – that they have come to be seen almost as laws.

Many changes have been made to the laws of sports, and many others have been mooted. In addition, every tournament has its own rules set to satisfy its own objectives, and these can vary substantially within the same sport and over time. There is thus plenty of opportunity for analysis of the effects of such changes and variations.

However, such analysis has its limitations. For *post hoc* analysis it is important to recognise that the effects of the law/rule changes need to be separated out from changes that would have happened anyway, while for proposals it is important to recognise firstly that evaluating such proposals depends critically on the objectives used and assumptions made, which frequently contain a subjective element, and secondly that such changes may prompt behaviour changes among players which are hard to predict.

Many such examples can be found of behaviour changes which were not intended. For example, in the 2012 Olympics, some badminton competitors deliberately lost matches in the group stages as a direct result of the tournament rules for formulating the knock-out stages – they were trying to avoid the best players (see <http://www.guardian.co.uk/sport/2012/aug/01/olympic-badminton-players-charged-lose>). While the badminton organisers were pilloried for this being allowed to happen, it could have happened elsewhere, since essentially the same system applied to many other sports as well. And in the men's track cycling competition, one competitor deliberately crashed after a poor start so as to take advantage of a rule which said a crash in the first lap would lead to a restart (see <http://uk.reuters.com/article/2012/08/03/uk-oly-cycl-ctmspr-hindes-day-idUKBRE87201X20120803>) – a rule designed to avoid penalising bad luck rather than to reward devious behaviour. Further examples are given at various points in this paper.

The paper is organised as follows. First we will consider the *post hoc* analysis of law changes; then *post hoc* analysis of tournament rule changes; then proposals backed by analysis for law changes; and finally proposals backed by analysis for tournament rule changes.

2. *Post hoc* analyses of law changes

This section considers analyses of changes to sporting rules or laws that apply to the playing of the sports themselves, across all tournaments. Conclusions are reached using a variety of methods as to

whether the desired ends have been achieved or not, and whether there have been any unforeseen consequences. The analysis in each case examined goes beyond a simple count, involving models and/or statistical analysis.

2.1 Scoring systems

In recent years a number of racquet sports have changed their scoring systems. In particular, the governing bodies of volleyball (in 1999), beach volleyball (also in 1999) and badminton (in 2005) have changed the rule that only the serving player(s) could score a point – now a point is scored from every rally by whichever side wins the rally. At the same time the number of points required to win a game or set was increased, to 25 for volleyball and beach volleyball and to 21 for badminton. Other changes were introduced at the same time, including a change in court dimensions for beach volleyball. The main intention behind these changes appears to have been to make match lengths more predictable, so as to suit the requirements of television, but there was also a hope that the matches would be more exciting for the viewer.

The effects of the change in volleyball were analysed by Kovacs (2009), using a simulation approach as well as statistical analyses of what had actually happened. It was found from the empirical data that match length had become significantly more predictable, and the simulation results showed that there was no significant effect upon win/lose probabilities.

Ronglan and Grydeland (2006) examined the effects of the change in beach volleyball, using a Mann-Whitney U-test. They produced some results that had not been expected, concerning a change in the relative frequency of attacking and defensive plays; after the changes the proportion of defensive plays was higher. Earlier, Giatsis (2003) had considered a particular women's tournament the last year under the old rules and the first year under the new rules, though with the added complication that in the latter case the matches had become best of three sets rather than a single set. As well as finding unsurprisingly that matches were longer than before, he also found an increased incidence of very close sets, which is obviously an important factor for spectators.

Percy (2007) also analysed the badminton changes both theoretically and empirically, using probability theory and simulation to assess win probabilities and giving an illustration from the actual results of the 2006 Commonwealth Games. He shows that the fairness and discriminatory nature of the new system is similar to that of the old system – in other words, win probabilities are not significantly changed. However, he does find that matches have become faster and more exciting, in line with what had been hoped.

At roughly the same time (in 2001), the rules of table tennis were changed. The number of services before the server changed was reduced from five to two, and the number of points required to win a game was reduced from 21 to 11. The number of games required to win a match was also changed in most tournaments, e.g. from three to four. Coupet and Réache (2006) used both simulation and actual results to demonstrate that the win probability of the weaker player increased – thus one can expect a higher proportion of competitive matches – and also that the importance of the choice of initial service was significantly reduced, which makes the game fairer.

2.2 Changes to permissible play

In recent years, both codes of rugby have implemented several minor rule changes. Eaves *et al.* (2008) undertook a very detailed study, using ANOVA, of moves within matches over the period 1992-2000, a period which involved several rule changes. They concluded that the rule changes had not led to major changes in play, but that there were a number of statistically significant changes of

detail, broadly in line with what had been intended. This included a significant reduction in the number of kicks into touch as a result of the 40/20 rule – though this rule gives teams an incentive to kick the ball into touch in certain circumstances, it gives perhaps an even greater incentive for opposing teams to intercept the ball before touch is reached – and an increase in the frequency of dummy half passes following the introduction of the 10-metre rule, whereby all but two opposing players must be ten metres or more from the ball at "play-the-ball" (previously this had been eight metres, and before that five metres).

In 1999 a number of Rugby Union rules were changed. The intentions were, among others, to make the game safer, to make it more exciting and to add continuity. Williams *et al.* (2005) examined the effects of these changes over the period 1999-2003 on the total match time and the total "ball-in-play" time, using Kruskal-Wallis and Mann-Whitney tests. They concluded that both increased significantly after the rule changes, but that the change was more pronounced in the Northern hemisphere than in the Southern hemisphere, which could be because of different interpretations of, or reactions to, the rules, but could also be because the situations before the rule changes had been different. The authors hypothesised that one unintended consequence of the greater continuity could have been an increased number of injuries – this was consistent with the findings.

The notion of the self-pass was introduced to (field) hockey in 2009, along with some other rule changes. Tromp and Holmes (2011) have analysed a number of measures before and after the change and the effects appear to have been very highly significant and in line with what was expected.; in particular the amount of time taken to take a free hit has virtually halved, making the game much faster.

Overall, it seems that some of the changes to the way in which sports are actually played have achieved the desired goals, but that in some cases – notably the rugby examples cited above – so many changes have been introduced at the same time as to make it impossible to detect a separate effect for every single change.

3. Post hoc analyses of tournament rule changes

This section considers changes which are not fundamental to the sports themselves, but apply to one or more tournaments. Again the studies we include involve post-hoc analysis, using a variety of techniques. The issues considered include decisions as to who competes against whom, which players are eligible for which teams, rewards for good performance, safety measures and others.

3.1 Drafts and team make-ups

Some team sports have rules concerning the make-up of teams. This includes issues relating to player drafts, notably in American team sports. The draft system operated by the National Basketball Association (NBA) up until 1984 gave teams who had been eliminated from the play-offs, and thus had nothing tangible left to play for (in the absence of promotion and relegation), an incentive to lose matches for the rest of the season because that would give them a favourable position in the draft for the next season.

In 1984 the NBA changed the rules in a way that removed this incentive – all teams who failed to make the play-offs were treated equally in the draft. However, in 1989 this incentive to lose was reintroduced when the system changed again.

Taylor and Trogdon (2002) undertook a logit analysis to detect whether teams were in fact responding to these incentives and found strong evidence that they were (not surprisingly). There is an irony in the situation that the USA, so keen on competition in business, is arguably the most anti-competitive sporting nation in the world when it comes to team sports.

Still with US basketball, Rodenberg and Kim (2012) undertook a regression analysis of the NBA's minimum age policy. Players were not permitted to compete at the highest level until they were 19 years old, supposedly in the players' own best interests, so as to avoid burn-out. Players' careers were analysed both before and after the rule was introduced, and the analysis detected no significant difference between the career performances of each group, suggesting that the rule was misguided.

3.2 Organisation of teams into divisions/groups

Other work has concerned the teams involved in a tournament. In American Football, the National Football League was reorganised in 2002 into eight divisions of four teams, with the declared objective of minimising travel. Mitchell (2003) treated this as a classical optimisation problem, which he solved using branch-and-cut methods. The conclusion was that the reorganisation was very close to optimal, under reasonable assumptions about constraints concerning the importance of traditional rivals being in the same division as one another.

Another consideration that can apply when determining groups of teams in a tournament is that of seeding. Scarf and Yusof (2011) used statistical analysis and simulation to gauge the effect of seeding the strongest competitors, using the FIFA World Cup to illustrate the analysis. They concluded that seeding was inherently unfair in that it always favoured the strongest competitors (since they are prevented from meeting other strong opponents early in the tournament), but that there was a compensatory increase in competitive balance (i.e. no serious mismatches) during the later stages of a tournament.

3.3 Rewards for winning

A related example from football concerns the rule in European competitions that group winners should be rewarded by playing the second leg of their next round (against the runner-up from a different group) at home. This is usually thought to be advantageous for psychological reasons, combined with the fact that, if extra time is played, they will be playing it at home. However, there is an opposite effect that, if the match is still tied after extra time, the other time will have had more time in which to score away goals, which form the first tie-breaker in the case of draws.

Eugster *et al.* (2010) used logistic regression to analyse the results from the European Champions League between 1994 and 2009, concluding that there was no significant advantage to playing the second leg at home; the teams that did so were more likely to progress to the next round, but this could be wholly attributed to the fact that they were the stronger teams, as would be expected from group winners.

3.3.1 The three-point rule in football

This links with a set of papers concerning the reward given to a football team in a league for winning a match. Until 1981 the universal rule was to give two points for a win and one for a draw, but the rules in England were then changed so as to give three points for a win. This rule spread gradually over the next 20 years until, by 2000, the new 3-point rule has become universal. The intention was

to make matches more exciting by reducing the occasions where both sides would be happy with a draw, which could often lead to very negative play towards the end of a match.

Mehrezet *al.* (1987) analysed matches from England and Israel (the second country to adopt the new point system) before and after the introduction of the 3-point system and concluded that there was no significant difference to be found. Fernandez-Cantelli and Meeden (2003) found a mixed picture, suggesting that there appeared to have been an effect in some places but not others.

In contrast, Dilger and Geyer (2009) considered the pattern of German football, crucially using Cup football as a control so as to discount changes that were happening anyway, and concluded to a high level of significance that the change had brought about a decrease in the number of draws and an increase in the number of victories by just one goal. It would be interesting to know how the use of controls could have affected the two studies mentioned in the two preceding paragraphs.

Dewenter and Namini (2011) have taken this further by looking at home and away teams separately for the German Bundesliga and conclude that the change had made home teams play more defensively (presumably being scared of losing a lead), especially where home advantage is strong, while away teams play more offensively (presumably reacting to the possibility of earning three points rather than one). Brocas and Carrillo (2004) make essentially the same point, using game theory to show how the 3-point rule acts as an incentive to make teams play more defensively when they are leading.

3.4 Reaching climactic excitement

In 1999 the National Hockey League (NHL) changed the points system for its ice hockey tournaments. If a match was decided in normal time, there would be two points for a win and none for a defeat as before, but if a match was tied, thus going into overtime, and the match was won during overtime, the eventual loser would be awarded a point as well as the winner being awarded two points.

The intention was to persuade each side to go for a win during overtime, and thus increase attacking play and reduce the frequency of ties after overtime had been played, and Abrevaya (2004) detected that these aims had indeed been achieved. However, he also showed that an unintended but predictable side-effect was that teams who were drawing as the end of normal time neared played more defensively until overtime, safe in the knowledge that this way their point would be safe while there was still the opportunity to go for two points. Thus significantly more matches went into overtime.

This has an interesting echo in the study carried out by Markovich (2008), who examined the effect of the recent introduction in football of an announcement as to the number of minutes' stoppage time to be played at the end of each half. He made a distinction between "coached" play and "improvised" play, the latter being more offensive with increased probabilities both of scoring and of conceding a goal. His regression analysis detected an increased intensity of play, often improvised play, during stoppage time, but that this was preceded by a period of rather defensive "coached" play before the announcement, remarking that "players seem to stand around, waiting to learn how much time they have left to work with".

3.5 Safety

Safety is an important consideration in many sports, and frequently rules are put in place with the aim of avoiding serious accidents and injuries, but these can go wrong as the following two examples show.

Some of the most important cycling races introduced a system whereby a red flag is waved to indicate that the race is one kilometre from its conclusion. This flag means that any competitor who crashes in the remainder of the race is given the same time as the group he or she was in at the time of the crash. The intention was to avoid penalising riders who, by bad luck rather than poor skill, were adversely affected by the scramble for position and time that often occurs at the end of such races.

However, it was found that there was an apparent increase of crashes occurring just after the flag was waved, which was not at all what was intended. Therefore, in 2005, the rule was changed so that the flag was waved 3 km from the end instead of 1 km. Lybbert *et al.* (2011) analysed three top tours – the Tour de France, the Giro d'Italia and the Vuelta a España – both before and after this change, and proved using tobit analysis that the main effect was an increase in the number and seriousness of crashes between 3 and 1 km from the end, showing almost incontrovertibly that riders were deliberately manipulating the rule by causing crashes that would otherwise have not occurred, hence *reducing* overall safety.

Another example came in the world of motor racing. Formula 1 racing has several safety regulations in place concerning the cars themselves and it is undeniably safer than it used to be. However, sometimes such regulations can have unforeseen effects. Potter (2011) undertook regression analysis to determine whether the changes in the safety of the cars had made drivers more reckless, since the effects of a crash were likely to be less serious, and concluded that they had. Moreover, he showed that the combined effect of car safety improvements and increased driver recklessness appeared to have *decreased* safety between 1963 and 1973.

3.6 Overview of post hoc analyses

These different analyses and varying conclusions demonstrate that determining the effects of changes can be rather more complex than might at first appear. In particular, it is remarkable to note how often changes have undesirable effects other than those which were intended. This suggests that there should be more prior analysis of intended changes, as in the following sections.

4. Prior analysis of changes to sporting laws

There are not many analytical papers which fall into this category. Perhaps OR/Analytics researchers recognise that the professional sporting bodies are best placed to propose changes to the way in which a sport is actually played. However, there are some interesting papers to report.

Barnett and Pollard (2011) propose a rule whereby an Australian Rules football match is not won until a team is leading by at least six points. The authors claim that this would increase fairness and spectator interest, but their argument is difficult to follow; their definition of fairness appears to be synonymous with the better team winning, which begs a lot of questions. They also suggest a “golden goal” rule during extra time for knock-out matches; as claimed, this would reduce the average length of those matches which went into extra time, though this would be counterbalanced by the fact that their other rule would mean more matches going into extra time.

The other three papers in this category all relate to football. Wright and Hirotsu (2003) concentrated mainly on the tactics surrounding professional fouls, but also put forward proposals for a different approach to penalising professional fouls, with referee being allowed to award penalty goals (as with penalty tries in rugby), and to award penalties from anywhere on the pitch, rather than producing red cards for such fouls. These proposals were shown to be much fairer for the team against whom the foul was committed as well as for the offending team, and it was also argued that this would almost eliminate professional fouls from the game of football.

Carrillo (2007) came up with an interesting idea regarding penalty shoot-outs, suggesting that they should take place *before* the start of extra time. This would avoid the common spectacle of two overtired teams simply going through the motions during extra time, waiting for penalties, since one of them would know they had to score a goal in extra time. This is the sort of idea that could usefully be trialled for a particular competition. It would mean more shoot-outs, which would be popular with some people and unpopular with others; and it would also mean that the shoot-outs would be less imbued with intense drama and passion, which again some people would prefer, but others wouldn't.

However, Partovi and Corredoira (2002) must take the prize for the most ambitious proposals. They interviewed experts and enthusiasts, using Analytic Hierarchy Process and Quality Function Deployment to argue that their proposals were simply a logical extension of what people appear to want. Two of their proposals were for new red card offences and a type of ball that swerves more, and these have in fact both been put into practice. It is perhaps less likely that their other three proposals will be put into practice in the near future: they are (a) to reduce the number of players per team from 11 to 9 (on the basis that players are faster and fitter than they used to be); (b) to increase the size of the goals (on the basis that goalkeepers are taller than they used to be); and (c) to abolish the off-side rule, which has been done for hockey to a mostly enthusiastic response, though hockey and football are of course very different in some respects.

These proposals touch upon the themes which run through the papers reviewed in the next section: fairness and competitive intensity.

5. Proposals for changes to tournament rules and organisation

Some of the studies included here have been commissioned by sporting bodies for specific purposes, but most are ideas put forward by the researchers themselves.

There are two potential pitfalls with all studies of this type: firstly that any proposed changes may well directly lead to changes in players' behaviour, making analysis unpredictable; and secondly that the objectives of such proposals may not be universally shared.

One renowned study that does not appear to suffer greatly from either of these problems is the work of Duckworth and Lewis (1998), who created a method ("the D/L Method") for determining targets and winners of rain-affected limited-overs cricket matches. Their method considers wickets remaining and balls remaining as resources, and their method is based upon a proportional reduction of the total resources available to a team whose innings has been shortened. D/L has been successfully adopted all over the world. Others have put forward variations which are claimed to be better, but as yet the D/L method reigns supreme.

For example, Carter and Guthrie (2004) put forward a variation whose objective is to maintain each team's probability of winning before and after an interruption, which is not the precise objective of

D/L (though in practice the difference is small). Bhattacharya *et al.* (2011) undertook analyses using regression suggesting that the method needed amending for twenty-over matches – their work looks sensible but was illustrated with just two matches, suggesting that perhaps there is not yet enough evidence for changing the D/L system. And Stern (2009) used tobit regression to suggest that slightly different models should be used for the side batting first and the side batting second. While this makes some sense – it is well known that the tactics will vary depending on whether a team bats first or second (see Clarke, 1988) – its adoption would be very controversial, especially since the logical conclusion of the work is that, even if a match is not interrupted at all, the target for the second team should be slightly different from just the first team's score plus one!

Even Duckworth/Lewis, however, is not immune to manipulation. For example, see <http://www.ecb.co.uk/news/domestic/twenty20-cup/sussex-v-kent,305816,EN.html> for an account of how a captain won a match in fading light simply by tossing the ball to his fastest bowler at *exactly* the right moment.

5.1 Fairness

The main objective behind this work was one of fairness, and this theme is repeated in a variety of contexts. Another cricket example, commissioned by tournament organisers, is described in Wright (1992). Here a tournament was required which conformed to the structure of neither a single nor a double round robin, but something between – thus each team played some teams once and others twice over the course of a season, which could lead to significant unfairness. The number of home and away matches needed to be equal for all teams, and there were some additional requirements regarding traditional rivals. A structure was devised to be as fair as possible over the course of five years – however, after the first year of operation the structure was changed again, so most of the results were never put into practice!

Swartz (2007) tackled a fairness issue in the highly competitive world of highland dance competitions, in which competitors perform four different dances in front of judges. The order in which competitors perform is determined entirely randomly, and this is thought to give an advantage to those who dance later. The paper describes a fairly simple algorithm for determining the dance orders which retains a random element, but makes sure that the sum of the position orders over the four dances is exactly equal for all competitors, so as to remove this potential advantage.

How do you ensure fairness when not every team has the same resources available to it? Percy and Scarf (2008) considered this issue in relation to quiz teams; it is a frequent occurrence in such contests for small teams to complain when larger teams are the winners. Using Bernoulli analysis, the authors recommend a Bayesian method for adjusting scores which incorporates a prior estimate of the difficulty of the quiz. However, they recognise that their analysis has limitations – not only may this prior estimate be hard to reach, but they assume that participants either definitely know or definitely don't know the answer to each question, and that if one person knows the right answer then that is the answer chosen by the team – which will probably overcompensate small teams.

Unfairness can strike at an early age, as shown by Hurley (2009) when considering the way in which age groups are structured for sports competitions. Those born earliest in their year group, whether based on a calendar year or an academic year, have an inbuilt advantage over those born later. Hurley showed how to organise groups such that the advantage rotates: those with a disadvantage at one time will hold an advantage later.

In sports involving more than one discipline, it may be important that the influence of each discipline is equalised as far as possible, so as not to favour a competitor who excels in one discipline over one who excels in another. Curtis *et al.* (2006) consider the triathlon, a contest involving swimming, cycling and running. Making the sensible assumption that, to be fair, a given standard deviation improvement in any discipline should have an equivalent impact on the overall result, they calculated that the respective distances should be in the ratio 1:17:4. This implies that the Olympic competition is unfair to those who excel at swimming, and that it could be made fair by increasing the swimming distance from 1.5 kilometres to 2.5 kilometres.

What appears to be fair can be very subjective. In many tournaments (e.g. football leagues), points are given for wins and draws, and the league positions of teams or competitors are determined by the number of points, with other considerations (e.g. goal difference) used only as tie-breakers. This probably seems fair to many if not most supporters. Sometimes there is also a system of bonus points, whose purpose may be to increase excitement and spectator interest (e.g. in rugby tournaments where an extra point may be given for scoring more than four tries).

However, there is a view expressed by Winchester (2008) in relation to Rugby Union, and by Lenten and Winchester (2010) for Australian Rules Football, that the proper allocation of bonus points can increase fairness as well; that it would be fairer for large wins to be rewarded more directly, and for large defeats to be penalised more directly, than just by being used as tie-breakers. For rugby their preferred allocation of points is three for a win, two for a draw, one for scoring two or more tries and one for losing by five or fewer points; for "Rules" the proposal is four points for a win, three for a draw, two for winning by 27 or more and two for losing by 26 or fewer. These allocations were found to maximise the match-up of the league positions with the results of their regression models of strength derived from the matches.

However, since the models were based on points scored rather than on wins, draws and defeats, there is a certain element of circularity in their arguments, and the results of adopting their proposals could be controversial. They point out that, for the 2002 AFL competition, if their proposed points allocation system had been used, two teams each with a record of nine wins, one draw and twelve defeats would have finished higher in the final league table than a team with twelve wins and ten defeats – many would regard such an outcome as highly unfair.

Another limitation of their work is acknowledged explicitly, when they say "the introduction of bonuses may alter team behaviour. For example, a team with a comfortable lead late in a game will be less likely to substitute key players when a margin bonus is included than under the current system. We do not account for changes in team behaviour induced by bonuses" (Lenten and Winchester, 2010). This limitation applies to almost all such proposals.

5.2 Competitive Intensity

It is certainly true that Lenten and Winchester's proposals (2010) would increase "competitive intensity" (CI). This is a term broadly defined to cover situations where at least one team, preferably more, has an incentive to perform to the best of their ability, both within a match and overall within a tournament. Thus a contest between two equally matched teams will be said to have high CI; a mismatch between a strong team and a weak one will be said to have low CI unless there is an incentive for victory by a large margin; and a tournament will maintain high CI until its end if important events (championship, promotion, relegation, qualification for playoffs or other tournaments etc.) are not settled until the latest possible date.

Maintaining high CI is thus a key goal of tournament organisers, not only for the sake of the tournament itself and its participants but also to keep spectator interest at a high level.

Differing approaches are used to keep CI as high as possible. One approach is to use financial incentives. Szymanski (2003) uses economic theory to explore ways in which prize money can be allocated so as to maximise the total competitive effort summed over all participants, without reaching any firm conclusions. Other approaches include drafts, promotion and relegation, special tournament formats, seeding and handicapping.

5.2.1 Drafts and team formation

We have already seen (Taylor and Trogdon, 2002) that some tournaments have draft systems designed so as to equalise the strengths of all teams, at least at the start of a season, which should in theory maximise CI, but they also noted that such rules tend to reduce CI, or even turn it on its head by providing an incentive to lose, towards the end of a season.

O'Shaughnessy (2010) aims to overcome this problem by means of a modified draft system for use in the Australian Football League (which covers Australian Rules Football). This system still favours weak teams but is flexible enough to ensure that, for example, a team who picks first in Round 1 of the picks will not necessarily pick first in Round 2, etc. There could still be some incentive to lose under this system, but the incentive would not be as strong.

A slightly different angle on this was studied by Ragsdale *et al.* (2008) for creating foursomes in golf. The authors designed a Decision Support System which uses mixed integer programming to create teams which are as equal as possible.

5.2.2 Promotion, relegation and tournament formats

Many tournaments involve promotion and relegation, which act as incentives as well as improving competitive balance for the following season. Puterman and Wang (2011) use NBA (National Basketball Association of the USA) data and perform statistical analysis and simulation to show that a system of three up, three down works best for a tournament of three divisions with ten teams in each, measured by the long-term average standard deviation of team quality within divisions. This takes account of the fact that a team's ability will vary from one season to the next, rather than trying to compensate for it with a draft.

A number of authors have addressed this issue for football. Scelles *et al.* (2011) use a simple model to suggest that CI can be maximised for Ligue 1 (the top French league), which contains 20 teams, by a method under which the first eight teams qualify for the championship playoffs, with an incentive to be ranked as high as possible, and with their league position also determining European competition entry for the following season. At the bottom, the 20th team is relegated and the teams ranked 16th to 19th take part in play-offs to determine which other team is relegated.

Goossens *et al.* (2012) were commissioned by the Royal Belgian Football League to examine three alternative formats with the main aim of maximising CI. They used simulation to determine that the best option is a rather complex system which starts with a standard double round robin and finishes with a series of play-offs. The system provides for the possibility that even the team finishing twelfth out of 16 in the round-robin stage can, via the playoffs, eventually become one of only four clubs to achieve qualification for one of the following season's European competitions.

Puterman and Wang (2012) consider the issue of promotion and relegation as applied to the main US golf competition, the PGA Tour, which has 180 participants. Under the current system, the top 125 players on the PGA Tour qualify for the following year's PGA tour along with 25 from the tier below, the Nationwide Tour, and a further 25 plus ties from a single 6-round tournament known as "Q-School". While acknowledging that the inclusion of Q-School as a means of qualifying for the PGA Tour creates high spectator interest for the Q-School itself, the authors carry out simulations using data from every year between 1998 and 2010 to show conclusively that the optimal number of qualifiers from Q-School, if the primary objective were CI, is zero. Their recommendation is that the top 150 from the PGA Tour should qualify for the following year's tour along with the top 30 from the NW Tour.

Another set of golf tournaments is analysed by Hall and Potts (2012), who consider the format of the FedEx Cup, a 4-tournament series which forms the end-of-season climax to the PGA Tour. The current format takes account of performance throughout the season for determining not just qualification for the FedEx Cup but also the final outcome. This has had some unfortunate consequences – for example, in both 2008 and 2009 the final winner was known before the final event, making it rather meaningless and uninteresting for both participants and spectators. The authors propose a new format which they show, using probabilistic analysis, to meet all three main PGA objectives: "all players have a reasonable opportunity to win at the TOUR Championship; all players are rewarded for consistently strong performance during the season; and the participation of marquee name players is guaranteed during network television coverage late in the event" (Potts and Hall, 2012).

McGarry and Schutz (1997) provide an overview of various tournament structures and analyse them in terms of the probability that the best team will win. They conclude that a knock-out system can be almost as effective as a round robin as long as it includes both seeding and double elimination (whereby participants are not eliminated until they have been beaten twice), but it may be questioned whether their objective is of pre-eminent importance as they claim.

Scarf *et al.* (2009) go further, considering a variety of structures against a number of possible criteria, including spectator interest, outcome uncertainty, competitive intensity and fairness. They recognise the difficulty of coming up with a single definition of fairness that all would accept.

5.2.3 Seeding

For many of the examples cited above, CI and fairness come into conflict at least to some extent, and in some circumstances the two can be diametrically opposed. One example involves seeding, which is clearly unfair.

Consider for example a top tennis tournament. Why is the draw always arranged such that the only player who is guaranteed not to have to play against the number 1 seed until the Final is the number 2 seed? Why should the number 2 seed be given this advantage which is denied to other weaker players? The reason is clearly to ensure high CI, especially at the latter stages of a tournament, even though it is at the expense of fairness, as we noted earlier following the analysis of Scarf and Yusof (2011).

Baumann *et al.* (2010) examine the issue of seeding in relation to the NCAA Basketball tournament between US Colleges popularly known as "March Madness", and they show that standard systems of seeding do not always maximise CI. They use data from more than 20 years and a simple probabilistic analysis to show that, under the current system, the 10th and 11th groups of seeds are treated advantageously in comparison with the 8th and 9th groups, thus undermining the principle of

using seeding to maximise CI, as well as adding to its unfairness. The authors recommend reseeding at each stage of the event in order to eliminate this anomaly, though they recognise that this could have drawbacks in that teams and spectators would have to adjust their travel plans at very short notice.

5.2.4 Handicapping

Sometimes participants and organisers are happy to sacrifice a great deal of fairness in order to achieve high CI. This is the case with handicap tournaments, as are common in golf. Swartz (2009) considers the Canadian system, which is designed such that, in a match between two people, each has a 50% probability of winning. Interestingly, the author uses this as his definition of fairness, whereas many would regard it as extremely unfair that the better player has no higher probability of winning than the worse player. He notes that, in many-player tournaments, this system is “unfair” to better players even by his definition, since the current method does not account for the fact that worse players have higher standard deviations of their round scores, and thus it is almost certain that one relatively poor player will have a really good day and produce a net score that is impossible for a good player to achieve. He proposes a new system that takes account of these standard deviation divergences to equalise win probabilities, using data collected at a Canadian golf club between 1996 and 1999.

McHale (2010) analysed the UK system of handicapping using data from 646 rounds of golf played at St Andrews in Scotland. By using logistic regression and simulation he found that the system has an inbuilt bias towards the better players, who had higher win probabilities for both match play and stroke play tournaments. While he discusses ways in which scaling factors could be used to make the probabilities almost equal, he does not recommend their use; instead he is in favour of keeping the current system, whereby worse players have a reasonable chance of winning, but better players still win most of the time, thus providing a good compromise between competitive intensity and fairness.

It is not only golf where handicapping is used. Keogh and O’Neill (2011) examine handicapping systems for ten-pin bowling, using data played in 1240 games in Dublin. They discover that “the distribution of bowling scores is approximately log-normally distributed with a common variance across players”. Having discovered this, they then show that, under the current handicapping system, better players still have a higher win probability than worse players. They propose a variation which will equalise win probabilities. Again this is put forward as “fair”.

5.3 Economy

Given the importance of economic factors to sporting bodies and tournament organisers, it is perhaps surprising that there has been almost no OR/Analytics work with the express purpose of saving money, apart from that to be found in scheduling/timetabling issues, which are not being considered in this paper.

Saltzman and Bradford (1996) did undertake an analysis of the make-up of the groups in the National Football League (American Football), with a view to minimising travel distance and thus saving money as well as time (assuming that travel costs are roughly proportional to distance, which is questionable when most travelling is done by air). They used quadratic programming to determine an allocation of teams to groups which would save about 1 million dollars per year compared with the allocation then in place (1995). However, there must have been other considerations at play, since the actual 1995 allocation of teams was so clearly a very long way

indeed from optimality if minimising travel were the only objective. The allocation changed shortly after the paper's publication and is now much closer to travel optimality.

6. And finally

Given all the above criticism of rule changes and reasons put forward as to why rules need to be changed, it is reassuring to read a study where the main conclusion is that everything is absolutely fine and dandy! Such a paper is that of Clarke *et al.* (2009), who used logistic regression analysis for the format of the World Professional Snooker Championship, considered fairness, competitive balance/intensity and efficiency, and found nothing to criticise at all!

7. Conclusions

Many OR/Analytics papers have been surveyed which consider the rules of sports and tournaments, whether commenting on a change or making proposals for changes. The post hoc analyses found that, even where the aims of a change had been achieved, there were often unforeseen consequences that need to be addressed. Proposals for rule changes were aplenty, though there is often a difficulty with the choice of objective being somewhat subjective, and again it not being clear whether any proposal would change participant behaviour in an undesired fashion.

Much of the analysis has involved statistical modelling, with various varieties of regression to the fore. Simulation is another technique which has been used on many occasions.

Overall, it would seem that this is just a taster and there may be plenty more such studies to come!

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