Modelling in Competitive Sports.

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1 Introduction

The purpose of this paper is to provide a summary review of literature written on modelling in competitive sport and also outline other possible means of modelling that could be developed further in sports, such as chaos theory. Teams and performers often demonstrate a stereotypical way of playing and these are idiosyncratic models which include positive and negative aspects of performance. Patterns of play will begin to establish over a period of time but the greater the data base then the more accurate the model. An established model provides for the opportunity to compare single performance against it.

> "The modelling of competitive sport is an informative analytic technique because it directs the attention of the modeller to the critical aspects of data which delineate successful performance. The modeller searches for an underlying signature of sport performance which is a reliable predictor of future sport behaviour. Stochastic models have not yet, to our knowledge, been used further to investigate sport at the behavioural level of analysis. However, the modelling procedure is readily applicable to other sports and could lead to useful and interesting results."
>
> Franks and McGarry (1996)

Mosteller (1979) set out guidelines when he developed a predictive model:

1. Use the past to predict the future -use only past scores to predict future ones.

2. Use weights - weigh recent games much more largely than games earlier in the season. Develop method from data for several years.

3. Use last year's data - for early games one would weigh up last year's last few games. As season progressed last year's games would be weighted less and less.

4. Estimate both strengths and weaknesses.

5. Adjust for home and away and for trends such as injuries, strengths found out.

6. Develop scores for injuries.

7. Consider morale.

Alexander et al (1988) used the mathematical theory of probability in the game of squash. Mathematical modelling can describe the main features of the game of squash and can reveal strategical patterns to the player. Squash is an example of a Markov chain mathematical structure:

The probability that A wins a rally when serving is	Pa
The probability that A wins a rally when receiving is	Qa
The probability that B wins a rally when serving is	Pb = 1 - Qa
The probability that B wins a rally when receiving is	Qb = 1 - Pa
If two opponents are of the same standing then	Pa, Pb, Qa, Qb = 0.5

The probability that A winning a point when serving is the sum of each winning sequence of rallies:

$Pa = 1/2 + 1/2^3 + 1/2^5 + 1/2^7 + \ldots = 2/3$ (geometric series)

Pa wins 9-0 = $(2/3)^9 = 0.026$

If A is stronger player with Pa = 2/3 and Qa = 3/5 then:

Probability that A wins when serving is 5/6; when receiving is 1/2.
Probability of A being in a serving state is 3/4.

The probability of winning a game is the sum of all the probabilities of each possible winning score, i.e. sum of p (9-0), p (9-1) . . . . p (9-8), p (10-9).

Other attempts to model team games (Ladany and Machol, 1977) theoretically have tended to founder upon the complexity of the numbers of variables involved and, at that time, did not base their predictions upon sound databases.

2 Empirical models

Hughes (1985) established a considerable database on different standards of squash players. He examined and compared the differences in patterns of play between recreational players, country players and nationally ranked players, using the computerised notational analysis system he had developed (Hughes, 1986). The method involved the digitization of all the shots and court positions, and these were entered via the QWERTY keyboard. Hughes (1986) was able then to define models of tactical patterns of play, and inherently technical ability, at different playing levels in squash.

- A detailed analysis of the frequency distribution of shots showed that the recreational players were not accurate enough to sustain a tactical plan, being erratic with both their straight drives and their cross-court drives. They played more short shots, and although they hit more winners they also hit more errors.

- The county players played a simple tactical game generally, keeping the ball deep and predominantly on the backhand, the weaker side of most players. They hit significantly more winners with straight drives. Their short game, consisting of boasts, drops and rally-drops, although significantly less accurate than the nationally ranked players, was significantly more accurate than the recreational players.

- The nationally ranked players, because of their far greater fitness, covering ability and better technique, employed the more complex tactics, using an 'all-court' game. They used time and pressure of shot to move their opponents out of position through combinations of shots.

- Finally, the serves of the county players and the recreational players, because of shorter rallies, assumed greater importance than the serves of the ranked players.

Fuller (1988) developed and designed a Netball Analysis System and focused on game modelling from a data base of 28 matches in the 1987 World Netball Championships. There were three main components to the research - to develop a notation and analysis system, to record performance, and to investigate the prescience of performance patterns that would distinguish winners from losers. The system could record how each tactical entry started; the player involved and the court area through which the ball travelled; the reason for each ending; and an optional comment. The software produced the data according to shooting analysis; centre pass analysis; loss of possession; player profiles; and circle feeding.

Fuller's (1988) intention of modelling play was to determine the routes that winning, drawing and losing teams took and to identify significantly different patterns. From the results Fuller was able to differentiate between the performances of winning and losing teams. The differences were both technical and tactical. Fuller identified nine quantifiable benchmarks:

1. Shooting efficiency for GS for winning/drawing teams bettered 73%.

2. Shooting efficiency for GA for winning/drawing teams bettered 65%.

3. GA attempted 42% of all shots with winning teams.

4. Shooting efficiency bettered 54% for winning/drawing teams from inner region.

5. Winning/drawing teams created 57% of shooting chances directly from own centre plays.

6. Winning/drawing teams scored 70% of shooting chances from own centre plays.

7. Winning/drawing teams lost on average 72 and 53 possessions per match respectively.

8. Winners lose 20% of possessions in the defending and centre third areas.

The research was an attempt to model winning performance in elite netball and more research needed in terms of the qualitative aspects i.e. how are more shooting opportunities created. the model should be used to monitor performance over a series of matches not on one-off performances.

> Every match is a contradiction, being at once both highly predictable and highly unpredictable.
>
> Morris (1981)

Treadwell, Lyons, Potter (1991) expressed that match analysis in rugby union and other field games has centred on game modelling and that their research was concerned with using the data to predict game content's of rugby union matches. They found that clear physiological rhythms and strategical patterns emerged. They also found that at elite level it was possible to identify key "windows" i.e. vital "moments of chronological expectancy where strategical expediency needs to be imposed." It appears that international matches and successful teams generate distinctive rhythms of play which can exhibit a team fingerprint or heartbeat. Lyons (1988) had previously analysed 10 years of Home Nations Championship matches to build up a database, and from this was able to predict actions for a match within 3 passes and 2 kicks. Franks et al (1983) had previously stated that they felt that one of the most important uses of quantitative analysis was the formation of a data base of past games to provide the possibility to formulate predictive models.

3 Empirical models in soccer

A number of research projects were not consciously attempting to create "models of tactics" in soccer, but in the presentation of their data and outcomes, often the findings intuitively moved towards defining optimal patterns of performance.

Reep and Benjamin (1968) collected data from 3,213 matches between 1953 and 1968. These matches included 9,175 goals, the passes leading to these goals, how possession was gained and the position of these actions were all recorded. It was found that 80% of goals resulted from a sequence of three passes or less. Fifty percent of all goals came from possession gained in the final attacking quarter.

In a modelling study of a different emphasis, Reilly and Thomas (1976) recorded and analysed the intensity and extent of discrete activities during match play in field soccer. They combined the use of hand notation with the use of an audio tape recorder, to analyse in detail the movements of English first division soccer players. They were able to specify work-rates of the different positions, distances covered in a game and the percentage time of each position in each of the different ambulatory classifications. The work of Reilly has continually added to this base of data enabling him to clearly define the specific physiological demands innot just soccer, but all the football codes (Reilly, 1992). This piece of work by Reilly and Thomas has become a standard against which other similar research projects can compare their results and procedures. This physiological model of performance, and its training implications, complement the other performance models and they should not be considered in isolation.

Bate (1988) explored aspects of chance in football and its relation to tactics and strategy in the light of the results presented by Reep and Benjamin (1968) and data from unpublished research collected by C.F.Hughes in 1987. Bate claimed that goals are not scored unless the attacking team gets the ball and one, or more, attacker into the attacking third of the field. The greater the number of possessions a team has the greater chance it has of entering the attacking third of the field, therefore creating more chances to score. The higher the number of passes per possession, the lower will be: the total number of match possessions, the total number of entries into the attacking third, and the total chances of shooting at goal. Thus Bate rejected the concept of possession football and favoured a more direct strategy. He concluded that to increase the number of scoring opportunities a team should:

1. Play the ball forward as often as posible.

2. Reduce the square and back passes to a minimum.

3. Increase the number of forward passes and forward runs with the ball of 40 yards or more.

4. Play the ball into space as often as possible.

Pollard et al. (1988) used Reep and Benjamin's (1968) method of notation in order to quantitatively assess determinants and consequences of different styles of play. It was suggested that elaborate styles relied upon multi-pass sequences of possession and that direct styles of play significantly relied on long forward passes and long goal clearances. In addition it was found that there was no relation between the degree of elaborate style and the use of width. Pollard et al. concluded that it was important for the coach to build up a style profile of each opponent for future analysis by using this type of quantitative assessment of playing style.

Harris and Reilly (1988) considered attacking success in relation to space and team strategy, by concentrating mainly upon space in relation to the defence and overall success of an attacking sequence. This was a considerable departure from many of the systems previously mentioned which have tended to disseminate each sequence into discrete actions. Harris and Reilly provided a variable index describing the ratio of attackers to defenders in particular instances, while simultaneously assessing the space between a defender and an attacker in possession of the ball. The variance of these were analysed in relation to attacking success, where a successful attack resulted in a goal, an intermediate attack resulted in a non-scoring shot on goal, and an unsuccessful attack resulted in an attack ending without a shot. The results showed that successful attacks tended to involve a positive creation of space, where an attacker passes a defender - an unsuccessful attack generally involved a negative use of space which enabled the defence to provide sufficient depth and concentration. This would seem to support Bates' (1988) conclusions concerning square and backward passing which involves slowing an attacking sequence in terms of direction.

One of the major developments in computerised notation was the development of a mini system devised by Franks (1983a). Franks configured a keyboard on a mini-computer to resemble the layout of a soccer field and designed a program which yielded frequency tallies of various features of play. The path of the ball during the game was followed, so off-ball incidents were considered extraneous. A video was time-locked into the system so that relevant sections of the match could be replayed visually alongside the computer analysis. His data was analysed to see if the Reep and Benjamin (1968) model was replicated at the highest international level - it was found that the same facts emerged about passing, shots and goal-scoring.

Church and Hughes (1986) developed a computerised notation system for analysing soccer matches using an alternative type of keyboard, called a concept keyboard. This is a touch sensitive pad that can be programmed to accept input to the computer. This permitted pitch representation to be graphically accurate and action and player keys to be specific and labelled. This considerably reduced the learning time of the system, and made the data input quicker and more accurate. The system enabled an analysis of patterns of play on a team and player level, and with respect to match outcome. An analysis of six matches played by Liverpool during the 1985/6 season resulted in a smple model of their winning and losing performance profiles, the most important of which were:

1. A greater number of passes were attempted when losing than when winning.

2. Possession was lost more often when losing.

3. A greater number of shots were taken when losing than when winning.

Hughes, Robertson and Nicholson (1986), used the same concept keyboard and hardware system developed by Church and Hughes (1986), but with modified software, to analyse the 1986 World Cup finals. Patterns of play of successful teams, those teams that reached the semi-finals, were compared with those of unsuccessful teams, i.e. teams that were eliminated at the end of the first rounds. A summary of the main observations is as follows:-

1. Successful teams played significantly more touches of the ball per possession than unsuccessful teams.

2. The unsuccessful teams ran with the ball and dribbled the ball in their own defensive area in different patterns to the successful teams. The latter played up the middle in their own half, the former used the wings more.

3. This pattern was also reflected in the passing of the ball. The successful teams approached the final sixth of the pitch by playing predominantly in the central areas while the unsuccessful teams played significantly more to the wings.

4. Unsuccessful teams lost possession of the ball significantly more in the final one sixth of the playing area both in attack and defence.

Hughes and Lewis (1987) extended this work, analysing attacking plays only, to examine whether such unsuccessful teams use different attacking patterns to successful teams. An attack was defined as any move or sequence of moves that culminated, successfully or otherwise, in an attempt on goal. A total of 37 individual action variables and 18 different pitch divisions were employed in the data collection programme. The data analysis programme employed chi-squre test of independence to compare the frequency counts of each action available, with respect to positon on the pitch, between successful and unsuccessful teams.

It was concluded that successful teams passed the ball more than unsuccessful teams when attacking, particularly out of defence and in the final attacking end of the pitch. As in the previous work by Hughes et al., the successful teams used the centre of the pitch significantly more than unsuccessful teams. Further differences demonstrated that successful and unsuccessful teams used patterns of play that vary significantly in attack. Implications were drawn with respect to the optimisation of training and preparation for success in elite soccer match-play.

Partridge and Franks (1989a and 1989b) produced a detailed analysis of the crossing opportunities from the 1986 World Cup. They carefully defined how they inerpreted a cross, and gathered data on the following aspects of crosses:

- Build up
- Area of build up
- Area from which the cross was taken
- Type of cross
- Player positions and movements
- Specific result of the cross
- General result, if the opportunity to cross was not taken.

Fifty of the fifty two games of the competition were analysed from video tape, using specifically designed software on an IBM XT Microcomputer that enabled each piece of information relating to crossing opportunities to be recorded and stored. The programme recorded the time at which all actions took place during the match, for extracting visual examples post analysis, in addition to the usual descriptive detail about the matches, i.e. venue, teams, etc. A second programme was written to transform and down load this data into dBASE III+. After which, this data base was queried to reveal selected results. The authors summarised their model of optimal crossing by considering, what they termed, `key factors'. These were as follows:

- Take the opportunity to cross the ball if a) a target player can contact the cross, b) you have the chance to play the ball behind defenders and eliminate the goalkeeper.

- The cross should be played a) first time, where possible, b) behind defenders, c) past the near post, d) without loft and hang time.

- Target players should be in position to contact the cross by a) individual moves to get goal side of the marking defender, b) being as direct as possible, c) not running past the near post to contact the ball, d) always making an attempt to contact the ball.

- Supporting players should position themselves to a) seal off the top of the penalty area, b) seal off the backpost area (not allow any ball to go through the backpost area).

- Crosses should not be taken from areas close to the corner flag. Instead, the crosser should dribble toward the goal and either win a corner or get into the penalty area and cross to a particular player.

In conclusion their results were then related to the design of practices to aid players understand their roles in the successful performance of crossing in soccer.

Yamanaka, Hughes and Lott (1992), using an updated version of the systems used by Hughes et al. (1988), demonstrated the ethnic differences in international soccer by analysing the 1990 World Cup. They attempted to create models of play based uopn ethnic differences. It was recognised at this time that British teams were playing in different patterns to all other teams in trhe rest of the world, but did European teams play differently to South American teams, and so on? They defined four groups, British Isles, European, South American and Developing nations and by analysing the respective patterns of play in matches with respect to pitch position were able to conclude on the different playing models of these international groups. They also presented data in a case study of Cameroon who had had such a successful World Cup, comparing their model to that of the orher groups to examine the way in which they had developed as a footballing nation.

The work of Gerisch and Reichelt (1992) used graphical representation of their data to enable easier understanding by the coach and players. Their analyses concentrated on the one on one confrontations in a match representing them in a graph with a time base, so that the development of the match can be traced. Their system can also present a similar time-based analysis of other variables, inter linking them with video so that the need of providing simple and accurate feedback to the players is attractively achieved.

Grehaigne (1994) analysed the configurations of the game according to positions of the player, their speed, and their directions and proposed a model to analyse the transition between two configurations of play that enables one to take time into consideration as the match evolves.

Franks and McGarry (1996) cited Charles Reep's work in soccer since the 1950's, and how the statistical analysis of this data reveals mathematical functions and consistencies of certain behaviours. The conclusions drawn from their work suggested that it would be of benefit to a side to maximise the probabilities of certain actions at the expense of others. Reep and Benjamin (1968) found that the goal:shot ratio was 1:10 and thus it would seem fair to suggest that an increase in the number of shots would lead to an increase in the number of goals. Since they also found that most shots came from passing movements with very few passes then the "long ball" or "direct style" of play becomes important.

Work by Franks (1988) found that passing movements leading to goals were even shorter than passing movements leading to shots, hence suggesting that there lies a sub-group within the shots on goal group.

Franks and McGarry (1996) described how sports analysis can move on from being a descriptive process to becoming a predictive one. If there is some level of consistency within the performance then future performance can be predicted from past matches through stochastic modelling. They sub-divide sports into two sections, those determined by score (squash, tennis, etc. where the result is win or lose) and those by time (soccer, rugby, etc. where the result is win, lose , or draw.) This is an important distinction when modelling aspects are to be discussed.

The characteristics of score-dependent sports are based largely on a structured sequence of discrete events where the relationship between each event is related to the opponent. Time-dependent sports are invasive and interactive and can be considered as relatively contingent in a temporary state. The structure of the sport is very important when it comes to deciding what method of modelling one should use to predict performance.

Score-dependent sports can be modelled by simply using discrete event models but the time-based ports need time models since the next event is always dependent on both event and time. Franks and McGarry suggested the so-far untried Poisson model for discrete events in time-dependent sports. They also discuss the importance of the number of competitors involved on the development of a model - the greater the number of competitors then the larger the scope for variability. This simply emphasises the problems facing coaches when they view a game. It would appear to be the case that the previous event only becomes of importance to the coach when a critical event has just occurred. The amount of data is one reason why little modelling has been directed into team games in a conceptual manner.

4 Catastrophe Theory

Kirkcaldy (1983) described catastrophe theory as:

> " . . . a descriptive model . . . which allows us to better appreciate the manner in which *multi-dimensional* systems operate and to make predictions of the behaviour of the systems under scrutiny."

The mathematical model was originated by Thom (1975) and later modified by Zeeman (1975; 1976). Kirkcaldy (1983) used the model to provide a possible explanation of how explosive effects can accompany small changes in arousal to produce an optimum level of performance or a sudden decrement in performance. It is concerned with the methods of attaining equilibrium states in qualitative mathematical language.

Poston and Stewart (1978) stated:

> "Catastrophe theory may be expected to give useful analyses of more widely varying data than do the current linear models. Of course, it requires the development of comparable statistical expertise for the essentially non-linear case before that expectation may be fulfilled."

Thom's (1975) 3-dimensional model of catastrophe attempted to explain the relationship between cognitive and somatic anxiety and athletic performance, and predict performance from this. Catastrophe theory predicts a negative linear relationship between the cognitive anxiety and the performance, but that the somatic anxiety also plays a role. Hardy and Fazey (1987) hypothesised that if somatic anxiety increases towards optimum while cognitive anxiety is low then performance will be facilitated.

5 Chaos Theory

The ability to predict performance is inherent in the process of effective planning., but is very difficult to do accurately. Errors in statistical methods of predicting are often attributed to forecasting error but chaos theory suggests that those errors imply that performances follow natural trends and are better explained by non-linear rather than the more traditional linear mathematics.

> "Chaos theory is the science that discovers order in nature's seeming randomness."

In more recent times scientists have discovered that certain systems within nature have chaotic dynamics and have an infinite variety of unpredictable forms but through a systematic process of self-organisation. The disorder of nature produces orderly patterns such as snowflakes. Other examples of non-linear chaotic systems are: weather, national economies, fibrillating hearts. It is possible to mathematically equate the beating of the heart that will provide values for the process over time. These solutions can be mapped through an "attractor" graph, which shows a chaotic system's solutions converge towards a specific path. A small change to the input will vary the pattern. Although this variation appears to be chaotic and random it is a reflection of a high order of complex events. This provoked interest in whether this pattern of chaos and self-organisation could also be evident in human situations.

Stacey (1993) examined the possibility of using this new frame of reference in the management sector. His investigation was based upon the fact that the behaviour of some systems within nature is so complex that the link between action and outcome simply "disappears in the detail of the unfolding behaviour." Scientists see this notion of causality as being inherent within chaos theory and applies to most natural phenomena and is the reason why nature is always creative.

In the management of human organisations chaos theory points towards the need for managers to create an unstable environment for effective learning and hence new strategic directions to evolve. There are certain key points on the behaviour of dynamic systems and their applicability to human situations.

1. Chaos is a fundamental property of non-linear feedback systems. All human behaviour are non-linear because one action always leads to a subsequent one and people tend to over or under react. Therefore in any situation involving human interaction there is a possibility of chaotic behaviour as well as stable or unstable behaviour. The key question is which state leads to successful performance. Success will lie at the border between a state of stable equilibrium (ossification and team work) and an unstable

state of equilibrium (disintegration and individual performance), that is in a non-equilibrium state between the two.

2. Chaos is a form of instability where the long term future is not known. When irregular patterns of behaviour operate away from equilibrium they will be highly sensitive to tiny changes and will completely alter the behaviour. Small changes leading to larger ones are common place occurrences in human situations. Stacey (1993) cited the example of VHS and Betamax.

3. Chaos has boundaries around its instability. Chaos is disorder and randomness at one level and qualitative pattern at another. When the future unfolds it often repeats itself but never in exactly the same way. "Chaos is an inseparable intertwining of order and disorder."

4. Unpredictable new order can emerge from chaos. Stacey (1993) highlighted eight steps to create order out of chaos:

a. Develop new perspectives on the meaning of control. Self-organising processes produce controlled behaviour although no one is control.

b. Design the use of power. When power is used as a force it is consented to out of fear or not consented to out through rebellion. Groups in these states are not capable of the complex learning needed to develop new perspectives and models. In a business environment open questioning and public airing of views is to be encouraged.

c. Encourage self-organising groups. Groups need to identify their own challenges and goals.

d. Provoke multiple cultures. Rotate people between their tasks and from external sources.

e. Present ambiguous challenges not clear long-term aims. Offer half-formed ideas for others to develop.

f. Expose the group to challenging situations rather than run away from the unknowable future.

g. Devote attention to improving group skills. "The route to superior learning is self-reflection in groups.

h. Create resource slack through investing in additional resources.

Priesmeyer and Baik (1989) used chaos theory to describe the performance of companies. They describe their organisational heartbeat as "quarter 1, quarter 2, etc.". What chaos suggests is that a certain cycle will be followed over time but that there may be a divergence from this pattern in response to any environmental changes. One company, Toro, which manufactured snow-throwers experienced a change to chaos. In the winter of 1979 the USA had limited snowfall, shocking the company from a stable period one pattern to a chaotic behaviour pattern and then to a more stable one again. This transition back to a stable pattern represents successful dampening of the chaotic condition. i.e. through introducing a price incentive program.

The applications of chaos theory to sport are so far limited to using the theories as a source of metaphors (Lyons and Hughes, 1996) - the idea of reducing some of the apparent chaos and linear dynamic models of sports such as soccer to predictive and stable differential equations is attractive but would seem some way in the future.

6 Critical Incident Technique

The term ´critical incident´ was first coined by Flanagan (1954) in a study designed to identify why student pilots were exhausted at flight school.

> "The critical incident technique outlines procedures for collecting observed incidents having special significance and meeting systematically defined criteria."

The technique was further developed at the American Institute for Research to continue "the systematic research on human behaviour in defined situations." Previous research on the pilots was undertaken by Miller (1947) and the conclusions were that pilots were eliminated for such reasons as poor judgement or insufficient progress. In an attempt to distil the analysis process, Flanagan concentrated on those actions that he deemed and defined as being the important actions.

The critical incident technique:

> "consists of a set of procedures for collecting direct observations of human behaviour in such a way as to facilitate their potential usefulness in solving practical problems, with emphasis on observed incidents possessing special significance."

The incidents noted are those that the observer believes to are both crucial effective and crucial ineffective behaviours. These incidents are then categorised according to the behaviours to constitute the critical requirements. Flanagan saw the technique as a flexible one which should be modified to meet the specific needs of any given situation, and research has been made not only with pilots but also with nurses (Teig, 1953), teachers (Domas, 1952) and administrators.

Jensen (1953) found the critical incident technique to be a sound, objective way of collating information, as does Merritt (1954).

> "The critical behaviours are derived from the reporter's description of actual teaching incidents, rather than their value judgements about critical teaching behaviours."

The critical incident technique is a powerful research tool but as with other forms of notating behaviour there are limitations inherent in the technique. Flanagan (1954) admitted that "Critical incidents represent only raw data and do not automatically provide solutions to problems" and Burns (1956) was even more critical:

> "The indiscriminate use of the critical incident technique in the establishment of success criteria . . . can only result in fetish collection of data which describes everything and explains nothing."

Another limitation of the technique is the total dependence on the reporters' opinions and this subjective element inherent in the use of the technique is often stated as a disadvantage. but Flanagan also pointed to the advantages of such a technique:

> "The critical incident technique, rather than collecting opinions, hunches and estimates, obtains a record of specific behaviours from those in the best position to make the necessary observations and evaluations."

Barclay (1968) used the critical incident technique in teaching beginners to swim. His methodology included a questionnaire asking both the teachers and the students to identify, if possible, two specific critical incidents which they believed to have helped and hindered the instruction. In his pilot study of 30 students, 48 critical incidents (28 effective and 20 ineffective) were indicated. A critical incident was used as long as the criteria laid down was met:

- It described an actual happening observed or participated in by the observer.
- It took place in beginning swimming instruction.
- It included a clear description of teaching behaviour.
- It showed a teacher behaviour/student outcome relationship.

Barclay tested for reliability by asking two judges to abstract critical behaviours from the same 50 incidents. Judge 1 identified 62 behaviours and agreed with the investigator on 85.5 % of the behaviours identified. Judge 2's corresponding figures were 68 and 88.9%. In the study a total of 1505 critical behaviours were extracted from the critical incidents - a 929 effective and 576 ineffective split.

Garis (1966) aimed to identify both ineffective and effective teacher behaviour in gymnastic instruction and thus establish specific guidelines for effective teaching. Over three thousand schoolgirls and over two hundred teachers from New York state were used in the research. The research undertook three major steps:

1. Testing the reliability of the abstracting process
2. Identifying and abstracting the critical behaviours from the incidents.
3. Categorisation of the critical behaviours.

This enabled Garis to establish a set of conclusions based on the critical incident technique which would provide a guideline of effective teaching for gymnastic activities to girls.

Hughes, David and Dorkin (1996) attempted to define critical incidents in soccer based upon some of the ideas of McGarry and Franks (1996). They also used the term, "perturbations" - sustaining the metaphor from chaos theory. By analysing shots on goals and looking for a perturbation(s) in play, some exceptional skill or a defensive error, they validated the concept and reality of the presence of perturbations (critical incidents) in soccer. In addition they compared successful and unsuccessful sides in the way they created perturbations and found these significantly different. They also analysed the models of critical incidents created by two sides, Manchester United and Newcastle United, over 4 matches of each and found that the two teams had different models of perturbations. These models were then sustained when the two teams were analysed in a single match against each other.

Critical incident, or perturbation, analysis seems to offer a way of making sense of all the masses of data that is available from an analysis of a team sport such as a soccer. The resultant data output can be so overwhelming so as to leave coaches and sports scientists struggling to see significant patterns amongst the thousands and thousands of bits of data. This method appears to direct analysts to those important aspects of the data that shape winning and losing models.

7 Summary

A number of authors have attempted to use empirical techniques to provide practical models with which to attempt to explain and predict behaviour in competitive matches. These are always limited by the "on the day" factor - someone performing either very badly or extremely well, thus skewing the whole outcome of the match, but in a large number of practical applications these empirical models produce reliable results.

The more theoretical models have the problem in moving from an algorithm to predictive data - so far no-one has achieved this with the catastrophe or chaos models. The mathematics of probability models seems more tractable but predictive models have so far been only limited to simple sports.

The critical incident technique analyses are really just an extension of the empirical techniques but they do seem to offer a fresh insight into matchplay in complex sports such as soccer and rugby.

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