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Extracting individual contributions to a team's performance

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Evaluating the individual performances of those who comprise a team is complicated by the fact that members have different responsibilities. A shooting guard in basketball is likely to score more points than a point guard, and a first baseman in baseball is likely to commit fewer errors than a shortstop, because their opportunities differ in both quantity and quality. These examples illustrate the difficulty in identifying effective team members merely by considering individual performance statistics.

If a team fails to accomplish its goals, it is pragmatically important to determine the locus of the difficulty. I propose to do so in an objective way, one that builds upon a familiar idea. In professional team sports, it is common to assess an injured player's impact by comparing the team's success while he was out of the lineup to that attained while he was active. If the rest of the team composition was the same before and during the period of injury, the difference reflects the impact of replacing one player. The analysis presented here generalizes that notion, decomposing overall performance as a function of the current occupant of each position on the team. Each individual is compared to others with the same responsibilities.

To facilitate such comparisons in controlled settings, the researcher can utilize substitution designs that impose systematic replacement of individual team members with other contenders who occupy the same position. Team performance can be separately observed for each combination. The ideal way to determine the various combinations is to create a factorial design in which positions within the team are the factors and contenders for those positions are the levels. Crossing the factors ensures that all contenders have an equal opportunity to be associated with one another.

In a field setting, the analyst may be able to decompose results from naturally occurring approximations to factorial substitution designs. I illustrate that decomposition with data from professional basketball. The data are scores that reflect short-term performance of the team, sorted according

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to which contenders were occupying the positions as the scores were generated.

The theoretical foundation for this decomposition is functional measurement (Anderson, 1981). In customary applications of that methodology, one of the goals is to derive estimates of subjective values, the internal counterparts of stimuli presented for an integrative judgment. In the current application, the corresponding goal is to estimate the quality of individual contributions to a team's performance. Here, I draw analogies between overall team performance and an integrated response, and between individual performances and subjective values.

In professional basketball, substitution is a routine aspect of the game, as coaches cope with fouls, rest tired players, and try to create better matchups. The data for the illustration are from the Los Angeles Lakers 2003-04 season. Two factors were created by regarding players as occupying either the frontcourt or backcourt position (a slight distortion of basketball reality, in which there are usually three specific frontcourt and two backcourt positions), yielding 16 combinations pairing each of four frontcourt players with each of four backcourt players. The eight players chosen for the analysis are the four who played the most minutes at each of the two positions. The performance measure is the score differential per 48 minutes (one complete game) while the pair was on the court. The data points represent averages over other teammates and over all opponents (Los Angeles Lakers player pair tandem stats, n.d.). Professional basketball is particularly useful

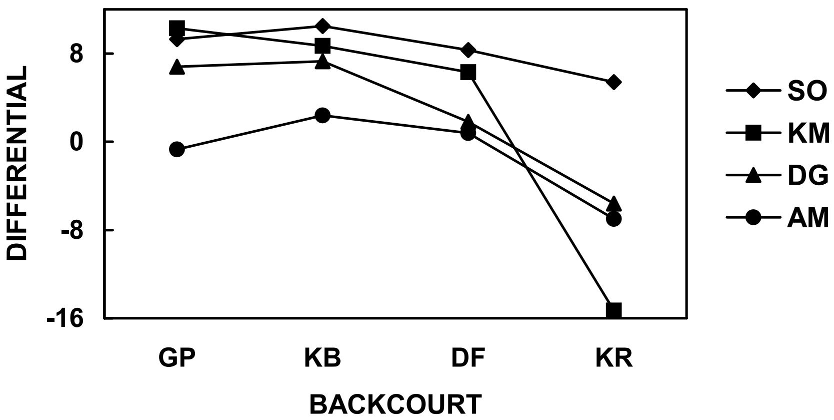

Figure 1. Differential points/48 minutes achieved by 16 pairs of 2003 Los Angeles Lakers. Each line corresponds to a frontcourt player.

for illustrating the analysis because it is a game in which many points are scored, thereby providing a stream of data associated with each pair.

The plot in Figure 1 shows that the differential was positive for most pairs, reflecting the fact that the 2003-04 Lakers were a successful team (56 wins, 26 losses). It is easy to visually compare the players who constitute each line in the plot; the higher the line, the better the team did while that player was on the court. SO was the most successful frontcourt player, and AM the least successful.

Exactly the same information is presented in Figure 2, but with the factors interchanged to facilitate comparing the backcourt players who now constitute the lines. Surprisingly, the very celebrated player KB was hardly more effective than GP, who was heavily criticized in the local media during the season and was not retained the next year.

Functional measurement analysis (Weiss, 2006) consists of evaluation of a structural model along with estimation of scale values. The two simplest models of team functioning are the additive model and the multiplicative model. The additive model posits that members contribute independently to overall team performance, so that poor individual performance by one member may be compensated for by excellent individual performance by another. For example, great pitching may win baseball games even if the hitting is weak. The additive model implies a lack of interaction between team positions.

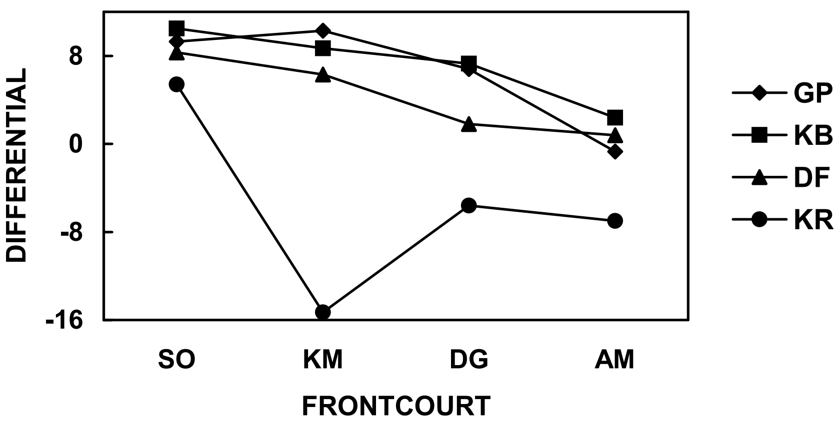

Figure 2. Differential points/48 minutes achieved by 16 pairs of 2003 Los Angeles Lakers. Each line corresponds to a backcourt player (replotted from Figure 1).

The multiplicative model, on the other hand, is characterized by interaction between positions, with the interactions concentrated in the multilinear components. Substantively, the multiplicative model implies that poor performance at any position results in overall poor performance, no matter how well the other team members do. For example, consider a bombing crew. If the pilot misses the location, it doesn't matter how well the others do; if the ordinance person doesn't arm the bomb properly, it doesn't matter how well the others do; if the bombardier times the release badly, it doesn't matter how well the others do. When a team functions multiplicatively, identifying a weak link is especially critical, because any investment in improving performance of the other members is wasted. A multiplicative relationship can be tested only if there are at least three levels per factor, so there would have to be at least three contenders for each position under consideration.

In designed experiments, model evaluation is usually carried out both statistically and graphically. Although the lack of an estimate of variability in the Lakers data prevents statistical evaluation, graphical analysis suggests that an additive model is a reasonable description of team functioning. The lines are generally parallel, as called for by an additive model, except for an anomalously low point when KM and KR played together. To the extent that an additive model is a correct description, the marginal means for team members are valid measures of their individual performances (Anderson, 1976). These means are not the number of points the player scored, but instead report how well the team as a whole did while the player was on the court.

The substantive import of an additive structure is that players perform at a given level, independently of whom they are paired with. The observed independence runs counter to the commonly held view that a good team has "chemistry", which I interpret as the notion that players perform more effectively when paired with particular teammates than might be expected from their individual capabilities. The only visible element of something like chemistry in the Lakers data is the negative effect of pairing KM and KR.

Just as the 2003-04 Lakers were a successful team, their cross-town rivals, the Los Angeles Clippers (Los Angeles Clippers NBA player pair tandem stats, n.d.), were unsuccessful (29 wins, 53 losses). All of the score differentials were negative except for the pairing of MJ and BS, the team's most effective players according to the present analysis (although EB was the acknowledged star of the team). However, an additive structure, similar to that for the Lakers albeit somewhat less regular, can be seen in Clipper team functioning as shown in Figures 3 and 4.

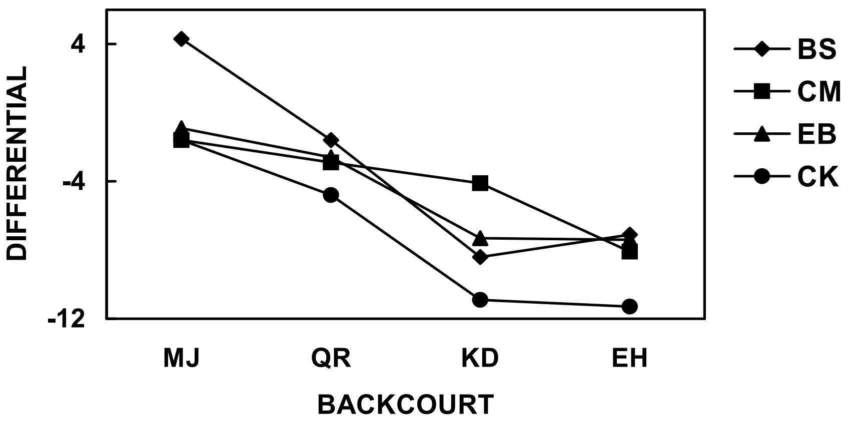

Figure 3. Differential points/48 minutes achieved by 16 pairs of 2003 Los Angeles Clippers. Each line corresponds to a backcourt player.

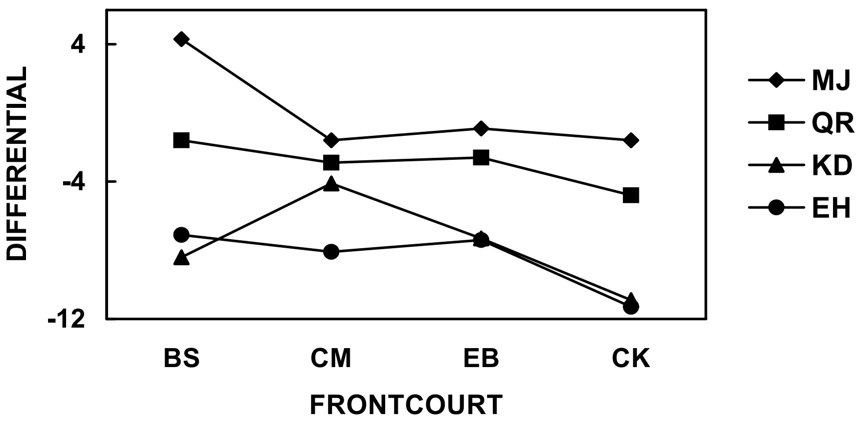

Figure 4. Differential points/48 minutes achieved by 16 pairs of 2003 Los Angeles Clippers. Each line corresponds to a frontcourt player (replotted from Figure 3).

Discussion

The analysis has implicitly invoked a stationarity assumption, that the contexts in which the pairs perform may be regarded as comparable across measurements. For each pair of basketball players, that context is their three other teammates and the five opponents, all of whom change within and across games. Over a long season, one may reasonably hope that variations in the performance of others on the court do not affect the observed patterns too much. The accuracy of the stationarity assumption for other applications needs to be considered on a case-by-case basis.

Another analytic concern is that the data points represent quite different amounts of time on the court. In trying to win games, coaches utilize their better players as much as circumstances allow. During the season, the coaches purport to know who those better players are. When the primary goal is instead to identify the most effective contenders, perhaps during the preseason, the functional measurement analysis might be usefully employed in conjunction with balanced substitution designs in which pairs play for equal durations.

The number of factors in the basketball analysis is somewhat diminished, since a team has five players on the court. If I had tried to impose a five-position design on the available data, there would not have been proper crossing of all factors and there would have been only two levels at most positions. Accordingly, I compressed the factors in a way that makes basketball sense, although some distortion in the comparisons may have occurred.

Controlled settings

In the laboratory, and perhaps in the workplace, it may be feasible to employ systematic substitution designs. We can implement designs that are balanced, and thereby fair, in the sense that each team member is paired equally often with those who contend for the other positions. The analysis may be implemented whenever there are at least two contenders for each position within a team. A systematic substitution design is presented in Table 1. In the example, there are two contenders for each of four positions. That is, as the team does its work, there are four members active at a given moment. All eight of the contenders (4 positions × 2) are assumed to be associated in that they share allegiance to the team's goals.

In this 2^4 factorial design, members 1 and 5 are contenders for Position A, members 2 and 6 are contenders for Position B, and so on. The

	Position			
Team	A	B	C	D
1	1	2	3	4
2	5	2	3	4
3	1	6	3	4
4	5	6	3	4
5	1	2	7	4
6	5	2	7	4
7	1	6	7	4
8	5	6	7	4
9	1	2	3	8
10	5	2	3	8
11	1	6	3	8
12	5	6	3	8
13	1	2	7	8
14	5	2	7	8
15	1	6	7	8
16	5	6	7	8

Table 1. Complete factorial design (2^4) comprising sixteen teams: two contenders (denoted by an integer from 1 to 8) for each of four positions (A to B).

scores to be analyzed are the performance measures observed for each of the sixteen teams that can be constituted by combining the contenders in all possible ways (full factorial crossing). We would normally observe each team more than once, so that an estimate of variability would also be available.

As the number of positions increases, complete factorial designs may be too large to be implemented conveniently. Fractional factorial designs (Cochran & Cox, 1957; Weiss, 2006) can come to the rescue. With fractional designs, all combinations are no longer observed, but still everyone can be paired equally often with the contenders for the other positions. A ½ replicate of the design in Table 1 is shown in Table 2. The sixteen combinations have been reduced to eight, yet all main effects can be estimated.

A stationarity assumption is also requisite in controlled settings. The analysis presumes that the contexts in which the team performs are comparable across assessments. "Context" might include opponents in a game or military setting, or production facilities in a manufacturing setting. The analysis also presumes that the act of substitution itself has no effect on performance. Of course, new teammates bring new abilities and ideas that

Team	Position A	B	C	D
1	1	2	3	4
2	1	2	7	8
3	1	6	3	8
4	1	6	7	4
5	5	2	3	8
6	5	2	7	4
7	5	6	3	4
8	5	6	7	8

Table 2. Fraction (½ replicate) of 2^4 factorial design comprising eight teams: two contenders (denoted by an integer from 1 to 8) for each of four positions (A to B).

conceivably can change the way tasks are carried out (Choi & Levine, 2004). There is some empirical evidence regarding the disruptive effect of changing a team's composition (Levine & Choi, 2004), but one might expect habituation to overcome this disruption as recurrent substitution becomes a normal aspect of the team's work. In everyday practice, substitutions among police, fire, medical, and sports teams routinely produce changes in group composition.

Conclusion

In general, the number of factors and levels to be included in an investigation is a pragmatic issue that depends on how many contenders at each position are considered worthy of observation. The 2^n designs are sufficient to compare two contenders per position, and are valuable for identifying weak links within a team. Computationally, the analysis remains straightforward for any number of factors.

It may turn out that a particular position yields no main effect. Under most experimental circumstances, the absence of a main effect is not very interesting. In the team context, however, the result covers two possibilities that have substantive importance. Either the contenders are equally proficient, or performance at that position is irrelevant to overall team performance. Additional experimentation, along the lines of either bringing in new contenders or eliminating the position, would be needed to distinguish the two possibilities. The second option might be especially attractive to hierarchical organizations seeking empirical evidence regarding the value of positions that may have only historical justification for their existence.

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Abstract

The success of a team depends on the individual capabilities of its members and on how they combine their efforts. Because team members have different responsibilities, individual performance statistics may not accurately convey how much a person contributes to the team's overall effectiveness. When it is feasible to substitute contenders for the various positions on a team, an objective comparison of individuals against their counterparts is available. A graphical decomposition of team scores allows for objective assessment of individual performances in context. At the same time, the pattern seen in the graph clarifies the structure of team functioning. The analysis is illustrated with data from two professional basketball teams, both of which functioned in an approximately additive manner. Systematic substitution designs can be used in controlled settings; these allow statistical evaluation to complement the graphical analysis.

Riassunto

Il successo di una squadra dipende dalle capacità individuali dei suoi membri a da come essi combinano i loro sforzi. Poiché i membri della squadra hanno responsabilità differenti, le statistiche della prestazione individuale possono comunicare non accuratamente quanto una persona contribuisce alla efficacia complessiva della squadra. Quando la sostituzione dei concorrenti nelle varie posizioni nella squadra è fattibile, diventa possibile un confronto oggettivo dei singoli individui con le loro controparti. La valutazione oggettiva della prestazione individuale nel contesto è possibile tramite una decomposizione grafica dei punteggi della squadra. Allo stesso tempo, la configurazione vista nel grafico chiarisce la struttura del funzionamento della squadra. L'analisi è illustrata con dati di due squadre professioniste di pallacanestro, entrambe le quali hanno funzionato approssimativamente in modo additivo. I disegni con sostituzione automatica si possono usare in scenari controllati; essi permettono la valutazione statistica a complemento della analisi grafica.

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