DECISION MODELING AND APPLICATIONS TO MAJOR LEAGUE BASEBALL PITCHER SUBSTITUTION

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Abstract
Relief pitcher substitution is an integral part of a Major League Baseball game as once a pitcher is changed, he cannot reenter the game. The decision to change a pitcher involves many factors and influences, including, but not limited to, the batter's handedness, the state of the game, the pitcher's tiredness, and the pitchers available in the bullpen. This research examines the influences that affect a manager's decision to substitute a pitcher and presents an Analytic Hierarchy Process model to both incorporate these influences and analytically determine the best pitcher substitution, i.e., the best choice of pitcher to face a given batting line-up. The objective of this model as well as its extensions is to help managers make the best pitcher selections and staffing decisions to improve the probability of winning the game. Historical Major League Baseball box scores are used to both demonstrate the model and validate the manager's decisions. This paper represents a somewhat unusual, although interesting and practical example of the use of decision modeling in a non-traditional application, namely Major League Baseball.

Keywords
Decision Modeling, Analytic Hierarchy Process (AHP), Influence Diagram, Major League Baseball

Introduction

Baseball is a dynamic and exciting game, one of both physical and mental strength. A typical game could make use of four or five pitchers by each team in an effort to outmatch and outwit the opponent. If a new pitcher enters the game for another and does well, the fans are pleased. If his performance is poor, fans may conclude that the substitution should not have been made. Hindsight always appears 20/20.

Hirotsu and Wright (2003, 2004, 2005) have previously examined baseball and player substitutions and have published three papers that model the problem using Markov Chains. The first paper considers pinch hitting (PH) policies when the designated hitter (DH) rule applies in the baseball game (Hirotsu and Wright, 2003). They define three main reasons for PH: matching batter handedness with pitcher handedness, attempting to have the other team change pitchers, and allowing another batter to make a plate appearance. Because the DH rule applies, the pitcher does not bat, and their model does not need to consider the situation of PH for a pitcher. Hirotsu and Wright's (2004) second paper extends their first model to incorporate the potential for pitcher substitution—that is, the pitcher has to bat in the offensive lineup unless substituted for a PH. This model considers defensive and offensive aspects of the game and considers a pitcher's defensive ability. Their third paper incorporates handedness into their previous model but does not consider substitutions made by the opposing team (Hirotsu and Wright, 2005). They define a new statistic, called DERA, which is an expected value of the ER a pitcher should concede over nine innings that can be calculated as a conditional expectation based on the handedness of batters. Overall, Hirotsu and Wright's models have extremely long CPU run-times, and a model that can robustly aid in staffing decisions while remaining accessible and easy to use is needed.

This paper addresses that need by considering the influences that affect a manager's decision to substitute pitchers and presenting an Analytic Hierarchy Process (AHP) model that incorporates these influences to suggest the best pitcher to face a given batter. The AHP is used as a decision support tool because it easily captures and synthesizes the preferences and attitudes of the decision maker through the use of pairwise comparisons. These comparisons allow the decision maker, in this case the manager, to evaluate and examine his preferences to given matchups and thus choose the best pitcher to face a given batter. Use of the AHP will allow managers to approach critical in-game situations from a disciplined evaluation rather than utilizing basic comparisons of statistics and gut emotions as is currently done by some MLB teams (Atkins, 2008). A decision support tool rooted in theory should help the manager make the best pitching selections so the team can win the game and keep the fans happy. However, the manager must also consider the upcoming schedule—he does not want to waste all his resources in one game so that he has little chance of winning subsequent games.

Assumptions

In order for the model to be feasible and represent an actual in-game situation, the following assumptions are made.

- The decision maker is the manager of the team currently playing defense. Typically pitching changes are made when a team plays defense.
- The manager does not have knowledge of the opposing manager's game plan. The substitutions by the other team are only known at the moment they are made.
- The only knowledge the manager has about the opposing team before the game starts is the starting lineup card and active 25-man roster. The information he gains about the opposing team during the game is acquired through observation of the game.
- All players on both teams will act in accordance with their statistics; that is, expect "average" performance for the players. For example, a .250 batter should be expected to only reach base via a hit about 25% of his plate appearances during the game.
- There are no mid-game roster moves. Only the 25 players listed on the roster at the beginning of the game are eligible to play during the game. A player will be unavailable due to injury only if he is injured during the game.
- The model considers a typical regular season game in Major League Baseball.
- The pitching starting rotation is set before the game and will not change during the game.
- The designated hitter rule applies; the pitcher will not bat when the team is playing offense.
- All rules and regulations of Major League Baseball regular season apply.

Variables and Alternatives

The game of baseball contains successive occurrences of stochastic events. Variables must be defined for each element of the game that is outside of the manager's control. This includes variables for states of the game, the pitcher's situation, bullpen statistics, and the scheduled batter's situation. These conditions are extensive and detailed. For example, Hirotsu and Wright (2005) define 1,434,672 potential states of the game alone.

The decision to substitute a pitcher in a game has two alternatives, namely

1. Leave the current pitcher in the game;
2. Replace the current pitcher with another pitcher from the bullpen.

If the pitcher is replaced, the pitcher in the bullpen to be used must be determined. The choice whether or not to leave the current pitcher in the game essentially exists at any given point in the game when the team is playing defense. However, a starting pitcher typically stays in the game through the first few innings. He is not replaced unless he has unusually poor performance or is injured. Therefore, the likelihood of the necessity of a decision and the alternatives being considered increases as both the game progresses and the starting pitcher becomes tired.

The ultimate decision maker in the problem is the team's manager. He will make the final decisions as to which players are in the game at which time. He will consult with the pitching and bullpen coaches to obtain detailed information on his pitchers and will be influenced by their responses. To some extent, the players are decision makers in the game. Their performance and attitudes will influence the manager and his assessment of the probability of winning the game.

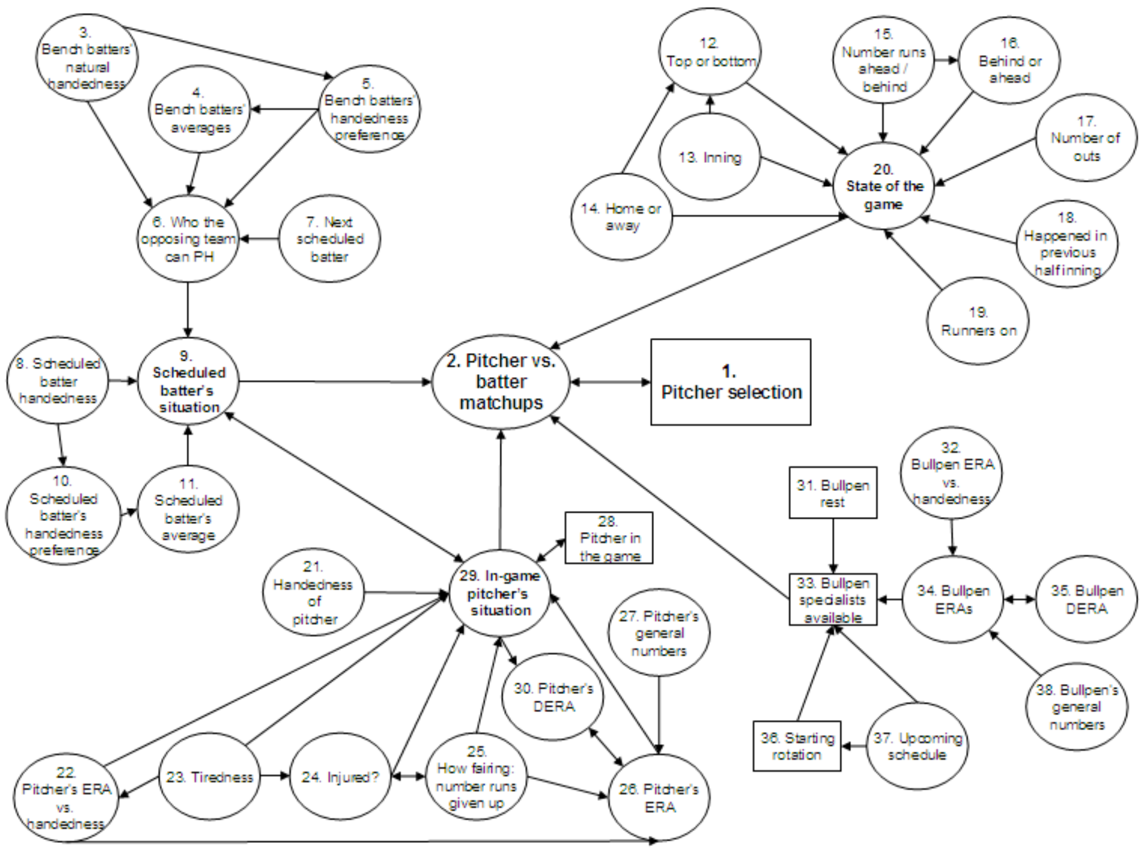
Using an Influence Diagram

An influence diagram provides clear structure to the problem by defining the relationships between aspects of the problem. In general, an influence diagram helps to define the problem's chance and decision elements through a collaborative effort between the decision maker and problem analyst. Relationships are defined by determining events that depend on outcomes of other events, decisions that depend on outcomes of events, and decisions that cannot be made until other decisions happen.

An influence diagram was selected to represent this problem because the diagram allows all forces in the game to be represented in one model. Since a game is stochastic in nature, many potential events can or cannot occur given the current state of the game. An influence diagram allows all events to be listed and related to each other, straightforwardly showing events that depend on other events, as well as the extremely small control the manger has over the game. Mapping the chain of relationships is essential for understanding how a game works and is helpful when formulating decision support tools to solve for the optimal substitution strategy. A visual map will also aid a manager in his understanding and perception of the problem. Seeing such a model will help him to realize all forces that affect and will be affected by his substitution policy as well as to determine aspects of the model that are incorrectly defined, omitted, or previously not considered.

The influence diagram for pitcher substitution can be found in Exhibit 1. Squares represent decision blocks, while circles are elements of chance. Item 1 is the goal, items 2, 9, 20, 29, 33 are main criteria, and all other items are subcriteria that roll up to the clusters' main criteria.

Exhibit 1. Influence Diagram



Using the Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) was developed by Thomas Saaty (1980). By definition, the AHP provides structure to very large complex problems. The method uses pairwise comparisons with scaling to rate both attributes and alternatives with respect to the attributes and scales the ratings to delineate strength of the comparison. AHP allows for intangibles to be numerically categorized and weighted according to their importance. Pairwise comparisons embody the principles of relative measurement and capture preference between two items. Essentially a pair of elements in a level of hierarchy is compared with respect to parent elements in the level above. These comparisons are made by using Saaty's Fundamental Scale of Absolute Numbers (Saaty, 1994). Some inconsistency is allowed in the comparisons and is expected; Saaty suggests an overall inconsistency ratio of 0.1 or less (Saaty, 1994). In the case of MLB, typically twelve pitchers are kept on the team's twenty-five man roster, with five of these pitchers being starters. Two to three relievers will be unavailable in a game due to rest, leaving approximately four to five pitchers available for the game as potential substitutions. Because pairwise comparisons are made in the aggregate in this model (Scala, 2008), using the AHP is reasonable. Eighteen comparisons will need to be made for three pitcher alternatives, twenty-six for four alternatives, and forty-six for five alternatives. Managers may not have to make each comparison for each situation; some comparisons such as criteria with respect to the goal can remain constant. Furthermore, the comparisons made for pitchers not used in the previous substitution can also carry over. Considering handedness matchups comprise a majority of pitcher substitutions; rarely five pitchers would need to be considered for one substitution.

The AHP assumes four axioms: reciprocal comparison, homogeneity, dependence, and expectations (Saaty, 1986). The pitcher substitution problem aligns with these axioms. Reciprocal comparisons hold because the manager is able to make comparisons and state the strength of his preference. Homogeneity holds because the model uses Saaty's Fundamental Scale of Absolute Numbers for pairwise comparisons to express preferences of importance. These preferences can be made between attributes and alternatives outlined in the influence diagram based on using the number of times cited in the literature by Hirotsu and Wright (2003, 2004, 2005) as well as knowledge from analysts and decision makers. Comparisons are done with respect to the goal of maximizing the opportunity of winning the game through the best selection of pitchers. Dependence holds because each level of attributes of the problem is dependent on the level above. Expectation holds because the structure of the AHP model defined below is sufficient for the proposed problem.

Based on the influence diagram analysis, there exists four main attributes in this model: state of the game, scheduled batter situation, in-game pitcher's situation, and bullpen specialists available.

The number of times each criterion and subcriterion, or a derivation of it, is cited in the literature by Hirotsu and Wright (2003, 2004, 2005) is used as frequencies in the model. Characteristics with the starred values do not appear in the literature but are felt by the author to be relevant to the determination. See Exhibit 2 for calculations of state and batter. Full calculations can be found in Scala (2008). The total value from which the criteria groups were normalized is 34.

Exhibit 2. Calculations of state and batter (Based on Hirotsu and Wright, 2003, 2004, 2005)

Node	Frequency	Value	Normalized
State of the game (State)			
12. Top or bottom	1	1	
13. Inning	1*	0.5	
14. Home or away	1	1	
15. Number runs ahead / behind	1	1	
16. Behind or ahead	1	1	
17. Number of outs	1	1	
18. Happened in previous half inning	1*	0.5	
19. Runners on	1	1	
Total		7	20.59
Scheduled batter situation (Batter)			
3. Bench batter's natural handedness	2	2	
4. Bench batter's averages	1	1	
5. Bench batter's handedness preferences	1	1	
6. Who opposing team can PH	1*	0.5	
7. Next scheduled batter	2	2	
8. Scheduled batter handedness	2	2	
11. Scheduled batter's average	1	1	
10. Scheduled batter's handedness preference	1	1	
Total		10.5	30.88

Weighting for the attributes is determined by taking the normalized sum value for each attribute defined by frequency of appearance in literature and rounding the ratios to correspond with the fundamental scale of absolute numbers. For example, to compare states vs. batter: take (normalized sum for states) / (normalized sum for batter) = 20.59 / 30.88 = .667. This implies that 20.59 should on average receive a rating of 1/3 in comparison, and 30.39 should receive a rating of 3 on average to be reciprocal. Therefore, batter is moderately more important than the state, according to interpretation of the fundamental scale. See Scala (2008) for further detail.

Rankings for the alternatives are based on batting averages for hitters and ERAs for pitchers. A Pugh Chart analysis was used for the alternative rankings. This is a straightforward tool that easily and accurately captures a pitcher's abilities. Each alternative was ranked for each of the relevant characteristics defined on the influence diagram. A +1 is assigned if the pitcher is above average, -1 if below average, and 0 if average or unable to be determined. The totals for each alternative are then used in the rankings. See Scala (2008) for detailed calculations. The absolute value of difference between alternatives with respect to an attribute determines the ranking for the AHP. A difference of 1 is "moderate", 2 is "strong", 3 is "very strong", 4 is "very strong", and 5 is "extremely", in correspondence with the fundamental scale.

Because the weighting scheme is generally determined, it can be used in any in-game situation. The available alternatives and the corresponding rankings for those alternatives would need to be modified to fit the situation.

Overall, the model proposes a decision support took that managers can use to evaluate their pitching substitution decisions. The amount of pairwise comparisons that need to be made are reasonable but still encompassing of the influences and forces that affect a manager's decision. In fact, a manager can make these comparisons before the game; he needs knowledge of the opposing team's roster and his available pitchers. This knowledge is readily available to him. Furthermore, he could set up a standard of comparisons to use across the situations; for example, he may consistently strongly prefer bullpen to batter. He may also set up a database of pitcher and batter matchups and corresponding comparisons to use each time his team faces a given opponent. The manager would then have to quickly review and modify the comparisons to incorporate new information. Once the model is set up, and the manager consistently uses it, maintenance would be relatively simple. Such continued support of the model can be facilitated through use of software packages such as SuperDecisions or Expert Choice.

As an illustrative example, the AHP analysis in Scala (2008) considers a game between the Cleveland Indians and the Boston Red Sox which occurred on April 25, 2006 at Jacobs Field in Cleveland, Ohio (Retrosheet, 2008). The Red Sox won the game with the score of 8-6. However, when Cleveland's starting pitcher, Jake Westbrook, left the game after the 5th inning, the Indians were leading 4-2. The first batter in the 6th inning was Mike Lowell, a right handed batter for the Red Sox. The illustrative AHP considers if Westbrook should have been left in the game, or if pitchers Jason Davis or Scott Sauerbeck should have replaced him. Three alternatives are considered because Hirotsu and Wright (2003, 2004) evaluate their models with three choices.

Analysis

Based on the AHP analysis, the optimal decision is to substitute Jason Davis into the game for Jake Westbrook. This was the decision made by Indians manager Eric Wedge; the model gave the same recommendation. Jason Davis held the lead, but he was later replaced for another player who gave up the lead. Having such a detailed analysis the model provides on-hand would have enabled the manager to make a decision beyond comparing numbers and personal feelings. He may not have wanted to remove Davis or have used other options had he had the model's analysis. The example uses rankings from the literature; in an in-game situation, a manager would use his rankings and comparisons. In reality, these preferences and list of available choices would also consider the upcoming schedule with the aim of winning the game tonight but not at the expense of future games.

Future Extensions

The AHP model presented in this paper can be extended in a variety of ways. For example, the assumption that players will act in accordance with their statistics can be extended to a random variable with a mean and standard deviation, rather than a deterministic input. Furthermore, the starting rotation or available pitchers could potentially be altered during the game if something major occurred, such as an injury. These situations could alter the rotation and pitcher availability, thus potentially changing the choices available in the model. Accounting for such situations would make the model more dynamic. A natural extension would be to incorporate a database of pairwise comparisons into the model, simplifying the analysis. Lastly, incorporating the team's expected value of wins for each potential substitution, the platoon advantage (having two players cover a defensive position, with the game's starter typically chosen to have the opposite handedness as the opposing team's starting pitcher), and the effect of win probabilities on future availability of pitchers are also future extensions of the model.

Conclusion

A manager cannot control if his team will win a game. Instead, he makes staffing decisions, and the ability of the players and the stochastic nature of the game results in victory or defeat. The manager's goal is to pick players that maximize the opportunity of winning the game, and, as a secondary goal, future games. The structures of the models presented in this paper are for regular season games in MLB. The same general structure can work for the post-season, but weights will have to be adjusted to reflect the urgency of best of five and seven game series.

Overall, baseball is a game of skill and chance. The opportunities for the momentum of the game to change at any time are what make the sport so exciting.

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Thank you for your interest in this research!

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