

Operations Research and Sports: A Brief Overview

ABSTRACT: Operations Research has had wide application to problems in sports - both on and off the field. Strategy, management, scheduling, player and team evaluation, and education have been particularly fruitful areas of application. This paper provides a thorough but nonexhaustive overview of these and other applications. Additionally, a brief discussion of recent and upcoming activities (symposia and conferences, media citations and interviews, books, etc.) is included.

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1. INTRODUCTION

Those involved in the sports industry have historically been reluctant to utilize systematic analytic methods to support their decision making processes (either on or off the field). Admittedly, decisions were generally made on the basis of wisdom accumulated from years of observation and interpretation, and this process surely had an analytic (if not systematic) component. However, the lack of systematic methodologies prevented ensuing generations from learning from previous generations of managers, coaches, and athletes.

The competitive urge was destined eventually to overcome this inertia. Once a single team effectively demonstrates the advantage (financial or competitive) of a particular strategy, its competitors inevitably begin to adopt similar strategies and devise their own variations of the original strategy. In the early days of the National Football League (NFL), the offensive strategies of American football teams focused almost exclusively on running plays. In the late 1940s and early 1950s, Coach Paul Brown's Cleveland Browns demonstrated the potential of the forward pass, and other teams' offenses quickly developed their own passing games. This advance also had off-field ramifications - fans enjoyed the resulting fast-paced game far more than the former focus on staid running plays (a strategy to which longtime Ohio State University coach Woody Hayes referred as, "three yards and a cloud of dust") and the popularity of the sport soared.

Coach Brown also instituted many other innovations that would soon be mimicked by his peers; his off-field innovations included use of game films and intelligence testing of potential players, while his other on-field innovations included adding a protective face mask to the players' helmets.

In baseball, starting pitchers were once expected to complete every game they started; as recently as 1969, Bob Gibson of the St. Louis Cardinals completed over 82% (28/34) of the games he started as a pitcher. During the 1960s and 1970s, managers of Major League Baseball (MLB) teams gradually began utilizing the strategy of replacing starting pitchers late in games (when the starting pitchers were fatigued) with fresh and well-rested pitchers (now called relief pitchers). Adoption of this strategy has been so universal that the Toronto Blue Jays' Roy Halliday led Major League Baseball by completing a mere 22.5% (7/31) of the games he started as a pitcher in 2007. The National Basketball Association (NBA), after watching its upstart competitor American Basketball Association's successful use of the three-point shot rule during the early 1970s, implemented a similar rule in 1979. Similarly, the National Hockey League's (NHL) pursuit of European talent did not earnestly commence until the newly formed World Hockey Association began signing European players in an effort to broaden its talent pool.

Obviously, once a single team demonstrates the competitive advantage(s) to be gained through proper application of a new strategy, its competitors inevitably begin to adopt similar strategies. So it has been with use of systematic analytic methodologies; as a few teams utilized these methodologies over the past few decades to create competitive advantages, other teams have been forced to use similar methodologies to maintain or regain their competitive stature. The role of Operations Research in support of decision making and analysis in sports has grown rapidly during this period. As sports continue to look to more scientific and quantitative methods and introduce a higher level of sophistication into their decision making processes (and in many instances enthusiastically embrace this approach), the contributions to be made by O.R. promise to continue to increase at a brisk pace.

2. EARLY APPLICATIONS – THE FOCUS IS ON STRATEGY

O.R. has been applied to a wide variety of sports, and it is not surprising that the earliest published applications were to baseball (a sport that generates an incredible amount of event-level data that cannot be matched by any other sport). Probably more surprising is that the earliest efforts were undertaken by a Lieutenant Colonel employed with the Canadian Department of Defense! George Lindsey recorded data from approximately four-hundred Major League Baseball games that he watched or listened to throughout the 1950s. His goal - use these data to develop recommendations on strategies for managers of baseball teams. He eventually summarized his results in the *Operations Research* paper, "Statistical Data Useful for the Operation of a Baseball Team" (Lindsey, 1959). Although this work was well received in academic communities, it was largely ignored by MLB. His follow-up article, "The Progress of a Score during a Baseball Game," (Lindsey, 1961) was published by *Journal of the American Statistical Association* but suffered a similar fate with MLB.

Carter and Machol (1971, 1977, 1978) took a similar approach in their application of O.R. to football. The authors used data they had collected on various field positions, downs, and ultimate outcomes (no score, touchdown, field goal, safety) to estimate the relative values of various decisions that confront coaches during the course of an American football game. During this same period Ladany collaborated as coeditor with Machol and Ladany on *Management Science in Sports* (1976) and with Machol on *Optimal Strategies in Sports* (1977).

A great deal of effort was devoted to concurrent and ensuing applications of O.R. to evaluate potential strategies in other sports. Examples include the pentathlon (Ladany, 1975), general team management (Hall, 1983), running (Camm and Grogan, 1988), pole-vaulting (Hersh and Ladany, 1989), golf (Hurley, 2002), cycling (Scarf, 2005), curling (Willoughby and Kostuk, 2005), cricket (Barr and Kantor, 2004; Scarf and Shi, 2005), climbing (Scarf, 2007), football (Hirotsu and Wright, 2002, 2003; Wright and Hirotsu, 2003; Scarf and Shi, 2008), and more American football (Brimburg et al., 1998; Hurley, 1998; Rosen and Wilson, 2007) and baseball (Freeze, 1974; Bukiet and Harold, 1997; Sokol, 2003; Cochran, 2006).

3. SCHEDULING SPORTS LEAGUES

Published accounts of the use of O.R. to schedule sports leagues began appearing regularly in journals during the 1980s. Bean and Birge (1980) developed an approach for scheduling to reduce costs and travel time for the NBA. Weiss (1986) investigated inherent inequities in sports league schedules and playoff systems. The development of decision support system to assist in scheduling sports leagues was the subject of Evans (1986), who worked on scheduling umpire crews for the American Baseball League (AL); Andreu and Corominas (1989), who were concerned with scheduling Olympic Games; and Farmer et al. (2007), who developed a system for scheduling umpire crews for professional tennis tournaments. Armstrong and Willis (1993) scheduled the Cricket World Cup, and Costa (1995) applied a tabu search algorithm to the NHL scheduling problem. Nemhauser and Trick (1998), Henz (2001), and Voorhis (2002) each worked on scheduling problems faced by a major U.S. college basketball conference, while Russell and Leung (1994) focused on scheduling a baseball league. Scheduling an English football league over holidays was the focus of Kendall (2007).

In a different but related stream of research, several operations researchers have examined scheduling to ensure equity in schedules across teams. Horen and Riezman considered various drawing methods for single elimination tournaments, while Clarke and Allsopp (2001)

work toward scheduling World Cup of Cricket tournaments fairly. The efficiency of divisional play to create more competition was looked at by Winston (1982); Cochran (2000) examined a similar problem in a power analysis of the 162 game MLB schedule. Fleurent and Ferland (1993) compared various way of allocating games in the NHL, while Rump (2006) considered a similar issue for home-away sequencing in best-of-seven game playoff series. Smith et al. (2006) and Smith (2008) consider bracket assignments in collegiate basketball and baseball tournaments, respectively. The work on sports scheduling is culminating in the publication of an entire book devoted to the topic, *Sports Leagues Scheduling: Models, Combinatorial Properties, and Optimization Algorithms* (Briskorn, 2008).

4. USING SPORTS IN THE O.R. CLASSROOM

During the mid 1990s published work providing evidence of the efficacy of using sports examples in O.R. classrooms began to appear regularly. The *Journal of Statistics Education* (<http://www.amstat.org/publications/jse/>) published a series of papers outlining strategies for teaching various concepts using sports examples. These papers are particularly notable because they include the associated data for classroom use by other instructors in a linked downloadable file. Starr (1997), Lock (1997), Watnick (1998), Nettleton (1998), Simonoff (1998), Cochran (2000, 2002), Watnick and Levine (2001), Winner (2006), Huber and Glen (2007), and Adolph (2007) have each contributed to this effort.

Tiger and Salzer (2004) authored the first sports-oriented paper published by *INFORMS Transactions on Education* (<http://ite.pubs.informs.org/>); they discussed a classroom simulation of daily play at a golf course. At this time Cochran (2004a) accepted the role of Guest Editor for the first annual special issue of *INFORMS Transactions on Education*. The chosen topic - the use of O.R. in the classroom. Several renowned O.R. scholars/ educators contributed across a wide variety of sports and O.R. methodologies in this special issue, which was published in September of 2004. Birge (2004) and Trick (2004) discussed ways they use sports scheduling to mathematical programming concepts in their classes (Birge focused on a problem in World Football while Trick focused on baseball and basketball examples). Effective demonstration of simulation techniques were discussed from a basketball perspective by Ammar and Wright (2004) and from an ice hockey perspective by Ingolfsson (2004). Bickel (2004) and Brimberg and Hurley (2004) demonstrated applications of decision making to baseball. Sokol (2004) discussed his use of baseball examples to give his students a more intuitive understanding of Markov Chains, while Kvam and Sokol (2004) and Willoughby (2004) provided insights into the general challenges of incorporating sports examples into undergraduate courses. Chlond (2004) offered an interesting classroom example from hockey, and Cochran (2004) shared a case and the associated teaching notes that he uses to demonstrate Simpson's paradox through integer programming applied to issues arising from the MLB players' strike of 1981.

Other papers on the use of sports in the O.R. classroom have appeared more recently. Cochran (2005) has demonstrated effective use of the popular *Strat-O-Matic* baseball board game to teach basic probability. **MORE**

Several courses on O.R. and sports are currently offered or in the development stages. Rev. Gabriel Costa developed a one-credit course at Seton Hall University on sabermetrics (the principles of baseball research espoused by the Society for American Baseball Research or SABR) that he has team-taught with John Saccoman (Costa, 1991). Benjamin Alamar teaches a class on sports statistics at Menlo College in California and a class on sports statistics for managers for the University of San Francisco Masters in Sport Management program. James

Albert teaches a section of introductory statistics using baseball examples at Bowling Green State University in Ohio (2002). James Cochran (Cochran, 2008b) has developed an analytic methods and sports course for Louisiana Tech University's sports marketing minor. Jeffrey Ohlmann has developed and uses a case study on forecasting and ordering game-day football programs at the University of Iowa.

The potential of sports examples to improve the quality of quantitative education is now widely recognized. The United States National Commission on Mathematical Instruction recently asked Cochran (2008) to address this (among other issues) in a presentation given at the committee's biannual meeting in April 2008.

5. OTHER INTERESTING APPLICATIONS OF O.R. TO SPORTS

Many operations researchers have concentrated on gambling in their research. Racetrack betting has been the focus of Hausch (1981, 1985), Bolton (1986), Bird (1987), Hausch and Ziemba (1990), Lo (1995), and Thalheimer and Ali (1995). Kaplan and Garstka (2001) considered the lower stakes mass appeal March Madness (U.S. Collegiate basketball) office pools, while Vergin and Scriabin (1978) reflected on a hybrid of office pools and higher stakes wagering on NFL Games. Fitt et al. (2006) looked at soccer spread bets.

Player and team evaluation have also been important areas of application. Several of these articles (Pollock, 1974; Levy, 1976; Cover and Keilers, 1977; Pankin, 1978; Golden, 1987; Henig and O'Neill, 1992; Zappe et al., 1993; Cochran and Levy, 1999; Fry et al., 2007; Terpstra and Schauer, 2007; Alamar and Weinstien-Gould, 2008;) have been concerned with evaluation of individual player performances. Others have dealt with evaluation of entire teams (Leake, 1976; Price and Rao, 1976; Rosner, 1976; Gerchak et al., 1995; Cochran, 1999, 2000, 2002, 2005; Coleman and Lynch, 2001; Martinich, 2002; Horowitz, 2004; Cassidy et al., 2005; Coleman, 2005; Baker and Kvam and Sokol, 2006; Scarf, 2006; McHale and Scarf, 2007; Thomas, 2007; Rump, 2008).

Several O.R./sports research papers have been published on other topics. Albright and Winston (1978) looked at the difference in final outcomes in winners'-outs and losers' outs rules in basketball. Larkey et al (1997) examined the role of skill in various games and sports; in a somewhat related effort, Henig and O'Neill (1992) considered games and sports in which the player performing the most difficult task is given an advantage. Adler et al. (2002) used integer programming to find the true magic number (wins needed to clinch a divisional championship) after considering the remaining schedule; these authors have also created a website (RIOT - <http://riot.ieor.berkeley.edu/~baseball/>) that calculates the true magic number for data input by the user. The fate of a football manager is considered from different perspectives by Hope (2003) and Bachan et al. (2007). Fairness and incentive in limited overs cricket matches was the topic of Carter and Guthrie (2004). Beis et al. (2006) discuss their experiences using O.R. to manage the 2004 Olympic Games in Athens. Thomas (2007) modeled the time between goals in ice hockey. Development of decision rules for bar quiz handicapping are considered by Percy and Scarf (2007). Percy also performed a mathematical analysis of badminton scoring systems (2007). Finally, Gerard Sierksma has created a group called *Team Support Systems* (<http://www.teamsupportsystems.com/>) that provides analytic assistance and consulting to sports teams.

6. RECENT AND FUTURE ACTIVITIES

Operations researchers now have a plethora of sports oriented activities available to them. Clusters of sessions at major conferences, entire symposia and conferences, journals, and tutorials on the application of O.R. to sports problems abound. With respect to journals, in addition to the aforementioned 2004 *INFORMS Transactions on Education* special issue on using sports in the OR classroom (<http://ite.pubs.informs.org/Vol5No1/Vol5No1toc.php>) and this special issue of *STATOR*, the *Journal of Quantitative Analysis in Sports* (JQAS) was established by Ben Alamar in 2005. Additionally, an English version of the Chinese journal *International Journal of Sports Science and Engineering* was established in 2007.

The formation of the SpORts section of INFORMS in 2004 by James Cochran, Michael Fry, Jeffrey Ohlmann, and Joel Sokol has led to a regular cluster of sponsored sessions at INFORMS conferences at the international, national, and regional levels. Other recent or upcoming O.R. conferences featuring sports-oriented sessions include 2006 EURO conference in Reykjavik, Iceland and the 2008 IFORS conference in Sandton, South Africa. In addition, entire symposia and conferences devoted to mathematical analysis of sports problems include the 2008 *Pre-Olympic Joint International Conference on Sports Science and Sports Engineering* in Nanjing, China (<http://www.olympiccongress.org/>); the 2007 *Symposium on Statistics and Operations Research in Baseball* (<http://mitch.watnik.com/symposium.html>) organized by Mitch Watnick; the 2008 *Symposium on Statistics and Operations Research in Baseball* (http://w4.stern.nyu.edu/ioms/events.cfm?doc_id=7983) organized by Jeffrey Simonoff; the 2007 *New England Symposium on Statistics in Sports* (<http://www.amstat.org/chapters/boston/nessis07.html>) organized by Mark Glickman and Scott Evans; the 2008 *Northern California Symposium on Statistics and Operations Research in Sports* (<http://nessors.wikidot.com/start>) organized by Benjamin Alamar; the *First International Conference on Mathematical Modelling in Sport: IMA Sport 2007* (<http://www.ima.org.uk/Conferences/Maths%20Modelling%20in%20Sport.htm>) organized by Phil Scarf; and a minisymposium on *Mathematics in Sport* (<http://www.ecmi2008.org/>) also organized by Phil Scarf for the European Consortium for Mathematics in Industry 2008 Conference.

Tutorials on O.R. and sports have been given by James Cochran for the 2005 INFORMS Conference on OR/MS Practice: Applying Science to the Art of Business and for the faculty at the Universidad de Talca, Chile. Cole Smith has given tutorials on this topic for 2007 Industrial Engineering Research Conference and the 2007 INFORMS International Conference in Puerto Rico.

Interest in applications of analytic methods to sports problems has increased with the newfound acceptance of these methods by the sports industry. Benjamin Alamar has been interviewed by *HyperCube: Science in All Dimensions*, the *Pittsburgh Tribune-Review*, the *Montreal Gazette*, and the *Wall Street Journal*. Jeffrey Ohlmann has been interviewed on his work on draft models by *Sports Weekly* and *Business Week*. An *Associated Press* story on Paul Kvam and Joel Sokol's LRMC model for the Division I U.S. collegiate basketball tournament was mentioned by *SI.com* and National Public Radio's *All Things Considered*; additionally, the tournament selection committee has been reviewing their work for the past two years. The *San Diego Union-Tribune* recently interviewed Christopher Rump about his work estimating the probability that Tiger Woods would complete the Pro Golfers' Association (PGA) grand slam. A representative of the *Edmonton Journal* interviewed Armann Ingolfsson about his classroom use of his NHL simulation. Finally, the work of Wayne Winston and Jeff Sagarin consulting with

the Dallas Mavericks of the NBA on relative value of potential choices in the annual draft of collegiate and high school players has been featured in the *New York Times*.

Several books on the subject have also either been recently released or are in production. In 2005 SIAM published *Anthology of Statistics in Sports*, a collection edited by Jim Albert, Jay Bennett, and James Cochran that was comprised of introductory material and articles on sports published by statistics journals through 2000. The editors are currently developing a second volume consisting of articles published since 2000. A similar effort, *Anthology of Operations Research in Sports*, is being developed by Cochran, Michael Fry, Jeffrey Ohlmann, and Joel Sokol. Wayne Winston is also writing a book for Princeton University Press on math and sports; this book is due to be released in April 2009.

This is an exciting time to be interested in applying O.R. to sports problems. I am honored to have contributed to this special issue of *STATOR*, I am very pleased by the interest of the Dutch Society of Operations Research and Statistics in sports problems, and I hope the articles in this issue motivate you to apply (or continue to apply) O.R. to problems in sports!

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