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A COMPREHENSIVE REVIEW OF DATA ENVELOPMENT ANALYSIS (DEA) IN SPORTS

Una revision comprensiva del análisis envolvente de datos (DEA) en el deporte

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ABSTRACT: Data envelopment analysis (DEA) is a deterministic mathematical programming technique, evaluates the performance and benchmarking of decision making units (DMUs) with several inputs and outputs. DEA, in addition to public and private sectors, finds application in the sports setting. As a result, a significant number of papers have been published that determine the athletic/economic/managerial efficiency by DEA in various sports. In this paper we present an extensive study on the application of various models of DEA in the following sports: Baseball, Basketball, Cricket, Cycling, Football, Golf, Handball, Olympics, and Tennis. It is found that DEA identified the sources of inefficiency in different team and individual games by means of benchmarking analysis and provided possible directions for improvement.

KEY WORDS: Data envelopment analysis, sports, efficiency, decision making units

RESUMEN: El análisis envolvente de datos (DEA) es una técnica de programación matemática determinista que evalúa el rendimiento y la evaluación comparativa de las unidades de toma de decisiones (DMU) con varias entradas y salidas. El DEA, además de en los sectores público y privado, encuentra aplicación en el ámbito deportivo. Como resultado, se ha publicado un número significativo de artículos que determinan la eficiencia atlética, económica y gerencial usando DEA en varios deportes. En este artículo presentamos un extenso estudio sobre la aplicación de varios modelos de DEA en los siguientes deportes: Béisbol, baloncesto, cricket, ciclismo, fútbol, golf, balonmano, Las olimpiadas y el tenis. Se ha encontrado que el DEA identifica las fuentes de ineficiencia en diferentes deportes individuales y de equipo por medio de análisis comparativos y proporciona posibles líneas de mejora.

PALABRAS CLAVE: Análisis envolvente de datos, deportes, eficiencia, unidades de toma de decisiones

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1. Introduction

Atlanta Hawks are efficient or Houston Rockets. If you have Lionel Messi or Cristiano Ronaldo, who would you choose? Or how about Kareem Abdul Jabbar and Michael Jordan? The question "who is efficient or who is better" is the one that everyone associated with sport seeks to find. The sport has always been subjected to intense scrutiny in terms of assessment and evaluation of performance. Teams and players are rated and ranked continuously by different methods. For example, in basketball, baseball, cricket etc. an ever expanding array of statistics support in evaluating the efficiency and performance of players. At the same time sport has copied the principles of the business world and resembles with it in various aspects like, players, coaches, managers, and administrators are constantly paid, games and sports have become branded products, fans have become customers and affinity with the corporate sector is established which become a function of sports economy.

Among the various methods, the parametric and nonparametric ones are frequently employed for the efficiency analysis. Regression analysis, Stochastic Frontier Analysis (SFA), Thick Frontier Approach (TFA), Distribution-Free Approach (DFA), Cubb-Douglas method etc. are classified under parametric approach. Typical nonparametric methods include Free Disposal Hull (FDH) and Data Envelopment Analysis (DEA) which is the popular tool for efficiency analysis. As per the literature available, researchers have evaluated two types of efficiencies in sports namely sports/athletic efficiency and economic efficiency using DEA.

The technique of frontier analysis was first suggested by Farrell (1957) and the mathematical framework was developed by Charnes, Cooper and Rhodes (1978). DEA is a nonparametric linear programming method which forms a linear function that envelops the best practicing DMUs so that all units lie on or below the frontier Doble (1995). Efficiency in DEA is the ratio of the weighted sum of outputs to the weighted sum of inputs of a DMU. In sports, a DMU can be an athlete, a player, manager of a team, coach, sports federation/sports club, or a game. The utility of DEA lies in that it provides information about an inefficient DMU by determining the value of inputs and outputs.

DEA has four orientations: input and output oriented, constant returns to scale (CRS) put forth by Charnes, Cooper and Rhodes (1978) and variable returns to scale (VRS) propounded by (Banker, Charnes and Cooper, 1984). The input oriented model called input minimization investigates the level to which inputs can be reduced for a constant output. On the other hand, the output oriented model or output maximization examines the extent to which outputs can be increased for constant inputs (Coelli *et al.*, 2005). CRS indicates a symmetrical increase in outputs when inputs are increased. Contrarily,

VRS implicits an unproportionate increase or fall in outputs when inputs are increased i.e. the efficiency can either drop or rise on the growth of the unit size (Avkiran, 1999).

On the basis of CRS, Charnes, Cooper and Rhodes(1978) put forth the CCR model. The model is suitable when all DMUs are operating at an optimal scale and measures technical efficiency which includes both pure technical and scale efficiencies. Pure technical efficiency illustrates the efficiency in transforming inputs to outputs whereas scale efficiency expresses whether a DMU is functioning at its optimal size so that any modification in its size will make the unit less efficient. The value of scale efficiency is obtained by dividing the gross efficiency by the technical efficiency. However, certain constraints may cause DMUs to be operating away from the optimal scale. Banker, Charnes and Cooper (1984) suggested an extension of the CRS model to account for VRS (named as BCC model). This model evaluates only technical efficiency, net of scale effect.

2. Method and Inclusion criteria

This study aims to systematically analyze the application of DEA in evaluating the performance and efficiency in nine popular sports. A total of 102 published articles were selected out of which 61 articles, published in 36 referred journals/books, were of the primary interest for the present study. Table 1 shows the list of journals/books in which the articles on the application of DEA in sports were published. Only those articles were included which were based on the application of DEA and its extensions such as cross efficiency, two-stage DEA, super efficiency, assurance regions, DEA slack based measure etc. Most of the research articles were searched from the DEA bibliography (Emrouznejad and Yang, 2018), using the keywords “sports and games”, “baseball”, “basketball”, “cricket”, “cycling”, “football”, “golf”, “handball”, “Olympics”, “NBA”, “soccer”, and “tennis”. Apart from the above bibliography, several papers were also downloaded from Google scholar.

Table 1. The 35 Journals/Books that have published papers on DEA in sports

Journal	Number of papers
Academy of Management Journal	01
American Journal of Operations Research	02
Annals of Operations Research	04
Applied Economic Letters	02
Applied Economics	02
Athens Journal of Sports	01
Central European Journal Operations Research	04
Computational Intelligence & Software Engineering	01
Computers and Operations Research	01
European Journal of Operational Research	06

European Journal of Sport Science	01
Expert Systems With Applications	01
Handbook on DEA	01
International Journal of Environmental & Science Education	01
International Journal of Management Science	02
International Journal of Sport and Health Science	01
International Journal of Sport Management and Marketing	01
International Transactions in Operational Research	01
Investigacao Operacional	01
Journal for Theory and Practice Management	01
Journal of Human Kinetics	01
Journal of Productivity Analysis	03
Journal of Quantative Analysis in Sports	01
Journal of Sport Management	01
Journal of Sports Economics	07
Life Science Journal	01
Management Decision	01
Managerial and Decision Economics	02
Munich Personal RePEc Archive	01
Pesquisa Operacional	01
Procedia-Social & Behavioral Sciences	01
Sport Business and Management	01
Technical Gazette	01
The Journal of the Operational Research Society	01
The Open Sports Science Journal	01
World Applied Sciences Journal	01

3. Basic DEA models

There are basic two types of DEA models: CCR and BCC with two orientation input and output as explained as below.

3.1. CCR Model

The mathematical formulation of DEA with the assumption of CRS was given by Charnes, Cooper and Rhodes (1978). Let "x_i" and "y_r" denote the $i^{th}\ (i = 1,2,3,....m)$input and $r^{th}(r = 1,2,3,.....s)$ output of $j^{th}(j = 1,2,3,....n)$ DMU respectively. The efficiency of k^{th} DMU (under evaluation) is defined as:

$$\max h_k(u,v) = \frac{\sum_{r=1}^{s} u_r y_{rk}}{\sum_{i=1}^{m} v_i x_{ik}}$$

Sub to (1.1)

$$\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1 \; ; j = 1,2,3,\ldots,n$$

$$u_r \geq 0 \; and \; v_i \geq 0 \; ; \forall \; r = 1,2,3,\ldots,s \; and \; i = 1,2,3,\ldots m$$

Where u_r and v_i is the weight of i^{th} output and i^{th} input in the j^{th} DMU respectively.

The mathematical formulation of the model (1.1) is in the fractional form and has infinite solutions. The fractional form of the mathematical model (1.1) can be transformed into a linear model following Charnes and Cooper (1962).

$$\max h_k(u,v) = \sum_{r=1}^{s} u_r y_{rk}$$

Sub to

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0; \forall \; j = 1,2,3,\ldots,n. \qquad (1.2)$$

$$\sum_{i=1}^{m} v_i x_{ik} = 1.$$

$$u_r \geq 0 \; and \; v_i \geq 0 \; ; \forall \; r = 1,2,3,\ldots,s \; and \; i = 1,2,3,\ldots m$$

The mathematical model given in the equation (1.2) above has a linear form but can't be solved under DMU technique, based on the principle of duality in linear programming. The standard form of envelopment model is as follow:

$$\theta^* = Minimise \theta_k$$

Sub to

$$\sum_{j=1}^{n} y_{rj}\lambda_j - s_r^+ = y_{rk}; \; r = 1,2,3,\ldots,s \qquad (1.3)$$

$$\sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- = \theta_k x_{ik}; \; i = 1,2,3,\ldots,m$$

$$s_r^+ \geq 0, \; s_i^- \geq 0, \; and \; \lambda_j \geq 0; j = 1,2,3,\ldots,n.$$

Where s_r^+ and s_i^- are input and output slacks. Thus DMU_k is efficient *iff* $\theta^* = 1$ and all slacks must be zero i.e. $s_r^+ = 0$, $s_i^- = 0$. If $\theta^* = 1$ and all slacks are nonzero, then DMU

under evaluation is weak efficient, and if $\theta^* < 1$, then the DMU_k under evaluation is inefficient.

3.2. BCC Model

The DEA envelopment model for considering VRS is the following:

$$\theta^* = Minimise\,\theta_k$$
$$s/t$$
$$\sum_{i=1}^{n} y_{rj}\lambda_j - s_r^+ = y_{rk}\ ;\ r = 1,2,3,\ldots,s$$
$$-\sum_{j=1}^{n} x_{ij}\lambda_j + s_i^+ = -\theta_k x_{ik}\ ;\ i = 1,2,3,\ldots,m. \quad (1.4)$$
$$\sum_{j=1}^{n} \lambda_j = 1\ ;\ j = 1,,2\ ,3,\ldots,n$$
$$\lambda_j \geq 0\ and\ \ s_r^+ \geq 0\ ,\ s_i^- \geq 0.$$

Where s_r^+ and s_i^- are input and output slacks. θ_k is the efficiency score of k^{th} DMU and lie between 0 and 1.

In the present study we try to evaluate the role of DEA in 9 games (Baseball, Basketball, Cricket, Cycling, Football, Golf, Handball, Olympics, and Tennis) based on the previously published articles in this area.

4. Results

4.1. Baseball

Baseball has been scrutinized from a long time by operations research and management science. The earlier work regarding DEA study on baseball was carried by Howard and Miller (1993) who applied DEA to the sphere of pay equity in baseball of 26 major league teams of United States. They analyzed the efficiency of 433 non-pitching players who transformed 29 inputs into a single output, that is, salary. It is noted from their results that 209 players were poorly paid, 166 players equitably paid and 58 players were highly lucrative. Anderson and Sharp (1997) employed DEA based measure called composite batter index (CBI) and conducted year wise analysis on American League and National League for the years 1901 to 1993. The results revealed that the industry of baseball batting is maturing and there is a need for an ordinal relation between the outputs.

DEA benchmarking method was used by Sueyoshi, Ohnishi and Kinase (1999) to estimate the offensive efficiency of 30 Japanese baseball players in Central League, in 1995. To overcome the inadequacy of DEA, the authors applied another benchmarking

approach - Offensive Earned Run Average (OERA) and Slack Adjusted DEA (SA-DEA), so that efficient baseball players could be ranked as per their efficiency scores. The DEA results showed that 53.3% of players were efficient and 46.7% inefficient. According to OERA results long hitters outperformed other hitters in the league and SA-DEA declared 11 players efficient as compared to 16 determined by DEA.

The efficiency of 30 teams in Major League Baseball (MLB) was determined by Sexton and Lewis (2003) during the 1999 season by two-stage DEA. The first stage output was considered as input for the second stage. They pointed out that for the teams in MLB to win the games and reach the efficiency frontier; each team has to spend a minimum of $23 million as total player wages. Furthermore, 26 of the 30 teams would have won more than 90% games if they had been organizationally efficient. Anderson (2004) also used DEA model to compare Babe Ruth and Barry Bonds performance in order to find out who was the most dominant baseball batter. Anderson clearly pointed out that in the years 1920 and 1921 Ruth was more dominant than Bonds with Ruth's performance in 1920 as exceptional.

Management efficiency of 8 Korean baseball teams was studied by Kang, Lee and Sihyeong (2007) for the 2004 season. They concluded that there was a financial deficit and lack of fan attendance among baseball teams in Korea. In order to compete neck to neck with the Western teams, sports teams in Asian countries have to make team management more effective along with cost control. To determine the minimum wages that has to be paid to the players in Major League baseball in order to be competitive in each year from 1985 to 2002 Lewis, Sexton and Lock (2007) used two-stage DEA. Their study showed that many teams were inefficient due of low player salary. The results also show that teams with large markets spend more on player salaries as compared to teams with small markets.

Capability, efficiency, and effectiveness of Major League baseball teams from 1901 to 2002 were estimated by Lewis, Lock and Sexton (2009) using DEA methodology. The outcome of their study was that defensive capability (pitching) and efficiency play an important role for teams to be effective in MLB. Performance of pitchers in Major League baseball from 1871 to 2006 was determined by Chen and Johnson (2010) and their findings pointed out that how the pertinent criteria for evaluating the performance of pitchers changes over the period of time. Furthermore, their results also revealed that the number of games played and innings pitched had an important role in evaluating pitching performance. Whereas, runs made, hits and shutouts had no remarkable role in determining the performance.

Miceli and Volz (2012) applied DEA to voting for the baseball players Hall of Fame (HOF) who played in the major league from 1876 to 2009. Their results displayed that about one-third of present members of HOF must be removed by more deserving players. Moreover, for the inclusion of players in HOF, the minimum percentage of

votes for position players and pitchers received should be 84% and 81% respectively. Table 2 shows input and output variables along with the name of authors and proposed methodology of DEA in baseball.

Table 2. Baseball DEA Studies

Author	Methodology	Inputs	Outputs
Howard, L.W., Miller, J.L. (1993)	CCR model	Stolen bases, games played, official at-bats, runs scored, hits, doubles, triples, home runs, runs batted in, batting average, putouts, assists, errors fielding average	The total salary of players
Anderson, T.R., Sharp, G.P. (1997)	DEA + composite batter index (CBI)	Plate appearances	Number of walks, singles, doubles, triples and home runs
Sueyoshi, A., Ohnishi, K., Kinase, Y. (1999)	DEA + offensive earned run average (OERA) + slack adjusted DEA	At bats and double plays	Number of singles, doubles, triples, home runs, runs batted in, steals, sacrifices and walks
Sexton, T.R., Lewis, H.F. (2003)	Two-stage DEA model	First stage: total player salary Second-stage: total bases gained and total bases surrendered	First stage: total bases gained and total bases surrendered Second-stage: number of games won
Anderson, T.R. (2004)	DEA-super efficiency	Plate appearances	Number of walks, singles, doubles, triples and home runs
Kang, J.H., Lee, Y.H., Sihyeong, K. (2007)	CCR model	Total player salary	Fan attendance and winning percentage of teams
Lewis, H.F., Sexton, T.R., Lock, K.A. (2007)	Two-stage DEA + logistic regression + gini index	First stage: total player salary Second-stage: total bases gained and total bases surrendered	First stage: total bases gained and total bases surrendered Second-stage: number of games won
Lewis, H.F., Lock, K.A., Sexton, T.R. (2009)	Network DEA model	Runs gained and runs surrendered	Games won
Chih Chen, W., Johnson, A.L. (2010)	BCC model	Games, earned runs, innings and outs pitched and hits	Wins, shutouts, strikeouts, saves and complete games
Miceli, T.J., Volz, B.D. (2012)	CCR model	For position players: hits, homeruns, batting average, on base percentage, slugging average, runs scored, runs batted and stolen bases	Number of votes

4.2. Basketball

Among the articles that measured the efficiency in basketball by DEA method, we highlight Cooper, Ruiz and Sirvent (2009) in which the effectiveness of 172 basketball players who participated in the Spanish Basketball League (called ACB league) during 2003/04 season were analyzed. The authors revealed that DEA can be used alternatively to the ACB index of player evaluation. Further, they focused on multiplier values for efficient players and how these values can be used to find the strength and weakness of each individual player.

The productive efficiency of 62 starting guards was examined by Lee and Worthington (2013) for 2011/12 season, a period coinciding with the outstanding performance of Jeremy Lin commonly referred as Linsanity. The results of their study indicated that between 29% - 42% of National Basketball Association guards were fully efficient including Jeremy Lin. However, Jeremy Lin rarely served as a benchmark for inefficient DMUs which indicate his unique style of play including altruistic play and team leadership. Radovanovic et al. (2013) measured the efficiency of 26 NBA players during 2011/12 season by DEA and Distance-Based Analysis (DBA). The results revealed that all the NBA players were situated in the efficiency range from 70% - 116% and 7 players had an efficiency score of more than 100% displaying true efficiency. DEA and DBA results were having a positive correlation (0.853), indicating that the two methods are in harmony with each other.

Table 3. Basketball DEA studies

Author	Methodology	Inputs	Outputs
Cooper, W.W., Ruiz, J.L., Sirvent, I. (2009)	CCR model	Minutes per game	Number of shorts
Lee, B.L. Worthington, A.C. (2013)	CCR model	Minutes per game	Points per game, rebounds per game, assists per game, steals per game, blocks per game and turnovers per game
Radovanovic, S., Radojicic, M., Jeremic, V., Savic, G. (2013)	DEA super efficiency model + distance based analysis (DBA)	Gross salary and minutes spend on the court	Number of points, assists, rebounds, steals, turnovers, and number of blocked shots
Hai Yang, C., Yu Lin, H., Ping Chen, C. (2014)	Two-stage DEA model	First stage: total player salary Second-stage: team's player performance	First stage: team's player performance Second-stage: games won and gate receipts

Measuring the efficiency of 30 National Basketball Association teams from 2003/04 to 2008/09 seasons Yang, Lin and Chen (2014)utilized a two-stage DEA model bifurcating overall efficiency into wage efficiency and on court efficiency. Wage efficiency of the

teams was determined in the first stage followed by on court efficiency, evaluated in the second stage. It was noted that the team efficiency ranged between 85.70% - 91.44%. Further, teams were high on wage efficiency as compared to the on court efficiency with average wage efficiency ranging between 85.22% - 92.62% and on-court efficiency ranging from 67.14% - 79.1%. Table 3 displays input and output variables along with the name of authors and proposed methodology of DEA in basketball.

4.3. Cricket

The authors after reviewing the literature found only a few studies related to the performance assessment in cricket Table 4. Singh (2011) used DEA to evaluate the performance of teams in Indian Premier League (IPL) for 2009 season. His results showed that only 3 teams out of 8 were globally technical efficient and Deccan Chargers despite winning the championship was deemed as inefficient because of high expenditures and comparatively less outputs. Also, the chief source of inefficiency was inconsistency in managerial skills on part of the franchise owners.

Amin and Sharma (2017) selected a cricket team by evaluating the performance of 60 batsmen, 60 bowlers, 10 all-rounders and 10 wicketkeepers in IPL for 2011 season. The authors with the help of DEA methodology found efficient and inefficient players from each capacity and ranked them as per DEA scores to select a required number of efficient squad for a cricket team.

Table 4. Cricket DEA Studies

Author	Methodology	Inputs	Outputs
Singh, S.(2011)	CCR model	Player's wage bill, coach salary, and other miscellaneous expenses	Points awarded, team's profit and revenue and net run rate
Amin, G.R., Kumar Sharma, S. (2017)	DEA model		For batsmen: highest score, average, strike rate, number of fours and sixes For bowlers: bowler's economy rate, bowling average and bowling strike

4.3. Cycling

In sports literature performance studies associated with professional cycling are very rare and the only study we came across was by Rogge and Puyenbroeck (2012) who used DEA to find out the performance of Tour de France cycling teams from 2007-2011. Table 5 shows a review of literature on performance evaluation in cycling. The cycling teams were categorized into 3 teams, namely ranking teams, sprint teams, and mixed teams. The results of their study highlighted that ranking teams generally achieved higher efficiency scores (120.14%) than sprint (80.06%) and mixed (85.44%) teams.

Further, big teams which were having large budgets outperformed the other teams both in terms of effectiveness and efficiency and were aimed at the big prizes.

Table 5. Cycling DEA Studies

Author	Methodology	Inputs	Outputs
Rogge, N., Van Reeth, D., Van Puyenbroeck, T. (2012)	DEA model	Team budget, cycling quotient points in tour team, percentage of cycling quotient points in tour team, number of tour starts, and tour team consistency	Prize money earned, cycling quotient points collected and prizes won

4.4. Football

Among the research articles that used DEA methodology in football, we feature the one by Haas (2003a) who evaluated the technical and scale efficiency of 20 football teams in the English Premier League 2000/01. Haas pointed out that about a quarter to one-third of the teams were on the efficiency frontier and inefficiencies resulted from the inefficient operation of the clubs.

Taking data from 2000 season Haas (2003b) evaluated the efficiency of teams in the Major League Football. The results showed that only 4 teams out of 12 were perfectly efficient and for inefficient teams the main source of inefficiency was widespread redistribution measures on the part of the league. Further, all teams had pure technical efficiency score of approximately 1, indicating that the inefficiencies must be ascribed to the insignificant scale of production.

The efficiency of German Bundesliga football teams for the season 1999/2000 was analyzed by Haas, Kocher and Sutter (2004)by using DEA procedure. In their study, they showed that only two teams out of 18 were CRS, VRS and scale efficient. Also, an important source of inefficiency was wage expenditure for players.

The DEA methodology was also applied to estimate the efficiency of 20 soccer teams that participated in the Spanish First Division during 1998/99 to 2000/01 seasons Espitia-Escuer and García-Cebrián (2004). It was noted from the results obtained that well classified but unproductive teams could have attained same results even with fewer resources or could have ameliorated their results by utilizing same resources. Also, the teams that finished highest in the league didn't always correspond with the efficient teams in the league. Espitia-Escuer and García-Cebrián (2006) calculated the performance of Spanish football teams from 1998 to 2005 using DEA and found that a team's final position in the league depends more on its efficient utilization of resources than potential. The DEA method determined how many points would have the team achieved if it had utilized its resources efficiently.

The performance of English Premier League football clubs during 1998/99 to 2002/03 seasons was estimated by Barros and Leach (2006)to find out if wealth affects sports

performance. The results obtained indicated that all clubs were technically efficient on both CRS and VRS but some among them were not scale efficient.

In their study Calôba and Lins (2006)assessed the performance of 35 football teams in Brazil using the same method of analysis. They compared the DEA results with the Brazilian Soccer Confederation and Placar (magazine) based results and pointed that all teams had attained different ranks in the three lists.

The efficiency of the offense and defense, athletic efficacy and social productiveness of 20 football teams that participated in First Division of the Spanish league for 2004/05 season was analyzed by García-Sánchez (2007). He detected that only those teams achieved a higher number of points that had a high operating efficiency (defense/attack) and their fans visited most to see them play.

In the study Guzmán and Morrow (2007) evaluated the efficiency of clubs in the English Premier League 2002-03 season by the same DEA procedure. They suggested that for the inefficient teams to reach the efficiency frontier must have their inputs (staff cost and other expenses) reduced by approximately 15.5%. Douvis and Barros (2008) estimated and compared football efficiency among Greek and Portugal football clubs between 1999/2000 and 2002/2003 (20 clubs x 4 years = 80 observations) by means of DEA. They found that Greek clubs are technically inefficient as compared to Portuguese clubs and inefficient clubs should change their managerial procedures to reach the efficiency frontier. Boscá et al. (2009) focused on an analysis of correspondence and dissimilarity between Spanish and Italian football league by estimating their technical efficiency in three seasons from 2000 to 2003 using mathematical optimization DEA method. Their results revealed that Spanish league was more analogous and competitive than the Italian league. It was also found that for a team in Italian league to be good ranked must be more defensive than offensive. But for the team in the Spanish league to be best rewarded must prove offense while playing at home as well as overseas.

Analyzing 14 French football clubs from 2004 to 2007 Jardin (2009) evaluated their efficiency. His study revealed that the main distinction between French soccer clubs and other championships lied in competitive balance level. Furthermore, one-third of the DMUs were on efficiency frontier and the cause of inefficiency was associated with the size of clubs and over-investment in players. Sala-Garrido, Carrion, Esteveand Boscá (2009) applied DEA method to analyze the efficiency of teams in the Spanish football league in eight seasons from 2000/01 to 2007/08. They pointed out that the topmost teams in the league had more attacking efficiency and in order to avoid the elimination, defensive efficiency should be of high priority for the teams.

Barros, Assaf and Sa-Earp (2010) examined the efficiency of 20 Brazilian football clubs covering 2006-2007 period first by traditional DEA method and then by bootstrap DEA model and compared the efficiency scores. It was known from the results that four football clubs (Gremio, Sao Paulo, Sao Caetano, and Vitoria) were efficient as per the

traditional DEA method. However, none of the clubs was close to frontier according to bootstrap DEA. The analysis even predicted that the size and location of the city had no impact on efficiency.

Applying DEA technique and directional distance function Gonzalez-Gomez and Picazo-Tadeo (2010) assessed the efficiency of Spanish football teams in the First Division namely, League, King's Cup, and European competitions for 2001/02 season. Their results showed that performance scores for League, King's Cup, and European competitions were 0.884, 0.438, and 0.789 respectively and Spanish football teams performed worst in the King's Cup. The efficiency of football teams in the Champions league from 2003 to 2007 by Espitia-escuer and García-cebrián (2010) pointed out that all teams had an efficiency score over 95% and overall technical efficiency lower than one. The inefficiencies found in the teams that participated in the Champions league from 2003 to 2007 resulted from misuse of resources.

Efficiency of Spanish first division football clubs for the period 1996-2004 was examined by Barros and Garcia-del-Barrio (2011). Their results displayed that Spanish football clubs were operating at high technical efficiency and only Barcelona had achieved global technical efficiency. Tiedemann, Francksen and Latacz-lohmann (2011) implemented nonconcavemetafrontier in DEA and extended it to assess the performance of Germany's Bundesliga football players from 2002/03 to 2008/09. The results showed that there is a positive relation between a team's average player efficiency score and its ranking in the Bundesliga league.

To measure the performance of Iranian football clubs Soleimani-Damaneh, Hamidi and Sajadi (2011) also utilized DEA . The results showed that there is a significant correspondence between the efficiency of the clubs and the remuneration paid to the players and coaches and between the efficiency of the clubs and the populace of the host city. However, excessive salary paid to players and coaches was a reason for the inefficiency of Iranian football clubs. On the other hand, government owned clubs were inefficient because of ineffective management. Kern, Schwarzmann and Wiedenegger (2012) applied two-stage DEA technique to evaluate the efficiency of English Premier League football based on 2006/07 to 2008/09 seasons and compared the results with one stage DEA to figure out the demerits of the latter and advantages of two-stage model. The results of one stage DEA highlighted that player salaries have to be reduced while net transfer balance has to be improved. In comparison, the two-stage method provided details about the off-field operations (player salaries and financial resources) are efficient.

The efficiency of Portuguese football clubs for seasons 2002/03 to 2008/09 was investigated by Ribeiro and Lima (2012). The results showed that the clubs that were spending more wages than they should, implying the inefficient utilization of their resources. Kulikova and Goshunova (2014) investigated the efficiency of 51 clubs from

Australia, Brazil, England, France, Germany, Italy, Netherlands, Portugal, Russia, Scotland and Spain employing DEA. They indicated that among 51 clubs only 12 clubs were technically and scale efficient. Many big football clubs were economically inefficient because of large investments and meagre profits. Santín (2014) proposed super-efficiency DEA model to measure the performance of Real Madrid's football players as per their position in the field: forwards, midfielders, defenders, and goalkeepers. Based on super efficiency scores, the author selected a possible super efficient squad from Real Madrid players.

The performance of 31 national teams that qualified for the 2014 FIFA world cup covering the qualification period between June 2011 and November 2013 was analyzed by Flégl (2014). He reported that only 12.9% of teams reached the efficiency frontier and the reason for low performance depended on the team's qualities. Djordjević, Vujošević and Martić (2015) analyzed the efficiency of the football teams that played in the qualification round of 2010 football world cup in South Africa with the help of two-stage DEA method. The first stage used inputs to produce outputs which were then considered as inputs for the second stage. They presented new results not on the basis of previously obtained results from technical and tactical framework of the game but from the analysis of the second phase in DEA considering offense and defense as new inputs. Villa and Lozano (2016) applied network DEA model to 380 matches played in season 2013/14 by the 20 teams of the Spanish first division league to assess their scoring efficiency taking into account the offense and defense actions of the two teams. Since the model provided target scores in each match letting to know what would have occurred if every team had been efficient.

The economic efficiency of 48 European clubs was measured by Pyatunin et al. (2016) utilizing DEA and its extensions – super efficiency and cross efficiency models. The results revealed that the richest clubs were more efficient because they had access to all the competitions and sources of revenue. Also, those clubs that dominated in their national championships were not most efficient clubs because they had utilized surplus inputs. Zambom-Ferraresi, García-Cebrián and Lera-López (2017) applied DEA methodology to appraise the efficiency of 94 clubs that participated in the UEFA Champions League (UCL) for 9 seasons (2004/05-2012/13). In their study, out of the total sample, only 1.4% of clubs were efficient and the sources of inefficiency were inappropriate sporting tactics and squander use of resources. The results also displayed that only 15 clubs out of 94 had applied proper sports tactics and 8 clubs had made judicious use of their resources.

The efficiency of English Premier League (EPL) clubs during 3 seasons 2012/13-2014/15 was evaluated by Zambom-Ferraresi, Lera-lópez and Iráizoz (2017) using traditional DEA and bootstrapped DEA models. Their results highlighted how well the large clubs were managed. The relegated teams had utilized the resources very well indicating that

if they had increased the inputs and if management would have been proper, there was a possibility in the increase of outputs. Table 6 shows the DEA studies in football.

Table 6. Football DEA studies

Author	Methodology	Inputs	Outputs
Haas, D.J. (2003a)	CCR+ BCC model	Club's total wages and salaries (excl. coach), coach salary and club's hometown population	Points awarded during the season and total revenues
Haas, D.J. (2003b)	CCR+ BCC model	Player's wage bill and coach salary	Points awarded during the season, total revenue and number of spectators in the stadium
Haas, D.J., Kocher, M.G., Sutter, M. (2004)	CCR + BCC model	Player's wage bill and coach salary	Points awarded during the season, total revenue and average stadium utilization
Espitia-Escuer, M., Garcia-Cebrián, L. (2004)	CCR + BCC model	Attacking moves players used, minutes of ball possession, shots and headers made	Points achieved and goals scored
Espitia-Escuer, M.,Garcia-Cebrián, L. (2006)	CCR model	Attacking moves players used, minutes of ball possession and shots at goal	Points achieved throughout the season
Barros, C.P., Leach, S. (2006)	CCR + BCC model	Number of players, player wages, net assets and stadium facilities expenditure	Points obtained in the season, number of tickets sold and turnover in the season
Caloba, G.M., Lins, M.P.E. (2006)	DEA + slack based measure (SBM)	Unitary value	National and international championships
Garcia Sanchez, I.M. (2007)	CCR + BCC model	Attacking moves, passes to penalty area, shots at goal, ball recovery, goalkeeper's action, stadium capacity and population of the province	Goals scored, inverse of goals received, points obtained by a team and the number of spectators who attended the matches
Guzman, I., Morrow, S. (2007)	DEA + canonical correlation analysis (CCA)	Staff cost, director's remuneration, and other operating expenses	Points won and turnover
Barros, C.P., Douvis, J. (2008)	Malmquist productivity index based on DEA	Number of players and total costs	Total receipt, championship points won and the total number of tickets sold

Bosca, J.E., Liern, V., Martinez, A., Sala, R. (2009)	CCR model	Offensive inputs: shots on goal, attacking plays made by the team, balls kicked into the opponents center area and minutes of possession Defensive inputs: shots at goal, inverse of attacking plays, inverse of passes to center area and minutes of possession by the opposing team	Goals scored inverse of goals received
Jardin, M. (2009)	DEA + Assurance region method	Club total wage and population size of the club city	Number of points and turnover at the end of season
Sala-Garrido, R., Carrion, V.L., Esteve, A.M., Bosca, J.E. (2009)	CCR model + DEA window analysis	Offensive inputs: shots on goal, attacks in penalty box, crosses in penalty box and minutes of ball possession Defensive inputs: shots at goal opponents, attacks and crosses by opponents in own penalty and minutes opponent had	Goals scored inverse of goals received
Barros, C.P., Assaf, A., Sa-Earp, F. (2010)	DEA bootstrap model	Operating cost (excl. labor cost), total assets and team payroll	Attendance, total receipts and points in the league
Gonzalez-Gomez, F.,Picazo-Tadeo, A.J. (2010)	DEA + directional distance function	Points acquired at the end of season, number of rounds played in the King's cup and number of matches played in European competitions	Number of players, average number of spectators per match, number of seasons played in the First Division and trophies in national and international competitions
Barros, C.P., Garcia-del Barrio, P. (2011)	DEA bootstrap model	Operating cost, total assets, and team payroll	Attendance and other receipts
Tiedemann, T., Francksen, T., Latacz-Lohmann, U. (2011)	CCR model	Playing time in minutes	Goals, assists, tackle ratio and pass completion ratio
Soleimani D., Hamidi, M., Sajadi, N. (2011)	DEA + analytical hierarchy process (AHP)	Coach wages, player wages, staff wages and team's fixed assets	Points received by the team, total revenues and number of spectators who watched the team's matches
Kern, A., Schwarzmann, M., Wiedenegger, A. (2012)	Two-stage DEA	Wage costs and net transfer activity	Sportive success, total revenue and stadium utilization
Ribeiro, A.S., Lima, F. (2012)	CCR model	Total wages paid, sum of five highest wages, sum of five lowest wages and the remaining sum	Rank in the first league

Kulikova, L.I., Goshunova, A.V. (2014)	CCR model	Total costs, intangible assets, borrowed capital, purchase of player's registration, personnel costs, average number of playing staff, number of points scored in national championship	Turnover and rank of club in the national championship
Santin, D. (2014)	BCC + super efficiency model	Number of seasons each player played	Number of games played , number of national and international titles won and goals scored by each player
Flegl, M. (2014)	CCR + BCC model	Number of used players, ratio of minutes played, matches played, and quality of the qualification group	Points gained and difference in for and goals against
Djordjevic, D.P., Vujosevic, M., Martic, M. (2015)	Two-stage DEA model	Total number of crosses, number of successful crosses, number of crosses in play, number of successful long through balls in play, number of successful passes in play, number of shots, number of shots on target, total number of fouls made, total number of air	Total number of recognized scored goals, effect of successful ones out of total passes in play, effect of successful ones out of total number of air duels, effect of successful ones out of total number of ground duels
Villa, G., Lozano, S. (2016)	Network DEA model	Ball possession, shots at goal, corner kicks, penalty kicks, goalkeeper's saves, turnovers, steals executed and economic value of the team	Total goals scored
Pyatunin, A.V. *et al.* (2016)	CCR + super efficiency +cross efficiency model	Staff cost, market value of a squad, country strength coefficient, participating in the European cups and participating in UEFA champions league	Revenues, points per game, qualification for the European cups, qualification for UEFA champions league and prize money for sportive performance in a European
Zambon-Ferraresi, F et al. (2017)	CCR + BCC model	Total attempts, ball possession and ball recoveries	Sports results
Zambon-Ferraresi, F., Lera-Lopez, F., Iráizoz, B. (2017)	DEA bootstrap model	Squad market value	Points gained, total revenue, stadium utilization and index of social media impact

4.5. Golf

The only study related to the application of DEA in golf was undertaken by Fried, Lambrinos and Tyner (2004), Table 7. They evaluated the performance of golfers for the 1998 season covering three major tours in the United States namely the Professional Golf Association (PGA), the Ladies Professional Golf Association (LPGA), and the Senior Professional Golf Association (SPGA). The authors pointed out that putting in golf may not be a stylish skill but it played a significant role in determining financial success. Moreover, players on the PGA and LPGA tours were at their best, whereas skills deteriorated unevenly with the age of seniors.

Table 7. Golf DEA studies

Author	Methodology	Inputs	Outputs
Fried, H.O., Lambrinos, J., Tyner, J. (2004)	CCR model	Driving distance, drives in fairway, greens hit in regulation, number of putts per green, scrambling and sand	Earnings per event

4.6. Handball

The game of handball has also not slipped from the hands of being evaluated in terms of performance and efficiency. Table 8 points DEA studies conducted in handball. The articles pertaining to the use of DEA in the game include the work of Gutierrez and Ruiz (2013a), who evaluated the game performance of players in the Spanish Handball League, the ASOBAL league, during the 2008-2009 season. A total of 66 players that had played in the back position in the league were evaluated. The study showed that only 10 players out of 66 were efficient and for the ranking of DMUs cross efficiency evaluation was used which also furnished a peer assessment of the players with different patterns of the game. Differences were seen between the ASOBAL league rankings and the ranking determined by cross evaluation.

Gutierrez and Ruiz (2013b) compared the game and competitive performance of 24 teams in the Men's 2011 World Handball Championship by using DEA and cross-evaluation. DEA results revealed that out of 24 participating nations only 9 were efficient. The obtained results when compared with the final classification in the competition proved insightful about the game and competitive performance of the teams.

Table 2.Handball DEA studies

Author	Methodology	Inputs	Outputs
Gutierrez, O., Ruiz, J.L. (2013a)	CCR + cross efficiency model		Number of goals scored per game from the 9 m line, number of goals scored from the line of 6m, number of assists per game, number of fouls made per game, number of seven meters cause per game and turnovers per game
Gutierrez, O., Ruiz, J.L. (2013b)	CCR + cross efficiency model		Number of goals scored per game from the 6m line, the wing position, goals scored from 9m and 7m, number of fast break and breakthrough goals and number of recoveries and blocks per game

4.7. Olympics

Several studies have evaluated and predicted the performance of different countries in the Olympics. Table 9 displays the review of literature on performance measurement in Olympics. The very first one was carried out by Lozano et al. (2002). They assessed the performance of the countries that participated in the last five Summer Olympic Games. Their results showed that out of 80 participating nations that won medals only 9 were efficient. Also, the host countries had performed better as compared to their historical average because of home advantage and at the same time, their organizational efficiency was very effective.

On the basis of efficiency Churilov and Flitman (2006) ranked the countries that participated in 2000 Sydney Olympic Games. The results highlighted that the countries with relatively less population and low GDP were doing well as far as the number of medals won was concerned and for the countries like China and India, they have to win more medals to justify their large population. Li et al. (2008) utilized DEA and its extension Assurance Regions (AR) to find out the Olympic achievements of participating countries in 6 summer Olympic Games held from 1984 to 2004. They grouped the participating countries into 4 economic categories: low-income, lower-middle-income, upper-middle-income, and high-income. It was noted from their results that out of 62 countries only 15 were efficient and majority among the efficient countries belonged to low and lower-middle-income groups.

Two types of rankings were determined by de Mello, Meza and da Silva (2008)for the Athens Olympic Games. In the first step they ranked each sport independently and in the second step, they measured the importance of each sport by the number of nations participating in each event. They concluded that the countries should concentrate more on sports having large number of medals such as gymnastics, athletics, swimming etc. rather than sports with few medals and participants like football, basketball, hockey etc.

Olympic performance of 46 countries that participated in 2004 Athens Olympics was evaluated by Yang et al. (2009) and ranked them on the basis of best and worst frontier scores. DEA technique was used to measure the efficiency of each DMU and inefficiency was measured by DEA related Jahanshahloo approach. The Ratio of the distance from the worst frontier to that from the best frontier was determined by the ratio of two distances (RDS) and ranking was done according to RDS scores.

Table 9. Olympics DEA studies

Author	Methodology	Inputs	Outputs
Lozano, S., Villa, G., Guerrero, F., Cortes, P. (2002)	BCC model	Gross national product and population of a country	Number of gold, silver and bronze medals won
Churilov, L., Flitman, A. (2006)	DEA + data mining techniques	Population of the country, gross domestic production per capita, disability-adjusted life expectancy and index of equality of child survival	Number of gold, silver and bronze medals won
Li, Y., Liang, L., Chen, Y., Morita, H. (2008)	BCC + context dependent assurance region (CAR)	GDP per capita and population of the country	Number of gold, silver and bronze medals won
De Mello, S., Baptista, J.C.C., Meza, L.A., Silva, B.B.D. (2008)	CCR + cross efficiency evaluation model	Unitary constant for all countries	Number of gold, silver and bronze medals won
Yang, F., Ling, L., Gou, Q., Wu, H. (2009)	CCR model	Population of the country, gross domestic production per capita, disability-adjusted life expectancy and index of equality of child survival	Number of gold, silver and bronze medals won
Wu, J., Zhou, Z., Liang, L. (2010)	Integer-valued DEA model	GDP per capita and population of the country	Number of gold, silver and bronze medals won
Li, Y., Lei, X., Dai, Q., Liang, L. (2015)	Two-stage DEA model	GDP per capita and population of the country	Number of gold, silver and bronze medals won
Lei, X., Li, Y., Xie, Q., Liang, L. (2015)	BCC model	GDP per capita and population of the country	Number of gold, silver and bronze medals won

The participating countries in 2008 Beijing Olympic games were analyzed by Wu, Zhou and Liang (2010) applying integer-valued DEA which is an extension tool of DEA model and allows to determine the efficiency of integer valued data precisely as compared to

traditional DEA model. Their results showed that only 13 countries were DEA efficient, whereas 15 countries were integer valued efficient and their score was not less than DEA score. Further, if a country was DEA efficient, then it was also integer valuedefficient.

Employing two-stage DEA, Li et al.(2015) evaluated the performance of 85 countries that won at least 1 medal in the 2012 London Summer Olympic games. In the first stage they evaluated the efficiency of athlete preparation (AP) and in the second stage efficiency of athletic competition (AC) was assessed. The results showed that for most of the participant's efficiency of AP stage was higher compared to the AC stage, indicating that they had poor performance during competition stage. Lei et al. (2015) considered two Olympics together to estimate the performance of twenty participating countries that had taken part in both the Vancouver 2010 Winter Olympic Games and London 2012 Summer Olympics using a parallel DEA approach.

Earlier studies evaluated the performance of participating countries in Summer Olympics only but the study by (Lei *et al.*, 2015) was first to consider Winter Olympics. As per the results, most of the countries displayed different performance in the two Olympics which was consistent according to their geographical features and indicated the level of sports of each participating country.

4.8. Tennis

Table 10 indicates the studies that were associated with the measurement of performance in tennis by DEA method include the work of Ramón, Ruiz and Sirvent (2012). They used DEA approach to derive a common set of weights (CSW) to rank a sample of 53 tennis players for 2009 season. The ranking was based on the statistics and related to the efficiency of the game of the players, unlike the Association of Tennis Professionals (ATP) ranking.

Ruiz, Pastor and Pastor (2013) also assessed the efficiency of 53 tennis players during 2009 season using DEA benchmarking analysis and ranked them by cross-efficiency evaluation, an extension of DEA. It was noticed that out of 53 players only 11 were efficient, further out of 11 efficient players 8 were ATP top ten players. Similar results were determined by Ramón, Ruiz and Sirvent (2012). Moreover, there was a difference between the ATP and cross-evaluation ranking because ATP ranking is based on the points that players attain in the tournaments whereas cross-evaluation ranking is based on the performance of the game of the players.

Performance of 40 tennis players for the 2012 season was evaluated by Chitnis and Vaidya (2014) by DEA methodology considering three inputs and eight outputs. As per their results, DEA provided a multidimensional overall assessment of the tennis players which was quite different from the ATP world tour rankings. Ramón, Ruiz and Sirvent (2012), Ruiz, Pastor and Pastor (2013) and Chitnis and Vaidya (2014) concluded that there were differences between the ATP rankings and DEA efficiency scores.

Table 10. Tennis DEA studies

Author	Methodology	Inputs	Outputs
Ramon, N., Ruiz, J.L., Sirvent, I. (2012)	CCR model	Nominal input with values equal to 1 for all the players	Percentage of 1st service, percentage of 1st service points won, percentage of 2nd service points won, percentage of service games won, percentage of break points won, percentage of points won returning 1st and 2nd service, percentage of break points converted and percentage of return games won
Ruiz, J.L., Pastor, D., Pastor, J.T., (2013)	CCR + cross efficiency evaluation model	Nominal input with values equal to 1 for all the players	Percentage of 1st service, percentage of 1st service points won, percentage of 2nd service points won, percentage of service games won, percentage break points won, percentage of points won returning 1st and 2nd service
Chitnis, A., Vaidya, O. (2014)	CCR model	Overall matches played, grand slam matches played and ATP world tour masters 1000 played	Overall matches won, grand slams won, ATP world tour masters 1000 won, tie-breaks won, number of finals won, matches won in the deciding set,
Glass, A.J., Kenjegalieva, K., Taylor, J. (2015)	BCC model	Attacking inputs: First serves in (%), points won on first serve (%), points won 2nd serve (%), average aces per match, average double faults per math, break points saved (%), service games won (%)	Prize money and matches won

Computing the attacking, defensive and overall efficiencies of the top hundred male tennis players during 2009 period Glass and Kenjegalieva (2015) also used DEA. They categorized the inputs according to attacking or defensive abilities, which provided more insight regarding the sources of inefficiency.

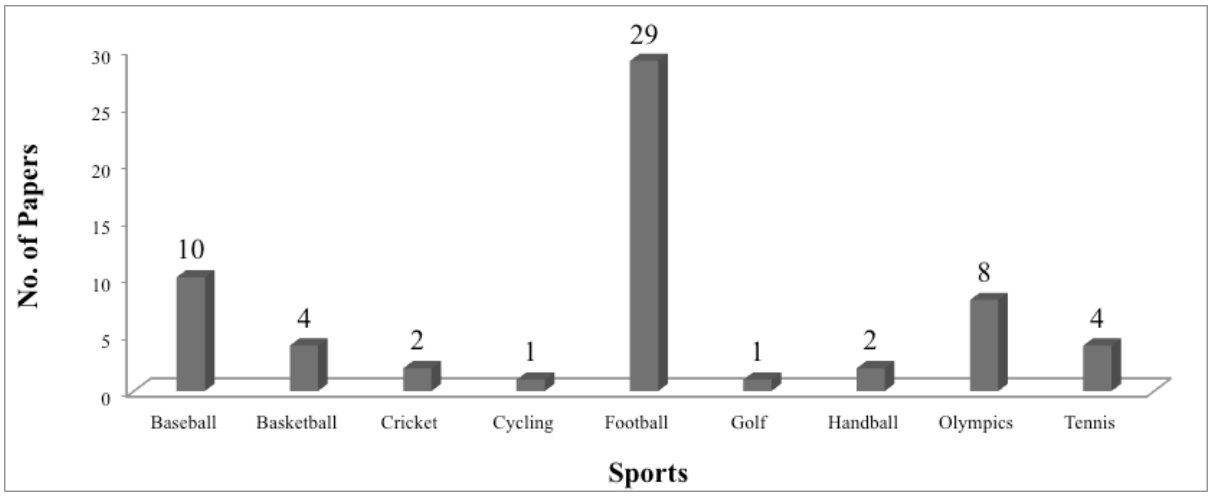

Figure 1.Use of DEA in different sports

5. Limitations of the study

The present study is having various limitations as: only journal papers and articles published in books were reviewed. Conference papers, doctoral thesis and working research papers (not published) were excluded. Also, articles not in the English language were not included in this study.

6. Conclusion

The assessment of efficiency of every system is essential to find its shortcomings so that subsequent improvements can be made. Despite the fact that, it is critical to know the particular effectiveness of a team/player so that they can be compared with others, the most significant objective in efficiency measurement is improvement. This review is a small step towards contributing to the field of Operational Research, explicitly to the theory of Data Envelopment Analysis in sports.

The purpose of this study was to analyze the sports in which DEA and its extensions were utilized. DEA proved to be a wonderful technique of performance assessment in sports. DEA provides a measure of relative efficiency where the performance of players/teams is evaluated with respect to others and helps to identify the strength and weakness of the game of the players. It also provides the possible direction of improvement and benchmarks for comparison purposes. DEA utilizes mathematical programming method to screen the performances of DMUs in connection to one another.

Among the nine games football has been scrutinized much by operation research. Further, researchers were more interested in performing analysis of English football clubs. There are very rare studies of football clubs from other countries. The reason

behind it is that English football clubs were first to appear on the stock market. Moreover, information limpidness and accessibility of information have led to the popularity of English football clubs. It was observed from the analyzed articles that only the performance of male players in different sports was taken into confidence by different authors.

We hope this review article may assist the researchers in better understanding the current status of the application of DEA in sports.

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