Building a Basketball Game Strategy Through Statistical Analysis of Data

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Abstract

Management practices may be based either on manager's intuition or on analytical and objective reasoning. Sports and, particularly, basketball can be considered as an indicative field where these differences in decision-making can be met. This paper has been motivated by the statistical analysis that the author conducted in the past in order to support the management of a Greek basketball team and specifically the decision-making process of its coach regarding the team's strategy during its games. The aim of the paper is on the one hand to present some indicative, simple ideas for the statistical analysis of basketball data, and on the other hand to show that any basketball team can improve significantly its decision-making process if it chooses to be statistically supported. Basketball data is numerous; consequently its elaboration can be extensive and fruitful.

Keywords: Basketball; Operations research; Statistical analysis; Regression model; IRAKLIS

1. Introduction

Management and decision-making process can be either intuitive, i.e. more subjective and spontaneous, or based on data, indexes, statistical analysis and, generally, quantitative methods of Operational Research (OR). The dilemma of choosing the appropriate management style is found in any type of operation where management decisions have to be made. The specific belief has been endorsed by many researchers, from various research areas: Brunswik (1956) was the first who suggested that decisions can be made either in an intuitive or an analytical mode. Since then, management styles were further studied by several researchers, such as Hammond (1988), Calori et al. (1995), Dunwoody et al. (2000), Khatri and Ng (2000), etc.

Sports and, particularly, basketball can be considered as an indicative field where several management decisions are taken every day (Raab and Johnson, 2006). However, mainly depending on the country and the popularity of basketball, these decisions and, more precisely, the part of them referring to the game strategy are made rather intuitively (Glöckner et al., 2012). For example, basketball in the U.S. and particularly in its major representative, the NBA, is strongly supported by the collection and the statistical analysis of various data, as well as quantitative techniques. See for instance Mike Zarren who is Boston Celtics' Assistant General Manager/Team Counselor[1]. He helps the team by evaluating potential trades and draft picks, and offers strategic advice to coach Glenn "Doc" Rivers (Dubner and Levitt, 2008). The U.S. basketball world has realized that sports constitute a business where a lot of money is at stake, therefore there is no room for managers' "inspirations" to rule hundreds of millions of dollars.

On the contrary, despite the popularity of basketball in Europe (which, however,

[1] www.nba.com/celtics/contact/front-office.html

cannot reach the sport attractiveness in the U.S.), it seems that the managing of this sport is done in many countries mostly by the so called “experienced” people. The latter usually believe that they do not need further help from indexes and statistics to make the necessary decisions, as their intuition is enough for them. Obviously, this is not always a conscious choice. In fact, it is often mandated by the economic barriers of their teams, while their management approach would probably be different in case of financial comfort.

Consider, for instance, Greece where basketball is the second most popular sport after football (soccer). Yet, this popularity does not help the people involved in teams’ management realize that a lot of money can be won or lost depending on the type of management they adopt and the quality of decisions they make. Consequently, the “experience” and the “unmistakable feeling” are thought to be enough for managers to optimize their decisions!

We should point out that it is not absolutely fair to consider this managerial behavior as an irrationality of the sports’ field exclusively; the same tendency can be noticed in almost every business activity of Greece (as well as Portugal, Spain, Italy and most of the South European countries). Most of the times managers in these countries do not use statistics, quantitative methods and OR to optimize their decisions. This happens mostly because

- even *if they know how to apply quantitative methods and OR* the specific way of management is time consuming; usually businessmen and executives ask everybody in their payroll to “run” - no matter if they do not know where to run to - and not to “waste” their time trying to carry out optimized techniques,
- while *if they do not know how to apply quantitative methods and OR* hiring consultants to train the company’s managers and/or solve the company’s managerial problem(s) would cost a lot! As a result, businessmen are interested in this type of

external help only if they manage to ensure an EU funding program.

On the other hand, Germany, France, England, etc. have promoted OR methods in the decision-making process of their companies. Nevertheless, as far as basketball is concerned most North Europeans believe that they have … better things to do in their leisure time, i.e. the popularity of basketball is very low. Therefore, the majority of people who are actively involved in basketball perceive it mainly as a hobby - which does not have particular needs for OR and statistics - and not as a professional activity that attracts the massive interest of crowds.

The selection between an intuition oriented or an OR supported decision-making process has to do with not only basketball coaching staff, but also with all management executives who are involved in a team's management, e.g. the owner, the president and the members of board, the general managers, etc. However, this paper focuses particularly on coaches who take instantaneously numerous crucial decisions regarding the outcome of a basketball game. This is their additional difficulty in comparison with all the others who usually have plenty of time to make a decision on every issue that influences the progress of the basketball team they work for. Moreover, it seems absolutely normal to all of us to watch coaches make intuitive decisions regarding their team's strategy in a game, the player substitutions, the team's tempo, etc. But is this way of making decisions the appropriate one?

Regarding the question "what do coaches believe about all these?", it is difficult to make a general statement; familiarization and, consequently, response of coaches to statistical support and OR techniques are different in the U.S., Europe or other countries which are less favorable to basketball. Moreover, coaches' tendency to use statistical information increases as time passes and so does maturity on this issue. Primarily, coaches are happy just to get

“numbers” printed on a piece of paper after the game. However, they quickly progress and begin to analyze the significance of the numbers and what they actually show. Lastly, coaches progress to a level of maturity where they use this data and information as a tool in planning and carrying out practices and game preparation. As a result, their team's and individual players’ performances are greatly improved.

In the U.S., several NBA teams already employ statistical analysis, and presumably, the continued and growing employment of statistical analysts suggest that the teams find their work to be useful. However, a competitor of statistical analysis and, generally, quantitative methods is the modern techniques of basketball scouting, according to which coaches and mainly their assistants x-ray their team’s opponent based on video analysis.

One aim of this paper is to present some simple ideas to analyze basketball data, as well as to show that even simple descriptive statistics can be helpful in supporting the decision-making process of any coach both before as well as during a basketball game. The assessment through regression analysis that we present substantiates this belief. An additional objective of our study is to show that a basketball team can benefit greatly if it chooses to be statistically supported. Basketball data is numerous, thus its elaboration can be extensive. Finally, the regression equations that are formulated in this paper contribute largely to the enrichment of the OR background vis-à-vis the decision-making process of basketball.

In what follows, after the literature review of Section 2, we present (Section 3) an indicative part of a statistical report that the author (who will be called “statistical analyst” – SA, hereafter) was preparing on a weekly basis, in 1999 to support the Greek basketball team of IRAKLIS and, specifically, its coach at that period, Dragan Sakota. In Section 4, we evaluate the conclusions of the statistical report using regression models, while in Section 5

we present some additional statistical and OR techniques which could be considered as interesting directions for future research. In Section 6 we discuss the response of basketball coaches to the statistical support of the decision-making process while, finally (Section 7), we make some closing remarks.

Regarding the team that this report refers to, i.e. IRAKLIS (www.iraklisbc.gr), it should be noted that it is a historic basketball club from Thessaloniki, Greece. Founded in 1908, IRAKLIS was the first club to win the national title in 1927-1928. IRAKLIS has participated twice in the European Euroleague (1996 and 2001). Many famous basketball players have played for IRAKLIS[2], like Xavier McDaniels, Jury Zdovdc, Walter Berry, as well as some very popular Greek stars like Dimitris Diamantidis, Sofoklis Shortsianitis and Lazaros Papadopoulos, who have also been successful players of the Greek national team.

On the other hand, Dragan Sakota (who will be called "coach" hereafter) is one of the most important Serbian basketball coaches. Apart from IRAKLIS, he coached several other European clubs like Crvena Zvezda (Serbia & Montenegro), Zadar, Cibona (Yugoslavia), and PAOK, Aris, Olympiakos (Greece), while he was the assistant coach (2004) and the head coach (2006) of Serbia & Montenegro national basketball team[3].

2. Literature review

Nowadays, quantitative methods and techniques that can improve decision-making in sports and specifically in basketball, present a growing popularity. The book of Oliver (2004) makes a significant contribution regarding the use of statistics in conducting basketball performance analysis. Among the various issues that it addresses, great interest can be

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[2] www.eurobasket.com/team.asp?Cntry=Greece&Team=276&Page=4

[3] http://www.eurobasket.com/coach.asp?Cntry=TUR&CoachID=49&AmNotSure=1

found in the normal distribution of data, the insights on a box score, the various tools that can be used for a team evaluation and the multivariate regression of basketball data. Albert et al. (2005) collect previously published papers on the use of statistics to analyze sports. Their book contains separate sections devoted to the major team sports, i.e., baseball, football, basketball and ice hockey. Winston (2009), who devotes a great part of his book on basketball, intends to introduce the reader to various models that are used to analyze sports. He notices that some of these models are used in practice by team management to aid in the decision-making process. Berri and Schmidt (2010) are inspired by the fact that people generally have trouble making "good" decisions. Based on experimental evidence they present various stories which, they claim, should not only change the way sports fans perceive the choices made by their favorite teams, but also impact the way economists and other social scientists think about human decision-making. Special interest can be found in the measurement of wins made in the NBA through regression analysis. The book of Berri and Schmidt (2010) can be considered as an extension of the one of Berri et al. (2006) who admit that although sports are played every day and numbers are recorded continuously, those numbers are poorly understood. Thus, through their book they actually make an effort to change the general picture.

As far as published papers on this area are concerned, the work of Zak et al. (1979) should be included among the most important ones; they estimate a production function for basketball teams and they apply it to data collected during the 1976-1977 NBA season. Their purpose is to examine the determinants of a team's performance. Many years later Schwertman et al. (1991) use the NCAA regional tournament as a great opportunity to apply probabilistic concepts. This way they develop an educational probability exercise. Ghosh and Steckel (1993) analyze playing statistics for two different seasons and classify NBA players as

scorers, bangers, dishers, etc. Their analysis of a team's role structure provides useful guidelines for selecting draft choices and executing trades. Kwam and Sokol (2006) present a model that predicts NCAA tournament outcome more effectively than standard ranking and rating systems, while it requires only basic input data. More specifically they present a model for ranking college basketball teams and for estimating win probabilities. Berri et al. (2007) reexamine several pieces of evidence previously presented in literature, demonstrating that decision makers in the NBA do not process information efficiently. They also present two empirical models which have been initially described in less detail in Berri et al. (2006). Kubatko et al. (2007) present some generally accepted basic variables of basketball analysis, thereby providing a common starting point for future research in basketball. The “basketball theory” that Sanchez et al. (2007) develop is very interesting and can be adopted in our paper too: a basketball team can be considered as a technical unit that produces an output combining inputs. Its objective is to maximize its sport successes subject to the constraint of not incurring economic losses. In other words, in each basketball game a team aims at beating the opponent and to achieve this target, it has to develop a series of play actions that, if carried out wisely, increase the winning probability. Recently, Goldman and Rao (2011) have examined the optimality of the shooting decisions of the NBA players, using a rich data set of shot outcomes. They model shot selection and allocation as a dynamic problem, and examine the behavior of professionals relative to theoretical standards of optimality they derive. Finally, Štrumbelj and Vračar (2012) investigate the use of Markov models for basketball match simulation and use a possession-based model to monitor the progress of a basketball match. The transition matrix of their model is estimated directly from NBA play-by-play data and indirectly from the teams’ summary statistics.

Moreover, there are a lot of papers regarding many other managerial issues, which

go beyond the competing part of basketball. For instance, Bean and Birge (1980) considering that the 22 teams of NBA (at that time) travel an unnecessary number of airline miles, consider several optimization methods to lower the total number of passenger miles the league travelled. They manage to develop efficient schedules which would lead in practice to savings of 757,000 $ or 20.4% over the NBA's current schedule. Much more recently, Sampaio et al. (2006) examine the differences in game-related statistics between basketball guards, forwards and centers playing in three professional leagues. They claim that the knowledge of these differences could allow the coaches to increase the effectiveness of the player recruitment process. Morse et al. (2008) examine through a regression equation the effects of roster turnover on season attendance in the NBA, over a five-year period (2000-2005). Popp et al. (2010) admit that player recruitment is both intense and expensive as coaches must recognize talent at an early age and from a broad geographic range. In their study they try to determine which factors are the most influential when international student-athletes choose to attend US universities. Moreover, they statistically compare such influences with those of domestic student-athletes to determine if significant differences exist between the two groups.

3. The statistical report

The statistical analysis support provided to IRAKLIS coaching staff was based on a short (about ten-page) booklet that SA prepared in the middle of every week. This way, the coach had enough time to study the report and prepare his team accordingly, ahead of the championship game that was held on Saturday afternoon[4]. Moreover, usually every

[4] In our paper we refer to a specific game of the season 1999 – 2000, in which IRAKLIS outperformed Maroussi 92 – 75. Nowadays, Maroussi (www.maroussibc.gr) is one of the greatest Greek basketball teams, participating in the Euroleague of

Wednesday a meeting took place between the SA and the coach, in order for the first to present and explain the main points of his analysis to the coach and his assistants. Wednesday's meeting was also a chance for both parts to talk about any additional ideas which could be included in the statistical analysis of the following week.

The statistical analysis was usually divided into four parts: the *first* one was about the performance of IRAKLIS during all previous games of the championship of 1999-2000, while the *second* part was about the performance of IRAKLIS' opponents in the specific series of games. The *third* part referred to the performance and the characteristics of the players of the forthcoming opponent (namely, in our case, Maroussi). The *fourth* part of the statistical analysis was about the performance and the statistical data of the players of IRAKLIS' forthcoming opponent in the previous championship (in our case during the championship of 1998-1999), either these players were in the same team or in a different one.

3.1. First part

Based on Table 1 and Figure 1, SA presented the performance of IRAKLIS during the first six games of the championship. More specifically SA pointed out the following:

i. "*IRAKLIS scored three times more than 75 points and managed to win the game*".

The usefulness of this remark for IRAKLIS' coach arose from the fact that considering stable his team's defensive performance, the offense was the one that determined mostly the outcome of a game. The interesting thing about this comment was the number of points IRAKLIS had to score to win a game. In other words, for a different team this number could be greater, for example 85 points or for an even better defensive team than IRAKLIS smaller, for example only 65 points. Obviously, SA did not "reveal" that when a team scores more it

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2009-2010, while in 2001 won its first European trophy (European Saporta Cup).

tends to win. However, even that simple conclusion can be very useful to be extracted through statistics, in order to strengthen them, enhance their value and unfold their ability to help the management of teams. Coaches (presidents, managers, etc.) who are unfamiliar with statistics need first to be convinced about the usefulness of statistics so they can later benefit from their use.

ii. "*During the 6th game (against Dafni), the number of free throw (1p) attempts reached for the first time in that championship a very high level, namely 19 free throws, in an away game. In the other two games where IRAKLIS was a visitor, namely against Near East and AEK, the number of 1p attempts was only 10 per game. Obviously, a similar remark can be made about the earned fouls*".

iii. "*The 3p percentage of IRAKLIS is probably the statistical category that is connected so closely with the outcome of a game: whenever IRAKLIS outgoes 45% in 3p percentage, its team wins the game*".

SA underlined that the players of IRAKLIS by paying attention to the "quality" of 3p shots they attempt, increase the potential of their team to be the winner of a game.

iv. "*In four (out of six) games so far, IRAKLIS attempted 19 to 20 3p shots. This fact indicates team's propensity*".

v. "*From Figure 1, it is easy to notice:*

- *the increasing number of IRAKLIS total rebounds* (Figure 1a)*,*
- *the progressively increasing number of turnovers* (Figure 1b) *and*
- *the stability in the number of assists: from 11 to 14 per game (with just one exception* - Figure 1c*)*".

Table 1 about here

Figure 1 about here

Regarding points ii, iv and v above, IRAKLIS' coach had to account for the specific team behavior and encourage his players to repeat any positive strategy, while avoiding any negative one.

3.2. Second part

In Table 2 SA analyzed the performance of IRAKLIS' opponents during the first six games of the 1999-2000 championship. His objective was to help the coach figure out how IRAKLIS' playing style affected the opponents' performance, as well as locate any good tactics and try to improve any damaging ones. More specifically, SA pointed out the following remarks:

vi. "*IRAKLIS managed to reinforce its stable defense performance in the last game of the championship, by allowing Dafni to score only 59 points. This was IRAKLIS best achievement this season, which improved its already excellent defensive performance: in the previous five games of the championship its opponents scored between 67 to 72 points*" (Figure 2a).

vii. "*Although during the first five games of the championship the number of 3p attempts per game of its opponents was almost stable (around 11-12 shots), against Dafni this number increased significantly (16 attempts)*".

SA claimed that the extremely low 3p percentage of Dafni (18.8%) justified IRAKLIS' choice to "allow" its opponent to attempt so many 3p shots.

viii. "*The distinctive increasing number of IRAKLIS (total) rebounds (mentioned previously) is combined with the constantly decreasing number of its opponents' rebounds*"

(Figure 2b).

ix. "*Excluding only one game, namely the one against Panionios, IRAKLIS lets its opponents have a constant number of about 10 assists*" (Figure 2c).

Table 2 about here

Figure 2 about here

Once again, regarding points vi, viii and ix mentioned previously, the coach had to figure out the remarks of SA, interpret the specific team behavior and manage to induce his players to repeat any positive tactics.

3.3. Third part

As mentioned previously, this part of the statistical analysis referred typically to the characteristics of the players of IRAKLIS' forthcoming opponent. Based on a simple box score of all the games played by the opponent until the moment of the statistical analysis (such as the one presented in Table 3) and the following simple equations, a more sophisticated table (such as Table 5) was created every week. More specifically, SA considered the following formulas (using the notation presented in Table 4):

$$ATG_x = \frac{MIN_x}{GP_x} \tag{1}$$

$$P2p_x = \frac{2pA_x}{2pA_t} \tag{2}$$

$$P3p_x = \frac{3pA_x}{3pA_t} \tag{3}$$

$$2p\%_x = \frac{2pM_x}{2pA_x} \tag{4}$$

$$3p\%_x = \frac{3pM_x}{3pA_x} \tag{5}$$

$$PI_{1x} = \frac{3pA_x}{1pA_x} \tag{6}$$

$$PI_{2x} = \frac{2pA_x + 3pA_x}{1pA_x + 2pA_x + 3pA_x}. \tag{7}$$

Table 3 about here

Table 4 about here

Table 5 about here

In our study, considering the number of games played by each Maroussi player during the interval of the first six games of the Greek championship, and the average playing time of each player per game, SA pointed out that "t*he two American players play almost throughout every game of their team: Amaya (35.7 min per game*[5]*) and Turner (35.2 min per game). Moreover, Maroussi coach usually prefers Korfas (26.2 min per game) and Panagiotarakos (21.3 min per game) to be parts of his team*". This remark was helpful to the coach because SA revealed that the two foreign players of Maroussi were almost indispensable, while their coach alternated all the rest in the three remaining positions of his team**.**

According to a different, "statistical" point of view, SA did not take into account the variant average playing time per game of Maroussi players and assumed that the analogies would be maintained in the game against IRAKLIS. Then, he noticed that:

x. "*The majority of 2p shots are attempted by the two foreign players of Maroussi, namely Turner (29.3%) and Amaya (26.6%). Moreover, the number of 2p attempts made by Papachronis (13.1%) and Panagiotarakos (10.4%) is significant*". SA observed that the foreign players were attempting more than 50% of the total 2p

[5] A basketball game in Europe lasts for 40 min

shots of Maroussi, namely 55.9%. Obviously, IRAKLIS should be very careful on their guarding.

xi. "*Korfas shoots most of the 3p shots of Maroussi, i.e. 32.5%.*

xii. "*The most successful shooters of Maroussi in 2p shots arise if Karaplis (who succeeded in his two 2p attempts) and Korfas (with only two successful - out of three - 2p shots) are ignored. Five players shoot with a percentage of more than or around 50%*".

SA informed the coach that four players, namely Amaya, Panagiotarakos, Papachronis and Turner, made 2p shots with at least a 50% accuracy percentage and tried more than 79.4% of the total 2p attempts of their team! Consequently, IRAKLIS' defense on them and especially on their 2p shots should have been more effective!

xiii. "*The three Maroussi players that present a very good 3p shots percentage (namely Falekas, Pandeliadis and Karaplis) attempt only 18.2% of the total 3p shots. All the other players that shoot for 3p have a much worse accuracy percentage*".

As the 3p shots would not have been a threat for IRAKLIS, SA suggested that it would have been preferable to "allow" this kind of shots, instead of 2p ones, in which Maroussi players proved to be far more efficient.

xiv. "*Examining two penetration indexes*[6]*, it comes out that mainly Panteliadis and Falekas, as well as Korfas and Karaplis, attempt a lot of drives during a game*".

Once again, the coach had to exploit the SA remarks xi and xiv by himself.

Considering another interesting index, namely the percentage of 2p shots that a team attempts,

[6] SA determined those indexes especially for this statistical analysis

$$P2p_t = \frac{2pA_t}{2pA_t + 3pA_t} \quad (8)$$

and the real data of Maroussi (obtained from Table 3), it came out that the value of this index for Maroussi was equal to 74.2%. Considering this, SA noticed that "*Maroussi prefers to attempt mostly 2p instead of 3p shots*".

Then, SA used the statistical data of the first six games of Maroussi players in the Greek championship of 1999-2000, reduced in an integrated time unit, i.e. the 40 min of a basketball game (Table 6), in an attempt to discover which of the players, while in court, could be a threat to IRAKLIS. Based on this analysis SA pointed out the following:

- *"Turner and Amaya win a lot of fouls during a game*".
- "*Apart from other statistical categories, the two foreign players are also Maroussi's best when considering defensive rebounds. In this category, Karaplis and Zourbenko are also important players*".
- "*As regards the offensive rebounds, only Amaya has notable contribution"*.

Consequently, SA mentioned that Amaya should be blocked out efficiently.

- "*Pandeliadis and Falekas are bound to make turnovers when under pressure. However, from all the players who take part in games (see Table 3), it is Turner and Panagiotarakos who make most of them*".
- "*Despite their large number of turnovers, Pandeliadis and Falekas still maintain a strong presence in "stealing" a lot of balls from their opponents*.
- "*Korfas and Falekas stand out when it comes to assists*".
- "*Finally, despite his limited playing time Zourbenko blocks a lot of his opponents' shots*".

Note that the highlighted players of Table 6 were not taken into account due to their limited

playing time.

Table 6 about here

3.4. Fourth part

The last part of the statistical analysis usually focused on the performance and the statistical data of the players of IRAKLIS' forthcoming opponent during the previous championship, no matter which team they played for. Three limitations of this approach were the following:

- The number of players examined in this part of the analysis was often restricted by the fact that many of the current (at the time) players of IRAKLIS' forthcoming opponent, especially the foreign ones, did not play for a Greek team the year before. Consequently no statistical data were available for them.
- The performance of players may differ when they have different teammates; the case of players who perform better or worse with specific teammates is usual in sports.
- The performance of players can vary between consecutive seasons. For example, players may suffer injuries or other kind of personal problems during a season that may have a detrimental effect on their performance.

In any case, the information collected was very helpful to IRAKLIS' coach.

Based on a simple initial table (see Table 7 in our case) and an interesting statistical category, a particularly useful final table (such as Table 8) was created. Apart from each player's percentage distribution regarding the various shooting spots, Table 8 presents the players' 2p and 3p percentages during the previous championship.

Table 7 about here

Table 8 about here

Ignoring the highlighted players of Table 7 (due to the limited number of shots they have tried), the following conclusions arose, regarding the preferred shooting spots of Maroussi players:

- "*As far as 2p shots are concerned, almost all players of Maroussi prefer the centre, i.e. the area around the free throw lane*".
- "*Only Turner does not seem to prefer a specific side of the court, either for 2p or 3p shots*".

This unpredictable playing style made him extremely dangerous.

- "*Regarding 3p shots, Korfas, who is the most important shooter of Maroussi, obviously prefers the left side of the court."*

SA mentioned that the fact that his 3p percentage was high made him an extremely dangerous offensive player.

- "*Manolopoulos and Panagiotarakos prefer to attempt 3p shots from the right side of the court, while Pandeliadis prefers the centre of the court*".

4. Assessment of the statistical report through regression analysis

The statistical analysis presented previously could be (much) more advanced in several points, if the unfamiliar with statistics "recipients" were convinced about their usefulness and the ability of quantitative methods and OR to improve the decision-making process. For instance, an indicative direction of the statistical analysis addressed to the coaching staff of IRAKLIS could be the determination of factors that affect significantly or not, positively or negatively the performance of a team or a player, based on properly designed regression

equations. According to the significance of those factors, the team's coach could identify the statistical categories that he should concentrate on during a game.

To this end, using data in several statistical categories (namely PTS, 1pM, 1pA, 1p%, 2pM, 2pA, 2p%, 3pM, 3pA, 3p%, OREB, DREB, TO, AS, ST, BL, EF) both for IRAKLIS and his opponents, and considering the total number of games of the 1999-2000 season (26 games), we arrive at the following multiple regression equation. In this model, the dependent variable Y expresses the difference between the total points scored and allowed by IRAKLIS at the final score of each one of the 26 games of the 1999-2000 championship:

$$\begin{aligned} y = & -3.353 + 65.44 \cdot 2p\%_t - 0.355 \cdot 3pA_t + 66.78 \cdot 3p\%_t - 1.71 \cdot TO_t + 0.59 \cdot DREB_t + 0.93 \cdot OREB_t \\ & - 0.22 \cdot 1pA_o - 96.8 \cdot 2p\%_o - 24.23 \cdot 3p\%_o + 1.7 \cdot TO_o - 0.62 \cdot OREB_o \end{aligned} \quad (9)$$

Table 9 about here

It should be noted here that in order to select the predictive variables of (9) we use the stepwise regression method, as well as one of the most common software for analyzing statistical data, i.e. MINITAB 16. The regression model in (9) explains 96.09% of the sum of squares and reveals the 11 statistical categories that contribute significantly to the prediction of the dependent variable Y, i.e. of the outcome of a basketball game of IRAKLIS, expressed by the difference between IRAKLIS' and his opponent's scoring. However, considering their p-values (Table 9) we can notice that four of them, namely the highlighted $3pA_t$, $DREB_t$, $1pA_o$ and $OREB_o$, do not make a significant contribution to the regression model at the $\alpha = 0.05$ level of significance. In other words, the fact that $p \geq 0.05$ for all these variables means that they may only be "accidentally" significant.

Adding as a potential predictor the ordinal variable HE, which takes the value 1 for every home game of IRAKLIS and the value 2 for every away game, we arrive at a slightly different regression model:

$$y = -6.579 - 6.9\,HE + 90.7 \cdot 2p\%_t + 54.7 \cdot 3p\%_t - 1.32 \cdot TO_t + 0.35 \cdot DREB_t + 0.86 \cdot OREB_t \\ -92 \cdot 2p\%_o - 32.6 \cdot 3p\%_o + 1.7 \cdot TO_o - 1.08 \cdot OREB_o \quad (10)$$

Table 10 about here

where 97.55% of the sum of squares is explained by the regression model. Here, considering the p-values of all predictors (Table 10) we can notice that only $DREB_t$ does not contribute significantly to the specific regression model, at the α = 0.05 level of significance.

Considering this model as more appropriate, we could represent its residuals (predicted minus observed values) versus fits in order to determine the randomness of the residuals, i.e. if they consist background noise. Normally, the residuals should be distributed randomly across the diagram, while any obvious patterns could indicate model inadequacy. In Figure 3, we cannot see any patterns apart from some extreme values; therefore, we can consider that the specific model is adequate for any further use.

Figure 3 about here

Getting back to model (9) and going one step further, we can consider that in practice it usually turns out that a predictor whose estimated coefficient has a p-value greater than α = 0.05 can be dropped from the model without affecting the error measures to a great extent. Consequently, continuing our previous remark we figure out that $3pA_t$, $DREB_t$, $OREB_o$ and $1pA_o$, could be in turn omitted from the regression model. The exclusion of each of these predictors leads to the same number of regression models, which explain 95.1%, 94.9%, 94.8% and 94.8% of the sum of squares, respectively. Moreover, by dropping all four parameters at the same time, the regression model is simplified as follows:

$$y = 10.79 + 67.28 \cdot 2p\%_t + 69.08 \cdot 3p\%_t - 1.43 \cdot TO_t + 0.993 \cdot OREB_t \\ -130.44 \cdot 2p\%_o - 30.16 \cdot 3p\%_o + 1.43 \cdot TO_o \quad (11)$$

Table 11 about here

This model explains 89.7% of the sum of squares and all its predictors contribute significantly to the prediction of the dependent variable Y (Table 11).

Based on the last model, we find out that four statistical categories of IRAKLIS and three of his opponents play the most significant role in the outcome of a game, i.e. the 2p and 3p shots percentage and the turnovers of both IRAKLIS and his opponent, as well as the offensive rebounds of IRAKLIS. Using this finding and, generally, the analysis of this Section we can easily "assess" various parts of the statistical report presented in Section 3. We can see that the significance of the 3p shots percentage of IRAKLIS had been pointed out by the SA with great emphasis (point iii). Moreover, SA had made indirect comments about the importance of IRAKLIS' turnovers (point v), as well as 1p attempts (point iv) and rebounds (point v) whose significance was identified in model (9). On the contrary, he had not made relevant comments for the other statistical categories whose significance is proved by the regression model (9). However, this can be attributed to various reasons such as the fact that the presented report had been based on only six games, while the derivation of (9) and (11) uses information from 26 games.

5. Some additional ideas of statistical analysis

Having the necessary game data, the suggested quantitative methods and statistical analysis addressed to the coaching staff of a team could be more sophisticated and helpful, in various other directions. In what follows we present some additional ones. First, the analysis could include *comparisons of statistical data* and, consequently, of *performance*, in several interesting statistical categories, between

- the team under study (TUS) - e.g. IRAKLIS - against another interesting team (e.g. the

best in the championship) or the forthcoming opponent of TUS, to identify points of supremacy or weakness of the former.

- a TUS player against
  - another TUS player (in statistical categories that this comparison is meaningful),
  - the best in a statistical category (e.g. the best in assists ranking),
  - the respective player of the forthcoming opponent of TUS (e.g. comparison of the two play-makers),
  - a player of special interest (e.g. the predecessor of TUS player),
- any interesting TUS pentad[7] against
  - another TUS pentad[7],
  - the best pentad[7] in a statistical category (e.g. offensive rebounds),
  - the pentad[7] of the forthcoming opponent of TUS that has the larger playing time,
  - a pentad[7] of special interest (e.g. the previous year's pentad of TUS),

Note that the mean values used for the aforementioned comparisons could also be used for conducting *Hypotheses testing* for the majority of those cases, in order to find out significant (or not) differences among players, teams, etc. Moreover, the above analysis could focus on a part of the statistical data and be differentiated according to various criteria (individually or in combination) like

- the home or away games,
- the period of game (e.g. using statistical data only for the 1st or 2nd, etc. period, or for the 1st or 2nd half of the game),
- the result of the game, i.e. using statistical data of the wins or the losses,
- the round of the championship, i.e. using data of the first round (or the beginning of

[7] or twosome/threesome

the season) or of the second round (or the end of the season),

- the domestic or European competitions,
- the strength of teams (adopting for example three strength levels, i.e. large, medium, small), etc.

Another interesting field of OR quantitative techniques could include the *formulation*, the *calculation* and the *exploitation for comparisons of complicated indexes*, and, mainly, *the monitoring* of their *values* in time. For instance, Kubatko et al. (2007) present some very interesting indexes such as i) an estimation of possessions for team t, i.e. $POSS_t$

$$\begin{aligned} POSS_t &= 2pM_t + 3pM_t + \lambda \cdot 1pM_t \\ &+ \alpha\left[(2pA_t - 2pM_t) + (3pA_t - 3pM_t) + \lambda \cdot (1pA_t - 1pM_t) - OREB_t\right] \\ &+ (1-\alpha)DREB_o + TO_t \end{aligned} \qquad (12)$$ [8]

ii) the points scored (PTS_t) and allowed (PTS_o) per 100 possessions, which are called offensive rating (OR_t) and defensive rating (DR_t), respectively, for team t

$$OR_t = \frac{PTS_t}{POSS_t} \cdot 100 \qquad (13)$$

$$DR_t = \frac{PTS_o}{POSS_o} \cdot 100 \qquad (14)$$

and iii) the rebound rate or rebound percentage for player x, i.e. $REB\%_x$

$$REB\%_x = \frac{\dfrac{REB_x}{REB_t + REB_o}}{\dfrac{MIN_x}{MIN_t}} \cdot 100 . \qquad (15)$$

Furthermore, on www.nba.com/statistics/efficiency.html the efficiency statistic for player x, i.e., EFF_x, is determined as

[8] Strong disagreement has been expressed regarding this formula of Kubatko et al (2007), which is an estimated measure of possessions arising through regression that is probably mis-specified. Considering the way they define a possession, an offensive rebound does not start a new possession, but a new play. However, in this equation possessions are defined in terms of missed shots, i.e. $2pA_t$ and $3pA_t$, missed free throws, i.e. $1pA_t$, and consequently in terms of offensive rebounds.

$$\begin{aligned} EFF_x &= PTS_x + REB_x + AST_x + STL_x + BLK_x \\ &\quad - \left[TO_x + \left(2pA_x - 2pM_x\right) + \left(3pA_x - 3pM_x\right) + \left(1pA_x - 1pM_x\right)\right]. \end{aligned} \tag{16}$$

This index allows NBA coaches to evaluate a player's game performance. However, Berri (2008) has come out in opposition of traditional linear weights-style NBA evaluation statistics like this one, claiming that they overvalue scoring and undervalue shooting efficiency.

The regression analysis which has been presented in Section 4 can encompass many more issues, such as the formulation of a “better” or a dynamically adaptive regression model, the determination of potential uses of the model, etc. Despite the belief of many researchers, who claim that “wins are simply determined by points scored and surrendered per possession in basketball”, regression analysis can actually give fruitful insights regarding the decision-making process in basketball. Obviously, a “master key” regression model, which would be optimal for any basketball team, of any country and any period of time, cannot be developed. Considering the dynamic nature of sports, any regression model should be determined per case and should be updated continually in order to be useful for decision-making purposes.

6. Concluding remarks

What we present in this paper is an indicative part of a statistical analysis that the author conducted on a weekly basis, a few years ago, to support a Greek basketball team, namely IRAKLIS, and, more specifically, the decision-making process of its coach at the time, Dragan Sakota. The analysis, though statistically simple, was impressive and helpful to the coaching staff of IRAKLIS. The impression of SA was that this analysis could not be more complicated at that moment, because the exploitation of the statistical analysis procedure should be

progressive so that everyone would have the necessary time to assimilate the whole process and understand the value of statistics and OR.

Undoubtedly, the future research can be more than wide as basketball statistics are at their infancy. In Sections 3 and 4 we refer to a few ideas. However, another interesting direction could be the on line, i.e. during the game, update of a team's or player's data and evaluation, using various statistical techniques - for example, the Bayes' theorem - in order to optimize the crucial decisions a coach needs to take during a game.

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Table 1: Basic statistical categories of IRAKLIS during the first six games of the Greek championship of 1999-2000

Game vs	Home/Away game	Points	Free throws			2p shots			3p shots			Earned fouls	Rebounds				Turnovers	Assists	Steals	Blocks
			made	attempts	%	made	attempts	%	made	attempts	%		Def.	Off.	Total	Opponent				
Aris	Home	**81**	19	28	67.9	22	41	53.7	6	13	**46.2**	22	30	11	41	33	15	13	5	12
Near East	Away	56	6	10	60.0	19	43	44.2	4	19	21.1	17	20	13	33	43	15	11	11	3
Peristeri	Home	**75**	18	28	64.3	15	35	42.9	9	19	**47.4**	26	18	16	34	31	10	11	7	1
AEK	Away	60	7	10	70.0	22	45	48.9	3	13	23.1	17	20	9	29	35	11	14	4	4
Panionios	Home	63	15	19	78.9	15	33	45.5	6	20	30.0	19	28	8	36	35	12	7	3	1
Dafni	Away	**81**	14	**19**	73.7	20	35	57.1	9	20	**45.0**	23	29	8	37	28	16	14	11	1
Total		**416**	**79**	**114**	**69.3**	**113**	**232**	**48.7**	**37**	**104**	**35.6**	**124**	**145**	**65**	**210**	**205**	**79**	**70**	**41**	**22**
Averages		**69.33**	**13.17**	**19**		**18.83**	**38.67**		**6.17**	**17.33**		**20.67**	**24.17**	**10.83**	**35**	**34.17**	**13.17**	**11.67**	**6.83**	**3.67**

Note: the colours in the 1st column represent the result of the specific game according to the colours of the score sheet given to winning and losing team respectively: for example IRAKLIS has won the game versus Aris and has lost the game versus Near East, etc.

Table 2: Basic statistics describing the performance of IRAKLIS' opponents during the first six games of the Greek championship of 1999-2000

Game vs	Power of opponent	Points	Free throws			2p shots			3p shots			Earned fouls	Rebounds				Turnovers	Assists	Steals	Blocks
			made	attempts	%	made	attempts	%	made	attempts	%		Def.	Off.	Total	IRAKLIS				
Aris	Medium	69	11	18	61.1	23	47	48.9	4	12	33.3	17	22	11	33	41	12	10	8	2
Near East	Small	67	17	28	60.7	22	38	57.9	2	14	14.3	21	28	15	43	33	19	11	3	3
Peristeri	Medium	72	24	38	63.2	18	33	54.5	4	11	36.4	25	20	11	31	34	11	10	6	3
AEK	Large	68	22	31	71.0	17	38	44.7	4	11	36.4	24	24	11	35	29	12	10	5	7
Panionios	Medium	67	10	15	66.7	21	49	42.9	5	12	41.7	18	25	10	35	36	9	15	7	1
Dafni	Small	59	10	14	71.4	20	43	46.5	3	16	18.8	19	19	9	28	37	17	10	5	3
Total		**402**	**94**	**144**	**65.3**	**121**	**248**	**48.8**	**22**	**76**	**28.9**	**124**	**138**	**67**	**205**	**210**	**80**	**66**	**34**	**19**
Averages		**67**	**15.67**	**24**		**20.17**	**41.33**		**3.67**	**12.67**		**20.67**	**23**	**11.17**	**34.17**	**35.00**	**13.33**	**11.00**	**5.67**	**3.17**

Table 3: Box score of the first six games of Maroussi in the Greek championship of 1999-2000

	Minutes of participation	Points	Free throws		2p shots		3p shots		Earned fouls	Rebounds		Turnovers	Assists	Steals	Blocks	
			made	attempts	made	attempts	made	attempts		Def.	Off.				For	Against
Falekas	40	12	4	4	1	2	2	3	2	0	0	4	4	3	0	1
Pandeliadis	77	23	8	13	3	15	3	5	8	4	2	9	3	4	0	1
Manolopoulos	70	16	2	2	1	3	4	12	3	1	1	2	2	0	0	0
Karaplis	51	17	4	5	2	2	3	6	3	8	1	2	1	2	0	0
Zourbenko	56	19	7	8	6	12	0	1	5	8	3	2	0	1	8	1
Panagiotarakos	128	38	3	4	13	23	3	12	4	10	2	10	5	5	1	2
Korfas	157	47	16	19	2	3	9	25	17	5	2	9	22	0	0	1
Papachronis	115	29	1	2	14	29	0	0	5	11	4	8	6	3	1	0
Turner	211	88	24	38	32	65	0	6	39	38	10	17	16	6	4	2
Amaya	214	102	22	37	37	59	2	6	36	35	30	15	8	4	3	1
Charalampidis	20	4	0	0	2	5	0	0	0	4	1	2	2	0	0	0
Logothetis	33	1	1	2	0	1	0	0	1	2	1	1	0	1	0	0
Anagnostou	28	9	3	6	3	3	0	1	3	3	1	3	1	3	0	1
										6[1]	5[1]					
TOTAL	1200	405	95	140	116	222	26	77	126	135	63	84	70	32	17	10

[1] Team rebounds

Table 4: Notation used in various formulas

Part A - For player x	ATG_x	average playing time per game for player x
	GM_x	games played for player x
	MIN_x	minutes played for player x and
	$1pA_x$	player's x free throw attempts
	$2pA_x$	player's x two-point attempts
	$2pM_x$	two-point shots made for player x
	$3pA_x$	player's x three-point attempts
	$3pM_x$	three-point shots made for player x
	$P2p_x$	percentage of two-point shots that player x attempts
	$P3p_x$	percentage of three-point shots that player x attempts
	$2p\%_x$	player's x two-point percentage
	$3p\%_x$	player's x three-point percentage
	PI_{1x}	player's x 1st penetration index
	PI_{2x}	player's x 2nd penetration index
	REB_x	rebounds for player x

Part B - For team t and the opponent team o	λ	the fraction of free throws that end possessions*
	α	a parameter, $0 \leq \alpha \leq 1$**
	MIN_t - MIN_o	minutes played
	$1pA_t$ - $1pA_o$	free throw attempts
	$1pM_t$ - $1pM_o$	free throw made
	$1p\%_t$ - $1p\%_o$	free throw percentage
	$2pA_t$ - $2pA_o$	two-point attempts
	$2pM_t$ - $2pM_o$	two-point shots made
	$2p\%_t$ - $2p\%_o$	two-point shots percentage
	$3pA_t$ - $3pA_o$	three-point attempts
	$3pM_t$ - $3pM_o$	three-point shots made
	$3p\%_t$ - $3p\%_o$	three-point shots percentage
	REB_t - REB_o	rebounds
	$OREB_t$ - $OREB_o$	offensive rebounds
	$DREB_t$ -$DREB_o$	defensive rebounds
	TO_t - TO_o	turnovers
	AS_t - AS_o	assists
	ST_t - ST_o	steals
	BL_t - BL_o	blocks (for)
	EF_t - EF_o	earned fouls
	PTS_t - PTS_o	points scored (allowed from the other team)

* Often $\lambda = 0.44$ (Kubatko et al., 2007)

** Often $\alpha = 1$ (Kubatko et al., 2007)

Table 5: Special statistical indexes for the players of Maroussi based on the data of the first six games in the Greek championship of 1999-2000

	GM_x	ATG_x	$2p\%_x$	$3p\%_x$	$P2p_x$	$P3p_x$	1st penetration index - PI_{1x}	2nd penetration index - PI_{2x}
Falekas	3	13.3	0.9 %	3.9 %	50.0 %	66.7 %	0.8	0.6
Pandeliadis	6	12.8	6.8 %	6.5 %	20.0 %	60.0 %	0.4	0.6
Manolopoulos	6	11.7	1.4 %	15.6 %	33.3 %	33.3 %	6.0	0.9
Karaplis	6	8.5	0.9 %	7.8 %	100.0 %	50.0 %	1.2	0.6
Zourbenko	4	14.0	5.4 %	1.3 %	50.0 %	0.0 %	0.1	0.6
Panagiotarakos	6	21.3	10.4 %	15.6 %	56.5 %	25.0 %	3.0	0.9
Korfas	6	26.2	1.4 %	32.5 %	66.7 %	36.0 %	1.3	0.6
Papachronis	6	19.2	13.1 %	-	48.3 %	-	0.0	0.9
Turner	6	35.2	29.3 %	7.8 %	49.2 %	0.0 %	0.2	0.7
Amaya	6	35.7	26.6 %	7.8 %	62.7 %	33.3 %	0.2	0.6
Charalampidis	3	6.7	2.3 %	-	40.0 %	-	-	1.0
Logothetis	5	6.6	0.5 %	-	0.0 %	-	0.0	0.3
Anagnostou	2	14.0	1.4 %	1.3 %	100.0 %	0.0 %	0.2	0.4

Note: the yellow highlighted cells represent the group of the best players of every statistical index, the blue highlighted cells represent the next level group, while in grey highlight we see the players with limited playing time, whose analysis should be taken into consideration with caution

Table 6: Statistical data of Maroussi players reduced in 40 min, based on the box score of Table 3

	Points	Free throws		2p shots		3p shots		Fouls won	Rebounds		Turnovers	Assists	Steals	Blocks	
		made	attempts	made	attempts	made	attempts		Def.	Off.				For	Against
Falekas	12.0	4.0	4.0	1.0	2.0	2.0	3.0	2.0	0.0	0.0	4.0	4.0	3.0	0.0	1.0
Pandeliadis	11.9	4.2	6.8	1.6	7.8	1.6	2.6	4.2	2.1	1.0	4.7	1.6	2.1	0.0	0.5
Manolopoulos	9.1	1.1	1.1	0.6	1.7	2.3	6.9	1.7	0.6	0.6	1.1	1.1	0.0	0.0	0.0
Karaplis	13.3	3.1	3.9	1.6	1.6	2.4	4.7	2.4	6.3	0.8	1.6	0.8	1.6	0.0	0.0
Zourbenko	13.6	5.0	5.7	4.3	8.6	0.0	0.7	3.6	5.7	2.1	1.4	0.0	0.7	5.7	0.7
Panagiotarakos	11.9	0.9	1.3	4.1	7.2	0.9	3.8	1.3	3.1	0.6	3.1	1.6	1.6	0.3	0.6
Korfas	12.0	4.1	4.8	0.5	0.8	2.3	6.4	4.3	1.3	0.5	2.3	5.6	0.0	0.0	0.3
Papachronis	10.1	0.3	0.7	4.9	10.1	0.0	0.0	1.7	3.8	1.4	2.8	2.1	1.0	0.3	0.0
Turner	16.7	4.5	7.2	6.1	12.3	0.0	1.1	7.4	7.2	1.9	3.2	3.0	1.1	0.8	0.4
Amaya	19.1	4.1	6.9	6.9	11.0	0.4	1.1	6.7	6.5	5.6	2.8	1.5	0.7	0.6	0.2
Charalampidis	8.0	0.0	0.0	4.0	10.0	0.0	0.0	0.0	8.0	2.0	4.0	4.0	0.0	0.0	0.0
Logothetis	1.2	1.2	2.4	0.0	1.2	0.0	0.0	1.2	2.4	1.2	1.2	0.0	1.2	0.0	0.0
Anagnostou	12.9	4.3	8.6	4.3	4.3	0.0	1.4	4.3	4.3	1.4	4.3	1.4	4.3	0.0	1.4

Table 7: Preferred shooting spots of Maroussi players, during the Greek championship of 1998-1999

		Left side	Centre	Right side	Total
2p shots	Falekas	2	2	3	7
	Pandeliadis	1	20	1	22
	Manolopoulos	1	3	1	5
	Panagiotarakos	7	11	3	21
	Korfas	6	21	6	33
	Papachronis	8	52	14	74
	Charalampidis	2	3	3	8
	Logothetis	1	2	1	4
	Turner	39	38	38	115
3p shots	Falekas	0	1	3	4
	Pandeliadis	17	20	6	43
	Manolopoulos	12	5	17	34
	Panagiotarakos	13	5	30	48
	Korfas	52	39	24	115
	Logothetis	1	2	2	5
	Turner	19	13	17	49

Table 8: Percentage distribution of the preferred shooting spots of Maroussi players, as well as their 2p and 3p percentages, during the Greek championship of 1998-1999

		Left side	Centre	Right side
2p shots	Pandeliadis	4.5%	90.9%	4.5%
	2p %	100.0%	15.0%	0.0%
	Panagiotarakos	33.3%	52.4%	14.3%
	2p %	28.6%	18.2%	0.0%
	Korfas	18.2%	63.6%	18.2%
	2p %	33.3%	38.1%	16.7%
	Papachronis	10.8%	70.3%	18.9%
	2p %	62.5%	28.8%	57.1%
	Turner	33.9%	33.0%	33.0%
	2p %	33.3%	31.6%	44.7%
3p shots	Pandeliadis	39.5%	46.5%	14.0%
	3p %	47.1%	30.0%	50.0%
	Manolopoulos	35.3%	14.7%	50.0%
	3p %	25.0%	0.0%	41.2%
	Panagiotarakos	27.1%	10.4%	62.5%
	3p %	0.0%	60.0%	16.7%
	Korfas	45.2%	33.9%	20.9%
	3p %	46.2%	38.5%	50.0%
	Turner	38.8%	26.5%	34.7%
	3p %	31.6%	15.4%	17.6%

Note: every yellow highlighted cell represents the most preferable shooting spots for each player (if there is one), while every blue highlighted cell represents the next most preferable shooting spots

Table 9: P-values of regression model (9)

Predictor	P-value
Constant (-3,353)	0.861
$2p\%_t$	0.000
$3pA_t$	0.078
$3p\%_t$	0.000
TO_t	0.000
$DREB_t$	0.057
$OREB_t$	0.000
$1pA_o$	0.051
$2p\%_o$	0.000
$3p\%_o$	0.016
TO_o	0.000
$OREB_o$	0.053

Table 10: P-values of regression model (10)

Predictor	P-value
Constant (-6,579)	0,633
HE	0,000
$2p\%_t$	0,000
$3p\%_t$	0,000
TO_t	0,000
$DREB_t$	0,148
$OREB_t$	0,000
$2p\%_o$	0,000
$3p\%_o$	0,000
TO_o	0,000
$OREB_o$	0,000

Table 11: P-values of regression model (11)

Predictor	P-value
Constant (10,79)	0,385
$2p\%_t$	0,000
$3p\%_t$	0,000
TO_t	0,001
$OREB_t$	0,001
$2p\%_o$	0,000
$3p\%_o$	0,005
TO_o	0,007

Figure 1: Rebounds, turnovers and assists of IRAKLIS during the first six games of the championship

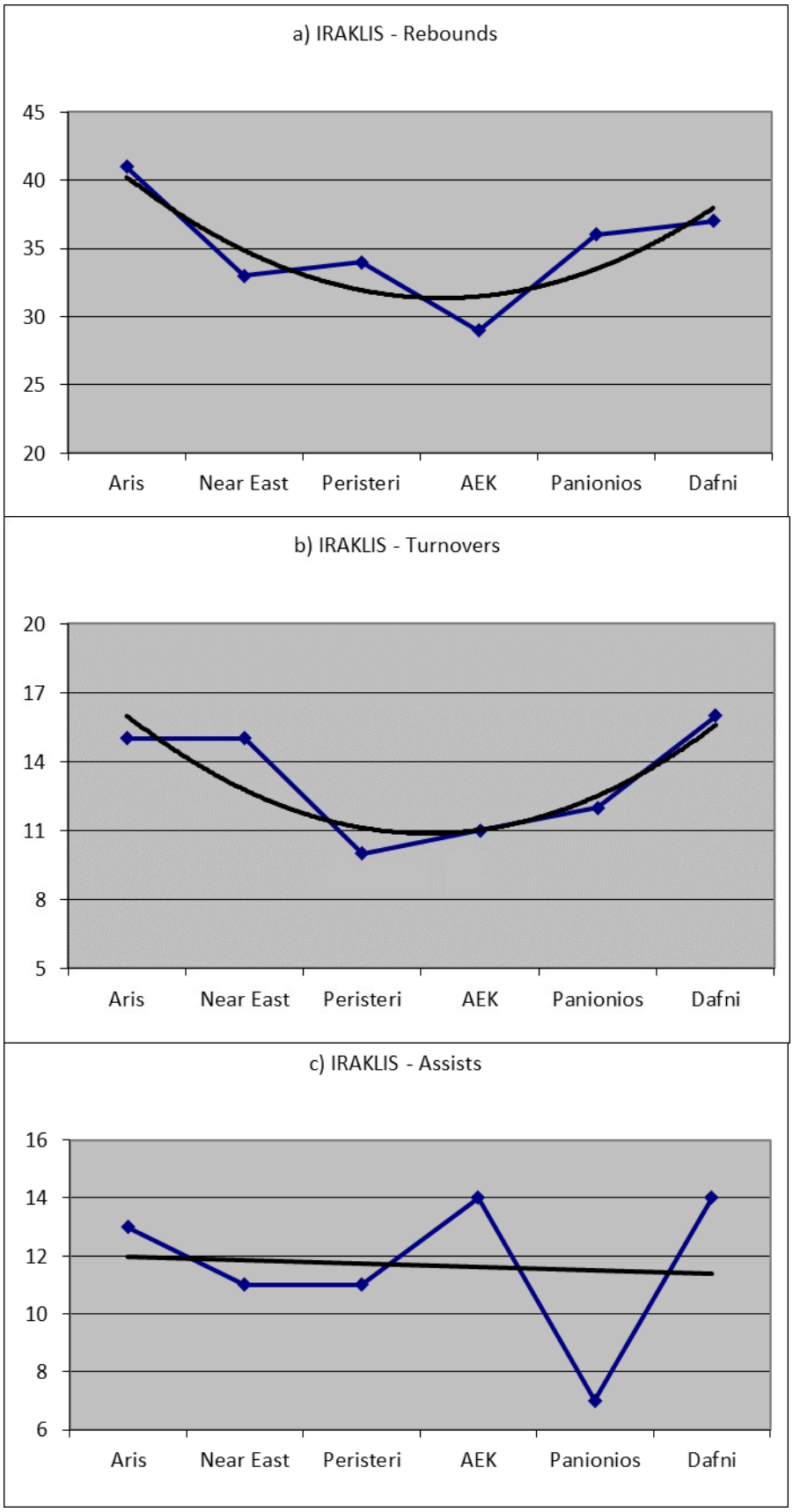

Figure 2: Defense, rebounds and assists of IRAKLIS' opponents during the first six games of the championship

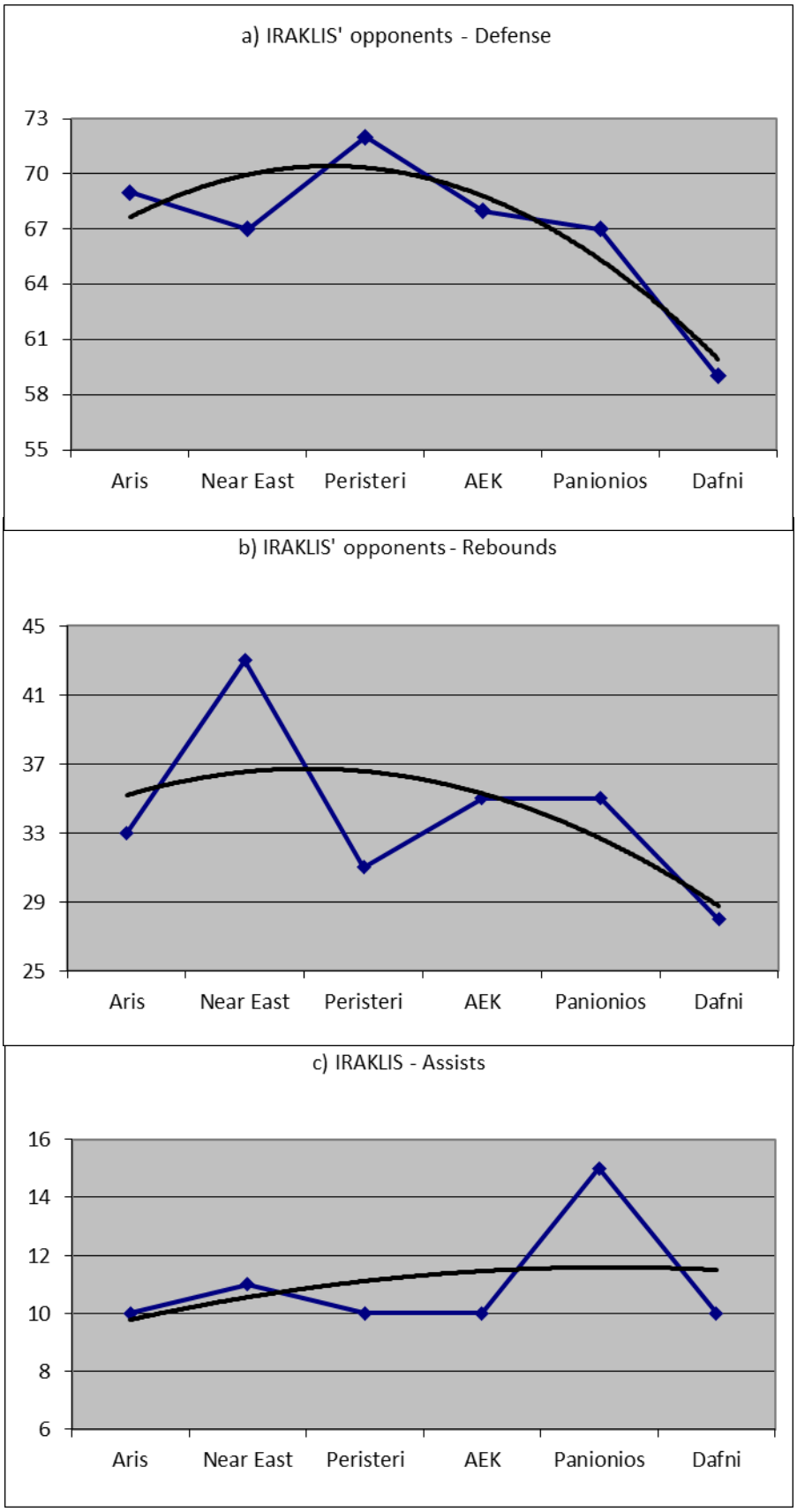

Figure 3: Residuals versus fitted values of the regression model (10)