EFFICIENCY OF HOCKEY TEAMS IN NHL

by

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Abstract: In this paper efficiency analysis is extended to team sports, more precisely to ice hockey North American in National Hockey League. Data of player compensation, league points, and playoffs results for the season 1996 - 1997 is analyzed using data envelopment analysis. Teams are assumed to be decision making units that maximize league points, constrained by funds available. As a result we obtain efficiency scores for each team that indicate efficiency of the team relative to other teams in NHL. Efficiency scores reveal how many league points and won playoff-games each team could have achieved by reasonable team composition, good coaching and correct tactical decisions. Furthermore, indirect information on relative contribution of forward, defence, and goalkeeping is revealed from weights assigned for these variables in multiplier formulation. All this information could be useful when managers build teams for the next season. Methodology formulated in this study is also applicable to any other professional team sports.

Key Words: *efficiency, DEA, sports, ice hockey, NHL*

1. INTRODUCTION

Professional sports have become nowadays a major scale economic activity. Ice hockey - "the coolest game on earth" - is one of the most popular and fastest growing major leagues in the North America. This is reflected also to the earnings of the players. The total salaries of National Hockey League (NHL) players were huge 661 million US dollars in season 1996 - 1997. Mario Lemieaux, the most valuable player in NHL, made over 11 million US dollars during season 1996 - 1997 alone, excluding sponsor contracts and bonuses.

It is not exaggerated to say that today success in professional sports league goes hand in hand with successful coaching and team management. In the real world, management of a team or a business enterprise always requires evaluation of own performance in the past as well as monitoring competitors' actions. It is often vital condition to learn from own mistakes and from rivals' innovations. However, evaluation of performance is not a trivially easy task. Typically the success shows on several success measures and depends on several factors. In these type of cases, data envelopment analysis (DEA)[1] method for efficiency analysis has provided valuable information for managers in the business as well as in the public sector.

[1] See Charnes, Cooper, and Rhodes (1978), and Banker, Charnes, and Cooper (1984)

Team sports offer fertile ground for applying DEA method: Firstly, DEA is generally very sensitive to differences in production environment. Frequently, the target units are differentiated to extent that no meaningful comparable units can be found. In sports, there are dozens of competing teams facing the same rules in the same ”battlefield”. Secondly, reliable, accurate data is often unavailable for small private enterprises or even for public institutions. On contrary, huge collections of reliable, accurate statistics are freely available on sports. Thirdly, due to current movement towards sharing responsibility to lower levels of organisation it often difficult to find a real decision maker that is actually in charge of the whole process. However, sports teams are usually coached with strong authority leadership.

Despite these simplifying characteristics, sports are complex and fascinating topic worth to examine. In last decades professionalization of sports leagues has inspired also economists and management scientists to apply their methods to team sports. Pioneer on economics of sports was Scully (1974) with his influential article *”Pay and performance in major league basketball”*. Since then economic analysis has been applied several times on team sports, mostly baseball (Porter and Scully 1982, Kahn 1993, and Mazur 1994 among others), but also on ice hockey (for example Jones and Walsh, 1987, and Jones and Ferguson, 1987), basketball (Zak, Huang, and Siegfried 1979), cricket (Schofield, 1988), and rugby (Carmichael and Thomas, 1995).

The purpose of this paper is to present a simple way to evaluate team performance in professional sports using DEA. In the application section the focus is in ice hockey, but the same framework is also applicable to any other professional team sport. DEA efficiency scores are used to provide valuable information for team management. It is important to know how far team can go with existing player contracts, and what new investments to players are needed, when building the team for the next season. It is also important to know if new trades should be negotiated for forwards, defencemen, or goalkeepers.

In the next section we present the theoretical basis for this paper starting generally of production functions in team sports, including choice of input and output variables. In Section three we give a short description together with a formal definition of DEA method. However, those who are not familiar with basics of production theory, concept of efficiency, or DEA method, but want to understand the theme thoroughly, should first consult a textbook such as

Fried, Lovell, and Schmidt (1993), or Charness, Cooper, Lewin, and Seiford (1994). Section four gets deeper into this particular case: We briefly present the league system including playoffs, and describe the data. In section five the results of three different models (simple productivity model, three input regular season DEA model, and three input playoffs DEA model) are reported, and interpreted. Finally section six gives the conclusive remarks.

2. THEORETICAL BASIS

2.1 Production Function

The most popular topic in the economic literature on team sports seems to be functionalization of "production" in sports. If we can find a meaningful functional relationship between inputs and outputs in sports, we are able to measure efficiency of players, coaches, or teams relative to that "production function". This section discusses issues related to choice of input and output variables and functional relationship between them.

The first step in search for the production function is to find meaningful input and output variables. Naturally, choice should be guided by what kind of information we are looking for. In this paper we want to find out which teams were coached efficiently, or in other words, which teams won large numbers of games relative to their player resources. Success in team sports is conventionally measured by league points, so natural choice for output measure is league points. Usually points are achieved by wins: In NHL, each team gets two points of a win, one point of a draw, and no points of a loss during the regular season. Still, most studies following Scully (1974) have measured success by percentage of games won, giving no credit for drawn games, even though a draw is a substantially better result than a loss.

In most professional leagues winning the championship does not require winning the regular season, but knocking all the opponents out in playoffs. Carmichael and Thomas (1995) argue for the use of winning percentage that calculation of an overall league point achievement would require the imputation of points for playoffs or "knock-out" games, in which points are not given and ties are not possible. However, regular season and playoff games are different in their nature, and summing up results of both games together may not be fair. Consider teams that struggle for entering playoffs. Usually the last team qualifying to playoffs meets the winner of the regular season in the first round. It is well possible that team entering the playoffs, but dropping out against the regular season winner, gets smaller winning percentage than a team that was not qualified to playoffs at all. This actually happens in this application: If we use winning percentages, three teams not qualified to playoffs (Washington, Hartford, and Tampa Bay) receive higher winning percentage than Ottawa or Montreal who made it to playoffs, but dropped out in the first round (see table 5.2). This is why we suggest distinguishing between the playoffs and the regular season games.

The choice of input variables is also ambiguous. Obviously, the primary inputs in team sports consist of physical and psychic factors such as player skills, talent, fitness, experience, team spirit, etc. Conventionally in the literature, production function in sports is implicitly written as

$$P = P(A_1 , A_2 , ... , A_n , I_1 , I_2 , ... , I_m), \qquad (2.1)$$

where league points (or alternatively winning percentage) P are a function of vector of player skills A_i , and a vector of non-player inputs I_j. Conventional approach has been estimation of this type of production function. The only problem of this approach is the difficulty of numerical measurement of the inputs such as player skills and fitness, let alone players' talent or team spirit. In our opinion this is not a very convincing method.

However, there is another indirect way to measure player inputs. Nowadays the value of each player is evaluated and priced on the market. If the player market is competitive, salaries of players approach to marginal revenue product (MRP), which is defined as product of marginal physical product and marginal revenue. Under effective competition salaries implicitly contain all the information available on players’ potential contribution for a team.

Table 2.1 provides some empirical evidence of salary as an indicator of player’s ability. It presented a correlation matrix of following variables: *salary, games played* (GP), *goals* (G), *assists* (A), *points* (PTS = G + A), *plus/minus* (+/-)[2], *penalty minutes* (PIM), *powerplay goals*

[2] A player is awarded a "plus" when he is on the ice for a goal his team scores, and is awarded a "minus" if he is on the ice when his team is scored upon.

(PP), *short handed goals* (SH), *game-winning goals* (GWG), *game-tying goals* (GTG), *shots*, and *percentage of scoring shots* (PCTG). Correlation coefficients were calculated from population of 832 NHL players on the season 1996 - 1997 (skaters only).

Table 2.1: Correlation Matrix of Individual Player Variables

	SALARY	GP	G	A	PTS	+/-	PIM	PP	SH	GWG	GTG	Shots	PCTG
SALARY	1	0,34	0,56	0,61	0,62	0,23	0,13	0,55	0,29	0,47	0,30	0,61	0,21
GP		1	0,60	0,70	0,69	0,10	0,50	0,47	0,32	0,53	0,27	0,76	0,40
G			1	0,79	0,93	0,20	0,14	0,86	0,50	0,84	0,49	0,88	0,63
A				1	0,96	0,29	0,15	0,72	0,41	0,68	0,36	0,87	0,43
PTS					1	0,27	0,15	0,82	0,47	0,79	0,44	0,92	0,54
+/-						1	-0,02	0,09	0,14	0,23	0,08	0,17	0,08
PIM							1	0,09	0,04	0,11	0,08	0,22	0,11
PP								1	0,35	0,71	0,41	0,80	0,47
SH									1	0,44	0,29	0,46	0,29
GWG										1	0,35	0,75	0,52
GTG											1	0,45	0,26
Shots												1	0,44
PCTG													1

Salaries were highly correlated with such traditional indicators of good performance as *goals, assists, and points.* However, correlation was not perfect: Skill, hard work, fortitude and teamwork are other important virtues that players are paid for. Also a simple variable as *games played* had a strong correlation to *points*. This is natural, since the best players get always lots of ice time. On the other hand, *plus/minus* value, which is surprisingly often proposed as a good measure for individual player's efficiency, had relatively weak correlation with any other variable.

Using player costs as inputs, we can write potential league points P for team k as a function of player costs C

$$P_k = P(C_k)\ , \qquad (2.2)$$
$$P'(C_k) \geq 0$$

which can be decomposed further as

$$P_k = P[C_{Gk}, C_{Dk}, C_{Fk}], \quad (2.3)$$

$$P_{CG}, P_{CD}, P_{CF} \geq 0$$

where C_{Gk} , C_{Dk} , and C_{Fk} denote costs of goalkeepers, defenders, and forwards, and P_{CG}, P_{CD}, and P_{CF} denote first partial derivatives of P with respect to C_{Gk} , C_{Dk} , and C_{Fk}. Production functions 2.2 and 2.3 simply state that league points are an increasing function of players' salaries. Note that by definition production function defines the *efficient* transformation relationship of inputs to outputs. Actual league points P^* for team k can be written as

$$P^*_k = \gamma_k P[C_{Gh}, C_{Dh}, C_{Fh}], \quad (2.4)$$

where γ_k , $0 \leq \gamma_k \leq 1$, is efficiency score for team k. Issues related to estimation of production function (2.4) with real world data are discussed in the next section.

2.2 Sources of Inefficiency

We can find fairly accurate quantitative estimates of inefficiency by methods described in Section 3. However, these quantitative measures do not reveal the ultimate origin of the observed weak performance. In this section we name few possible reasons why teams may produce less points than their salary budged would imply.

Firstly, team management may overestimate the real value of a player when they negotiate of salary. As a result, salary of a player exceeds the expected marginal revenue product of a player. On the team level overrated and underrated players tend to cancel out each other, so overestimates are serious problem if they are systematic, or they are made with the most expensive key players. Hiring overrated players is primarily managers' failure, although in some teams also coaches and even certain key players (such as Gretzky or Lemieaux) have strong influence on player selection.

Second factor is weak teamwork and bad personal relations. Formally speaking, this means that the value of the team falls short of the total value of individuals that form the team. It is largely on coaches' responsibility to find the right lineups as well as to motivate players and keep up the good humour. However, even one non-cooperative individual is able to ruin all the effort of others, so we should not always blame of coaches.

Thirdly, key individual players who bear large responsibility of a team may fail even though managers have, quite correctly, high expectations on them. Although a good coach should be able to sense which players are "hot" at the moment, it is sometimes impossible to predict a failure beforehand. We should remember that often one small mistake turns the course of the game. This third factor is largely on players' responsibility, although managers and coaches can influence it.

Fourthly, we can summarize other sources of inefficiency by the title "bad luck". For example, injuries are an important factor affecting results that is largely beyond the control of any managers, coaches, or players, although coaches can try to save their key players of injuries by tactical choices and lineup changes. Hockey teams are often equal in strength and skill, so marginal factors, or simply luck, may determine the result.

In most cases it is the coach and sometimes the general manager who is fired when team does not win games at the expected rate. Thus, we could perhaps speak of efficiency of coaches or managers in this paper. However, the roles of coaches and managers are not the same in every team. Some teams have clear division of labor and responsibility between the coach and the general manager. In other teams, there is a strong coach with authority while the general manager is more like figurehead. In many teams, the coach and the general manager are the same person. Furthermore, experienced top players such as Wayne Gretzky have lot of authority to coaches and managers[3]. That is why we speak in this paper of efficiency of teams rather than managerial efficiency.

2.3 Competitiveness of Player Market

Assumption of competitive markets is crucial to the analysis. We discuss this issue here shortly, because salaries are not meaningful as inputs unless markets are not competitive. Before 1972 NHL was the only professional hockey league in the world, which enabled teams to abuse their monopsomy power by paying smaller wages than MRP would have implied. After that events such as emergence of a new competitor, World Hockey Association (WHA), in North America 1972; increasing professionalism in European national leagues (Sweden, Finland, Germany,

[3] When he was traded from Edmonton to Los Angeles, many of his ex-teammates followed him in the few years.

Switzerland, and Italy); and grown influence of the Players Association[4] have dulled the former monopoly power of NHL. Despite the failure of WHA in 1978 NHL has not been able to force salaries down again. Jones and Walsh (1987) report also empirical results that fail to reject the hypothesis that, in the presence of effective competition, salaries approximate MRP.

Intuitively it is clear that a team has no incentive to pay higher salary than the MRP of a player. On the other hand, a player has no incentive to accept a deal with lower wage than his expected actual worth if he has opportunity to play in competing team or league instead. Since there is a large number of both players and teams acting on the market, the possible restrictions for competition must rise either from the negotiation process, or from the restrictions by the league.

In NHL salaries of the rookies are restricted to below 900 thousand US dollars in the first season. Thus, it is possible that some talented rookies get less than their actual MRP. But in reality such talents are few, and salary restriction can be evaded by paying higher bonuses, so this is not a big problem. There are also “option” and “compensation” clauses that restrict movement of the players from one team to other, and give teams some degree of monopsony power.

More serious problem is the fact that some contracts are made several seasons onwards. Rational agents (player, team, or their representatives) must form expectations of the actual discounted MRP of the player and negotiate the salary for the contract period based on these expectations. If performance of player changes during the contract period, the salary is not necessarily equal to MRP of the player in each year of the contract period. However, unexpectedly rapid growth of players' earnings has led to shorter (1-2 year) contracts because young developing players are better off when they are able to renegotiate they deal after each season.

[4] Manifestation of this was the strike by NHLPA in the beginning of season 1994-1995 that cut the regular season shorter and caused substantial losses for teams.

3. MEASUREMENT OF EFFICIENCY

In the previous section we defined an implicit production function describing mathematical relationship between inputs and outputs, when production process is efficient. In this section we briefly discuss issues related to empirical estimation of production functions from data. By efficiency we mean that it is technically impossible to produce more output with the given inputs, or respectively, it is impossible to produce the same output with fewer inputs. Since production function describes by definition the efficient production possibilities frontier, we cannot use conventional ordinary least square (OLS) regression techniques. We are interested of “best practice” production frontier instead of “average practice” revealed in OLS regressions. However, most previous studies on team sports lack this theoretical insight of production theory and measurement of efficiency. From the numerous references made in the previous sections, only Porter and Scully (1982), Mazur (1994), and Slottje et all. (1994) apply the modern "best practice" frontier approach.

There are two basic approaches within "best practice" frontier techniques. If we knew the explicit functional form of production function, or if we were able to make a well-justified assumption on it, we could apply parametric (or econometric) methods such as stochastic frontier analysis (SFA). However, in this application we do not know the explicit functional form. Furthermore, we have no theory, nor empirical evidence to support any assumptions about it. Thus, in this application we first resort to a non-parametic DEA method.

Hereafter, the quantity of input i used in production is denoted by x_i and quantity of output j produced is denoted by y_j. DEA efficiency measure (or efficiency score) is defined as a ratio of a weighted sum of outputs to weighted sum of inputs (Charnes, et al 1978). Non-negative weights are chosen for each unit, whose performance is evaluated, in the most favourable way for it. Only constraint is that the efficiency score of the most efficient unit is by definition one. Formally,

$$\begin{aligned} &\underset{\{v,w\}}{Max}\; f^k = \frac{\sum_{j=1}^{J} w_j y_j^k}{\sum_{i=1}^{I} v_i x_i^k} \\ &s.t. \\ &\frac{\sum_{j=1}^{J} w_j y_j^n}{\sum_{i=1}^{I} v_i x_i^n} \le 1 \;\forall\; n = 1,\ldots,N \end{aligned} \qquad (3.1)$$

If we had only single input and single output (as in production function 3.2), this formula reduces simply to traditional (partial) *productivity* measure (y/x). Thus, DEA efficiency score can be interpreted as a freely weighted total productivity index.

DEA efficiency scores are conventionally solved using linear programming. In this application the efficiency score of team k is $1/\phi^k$, where ϕ^k is obtained as the optimal solutions for the following constrained maximization problem:

$$
\begin{aligned}
&\text{Max}_{\{\phi,\lambda\}} \quad \phi^k, \\
&\text{s.t.} \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad (3.2) \\
&\phi^k y_i^k - \Sigma_r \lambda^r y_i^r \leq 0, \qquad\qquad i = 1, \ldots, I, \\
&\quad x_j^k - \Sigma_r \lambda^r x_j^r \geq 0, \qquad\qquad j = 1, \ldots, J, \\
&\qquad\quad \phi^k, \lambda^r \geq 0, \qquad\qquad\quad r = 1, \ldots, n.
\end{aligned}
$$

Note that model (3.2) measures efficiency as a possible relative increase in output, and is thus called output oriented DEA-model. Efficiency can also be measured as a possible relative reduction of inputs, called input orientation. The choice of orientation can affect the results considerably. Unfortunately there is no rule for correct choice, but it rather depends on case. However, in this application it is obvious that every team in NHL is there to win Stanley Cup, whatever the cost, so preferences of DMUs are best taken into account by choosing output approach.

In the model (3.2) it is also assumed that production function exhibits constant returns to scale. This assumption can be rejected by simply imposing an additional constraint. Returns to scale can be specified as non-increasing by adding the constraint

$$\sum_r \lambda^r \leq 1 \quad . \qquad (3.3)$$

This constrain allows either convex combinations of some inputs and some outputs, or convex combinations of the origin and some inputs and outputs. Changing this constraint to strict equation

$$\sum_r \lambda^r = 1 \qquad (3.4)$$

provides variable returns to scale model. Likewise constraint (3.3), this constraint allows the convex combinations of inputs and outputs, but excludes the origin. Hereafter, the constant returns to scale model is referred as CRS, non-increasing returns to scale as NRS, and variable returns to scale as VRS.

By duality, the same results can also be obtained using so called multiplier side formulation:

$$\begin{aligned} &\text{Min}_{\{\phi, \lambda\}} \quad \sum_i \lambda^i x_k^i + \upsilon, \\ &\text{s.t.} \qquad\qquad\qquad\qquad\qquad\qquad (3.5) \\ &\sum_j \phi^j y_k^j = 1, && i = 1, \ldots , I, \\ &-\sum_j \phi^j y_r^j + \sum_i \lambda^i x_r^i + \upsilon \geq 0, && j = 1, \ldots , J, \\ &\qquad \phi^j, \lambda^i \geq 0, && r = 1, \ldots , n. \end{aligned}$$

Formula (3.5) defines VRS version. CRS version can be constructed by restricting parameter υ to be zero. By this multiplier side formulation we also obtain optimal lambda coefficients for each input and each unit that can be interpreted as marginal contribution (or "shadow price") of that particular input.

If we were particularly interested of parametric estimate for a production function, we could run (logarithmic) OLS regressions for data consisting of the efficient observations in terms of

DEA. In this application, however, the number of observations is way too small for this exercise.

4. DATA DESCRIPTION

4.1. League system

There were 26 teams in NHL[5] during the season 1996-97. Teams are reported in table 4.1 along with their general managers and coaches. Due to long geographical distances, the league is divided between two conferences (Eastern and Western Conference), and further into four divisions (Northeast, Atlantic, Central, and Pacific) so that Northeast and Atlantic divisions together form the Eastern Conference, and Central and Pacific divisions form the Western conference. During the regular season each team meets teams of the other conference twice; once home and once away. Teams in the same conference, but other divisions encounter four times (twice home, twice away). Home division teams face up each other five times. In addition, there are two or three additional interdivisional games depending on team, in order to equalize the total number of games during the regular season to 82, and the number of home matches to 41 for each team.

After the regular season, the best eight teams of both conferences qualify to the playoffs. Playoffs are played using standard ”best out of seven” cup system. The regular season winner meets the eighth team of the same conference, the second team the seventh one, and so forth. The team that wins four games in the series continues to the next round, and the losing team drops out. Winning teams start new playoff series, and the matching the teams is based on conference standings of the regular season. Again, winning teams continue to the third round, where the winning team becomes a conference champion. The champions of both conferences meet in the Stanley Cup finals.

Table 4.1: NHL teams with their general managers and coaches 1996-97

[5] By year 2000 the league will expand to 30 by four new teams. At the same time, conferences and divisions are rearranged.

Location	Team name	General Manager	Coach	Other business
Eastern Conference		*Northeast Division*		
Boston	Bruins	Harry Sinden	Steve Kasper	Food, sports, marketing
Buffalo	Sabres	John Muckler	Ted Nolan	Market chains, banking
Calgary	Flames	Doug Risebrough	Pierre Pagé	?
Hartford	Whalers	Jim Rutherford	Jim Rutherford	Computers
Montreal	Canadiens	Serge Sevard	Jacques Demers	Molson-brewery
Ottawa	Senators	Randy Sexton	Jacques Martin	Computers, paper
Pittsburgh	Penguins	Craig Patrick	Ed Johnston	Movies
Eastern Conference		*Atlantic Division*		
Florida	Panthers	Bryan Murray	Doug MacLean	Video, baseball, Am. Football
New Jersey	Devils	Lou Lamoriello	Jacques Lemaire	Forwarding agencies
New York	Islanders	Don Maloney	Mike Milbury	Freight, engines
New York	Rangers	Neil Smith	Colin Campbell	ITT Corporation
Philadelphia	Flyers	Bobby Clarke	Terry Murray	Movies, television
Tampa Bay	Lightning	Phil Esposito	Terry Crisp	?
Washington	Capitals	David Poile	Jim Schoenfeld	Construction
Western Conference		*Central Division*		
Chicago	Blackhawks	Bob Pulford	Craig Hartsburg	Real estate, alcohol
Dallas	Stars	Bob Gainey	Bob Gainey	Shopping malls
Detroit	Red Wings	Scotty Bowman	Scotty Bowman	Pizza, baseball
Phoenix	Coyotes	John Paddock	Terry Simpson	Real estate
St. Louis	Blues	Mike Keenan	Mike Keenan	?
Toronto	Maple Leafs	Cliff Fletcher	Mike Murphy	Vegetables
Western Conference		*Pasific Division*		
Anaheim	Mighty Ducks	Jack Ferreira	Ron Wilson	Disney-films, amus. Parks
Colorado	Avalanche	Pierre Lacroix	Marc Crawford	Videos, movies
Edmonton	Oilers	Glen Sather	Ron Low	Oil, real estate
Los Angeles	Kings	Sam McMaster	Larry Robinson	Real estate
San Jose	Sharks	Dean Lombardi	Jim Wiley	Finance
Vancouver	Canucs	Pat Quinn	Pat Quinn	Real estate, transport

(source: Inside Hockey, 1996)

4.2. Salaries

As we see in Table 4.1, most NHL teams (organizations) have also other activities beside hockey. Since in this paper we are interested of hockey teams, not the success in the real estate business, we cannot use such measures as annual turnover or profit as a success indicator. However, we have accurate information of players' salaries as well as game results from the regular season as well as from playoffs. Additional statistics on salaries of coaches and/or general managers would be also useful, but as far as we know, that information is not public.

The statistics of the player salaries were reported by NHLPA[6] (1997). All the other information was taken from official NHL statistics (NHL, 1997). The salaries of 825 players were reported on salary statistics. Salaries of those players who signed the contract after the season had started were missing.

Figure 4.1 reports total salaries of paid by each team divided to goalkeeping, defence, and forward. We see that richest teams paid more than twice the salaries of teams with smallest budgets. We also see that there were considerable differences in allocation of funds between positions. Colorado and Buffalo paid relatively high salaries for their goalkeepers (about 20% of the total budget), while Calgary, Los Angeles and Montreal allocated only about 6 per cent to goalkeeping. Washington and Hartford paid about 40 percent of their salaries to defencemen, and less than 50 percent to forwards. Pittsburgh, Anaheim and Vancouver relied most to their forwards (almost 70% of salaries), while their defence got only abot 20 percent of salaries.

All the salaries are paid either in US dollars or in Canadian dollars. Salaries paid in Canadian dollars were converted into US dollars using the mean of the daily average exchange rates from September 1. 1996 to June 30. 1997 (1 Can$ = 0,7324 US$). Average daily exchange rates were reported by PACIFIC (1997). The changes in the exchange rate between the two currencies were minor despite the free float regime, so this should be a sufficient estimate.

[6] Abbreviation for National Hockey League Player Association. NHLPA owns the copyright of the statistics. Used with kind permission.

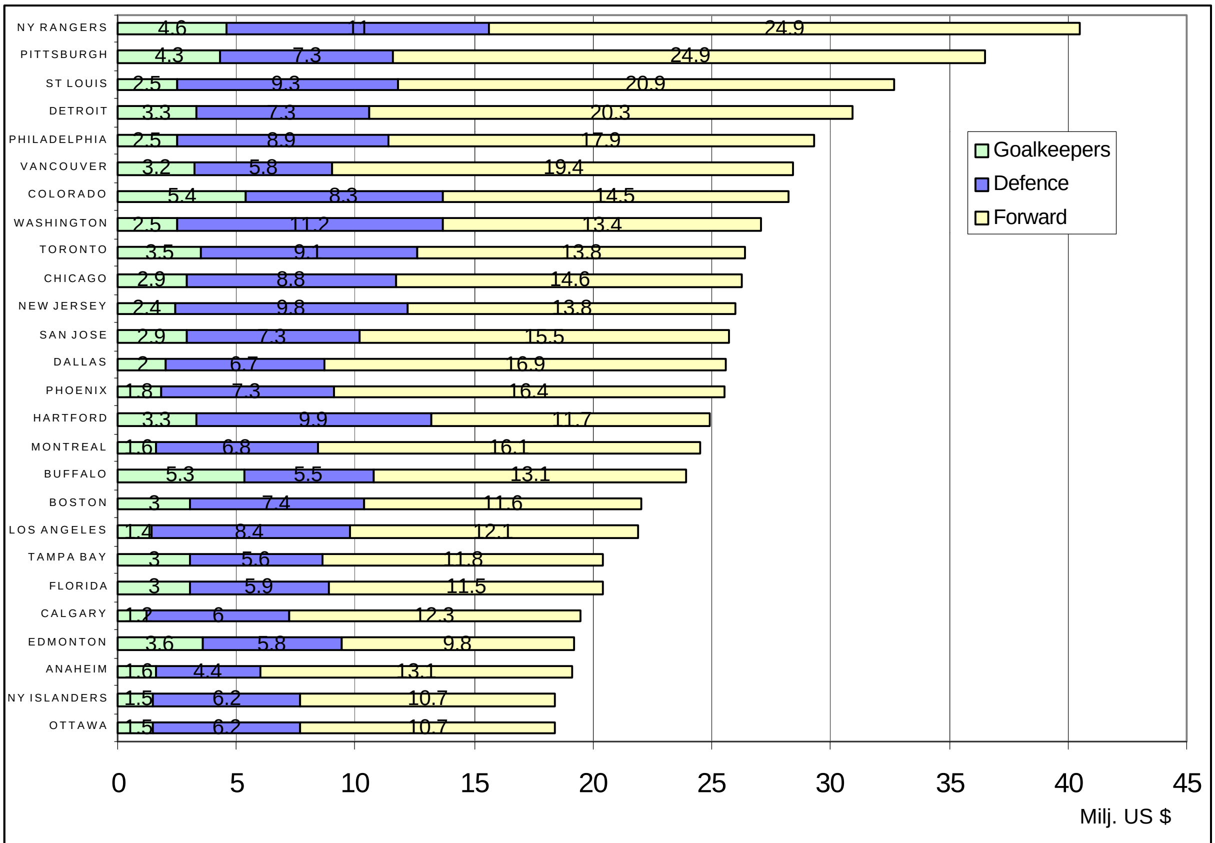

Figure 4.1: Total salaries of goalkeepers, defenders, and forwards

Total number of 90 players were traded from one NHL team to other during the regular season. Trading does not affect the players' salaries, but teams who have traded for a player have an option to negotiate and make a new deal of the payment arrangements[7] (McAllister, 1997). Since the payment arrangements are not public, the salaries were shared between the trading teams according to the percentage of games the traded player played in each team. These shares may differ from those that teams actually agree to pay, but they measure objectively what it is meant to measure, that is, the resources available for the manager during the season.

[7] This was kindly pointed out to me by Mr. Steve McAllister from NHLPA (manager, media relations)

5. RESULTS

5.1. Average prices of a league point

A good measure of overall economic success for a team might be the average price of achieved league point. It can be computed simply by dividing the points achieved by each team by total salaries of each team. Table 5.1 reports the results in decreasing order.

The average price of league point would be a sufficient measure of overall economic efficiency, if we accept production function (2.2) to exhibit constant returns to scale, or in other words, each league point is equally valuable for team independent of total sum of points.

Table 5.1: Average prices of league point

Team	Points	Tot. Salaries (Milj. US$)	Average price of a point (1000 $)	Relative efficiency
ANAHEIM	85	19.12	225.0	1.00
FLORIDA	89	20.39	229.1	0.98
EDMONTON	81	19.19	236.9	0.95
OTTAWA	77	18.41	239.1	0.94
DALLAS	104	25.57	245.8	0.92
NEW JERSEY	104	26.04	250.4	0.90
NY ISLANDERS	70	17.94	256.3	0.88
BUFFALO	92	23.93	260.1	0.86
COLORADO	107	28.06	262.2	0.86
CALGARY	73	19.45	266.5	0.84
TAMPA BAY	74	20.38	275.4	0.82
PHILADELPHIA	103	29.36	285.0	0.79
PHOENIX	83	25.49	307.1	0.73
MONTREAL	77	24.46	317.7	0.71
CHICAGO	81	26.23	323.8	0.69
LOS ANGELES	67	21.84	325.9	0.69
DETROIT	94	30.87	328.4	0.69
HARTFORD	75	24.87	331.6	0.68
WASHINGTON	75	27.05	360.7	0.62
BOSTON	61	22.02	360.9	0.62
VANCOUVER	77	28.37	368.4	0.61
TORONTO	68	26.46	389.2	0.58
ST LOUIS	83	32.71	394.1	0.57
SAN JOSE	62	25.64	413.5	0.54
PITTSBURGH	84	36.49	434.4	0.52
NY RANGERS	86	40.41	469.9	0.48

On the average, Anaheim paid the lowest price for points it achieved while New York Rangers paid highest salaries per league point. However, ice hockey is not an economical contest: The purpose is to win games whatever financial investments it takes. It might be the case that it gets increasingly difficult to obtain high number of points, which would suggest decreasing returns to scale. Then it would be reasonable to use DEA also to estimate production function (2.2). This is illustrated with a simplified example in figure 5.1.

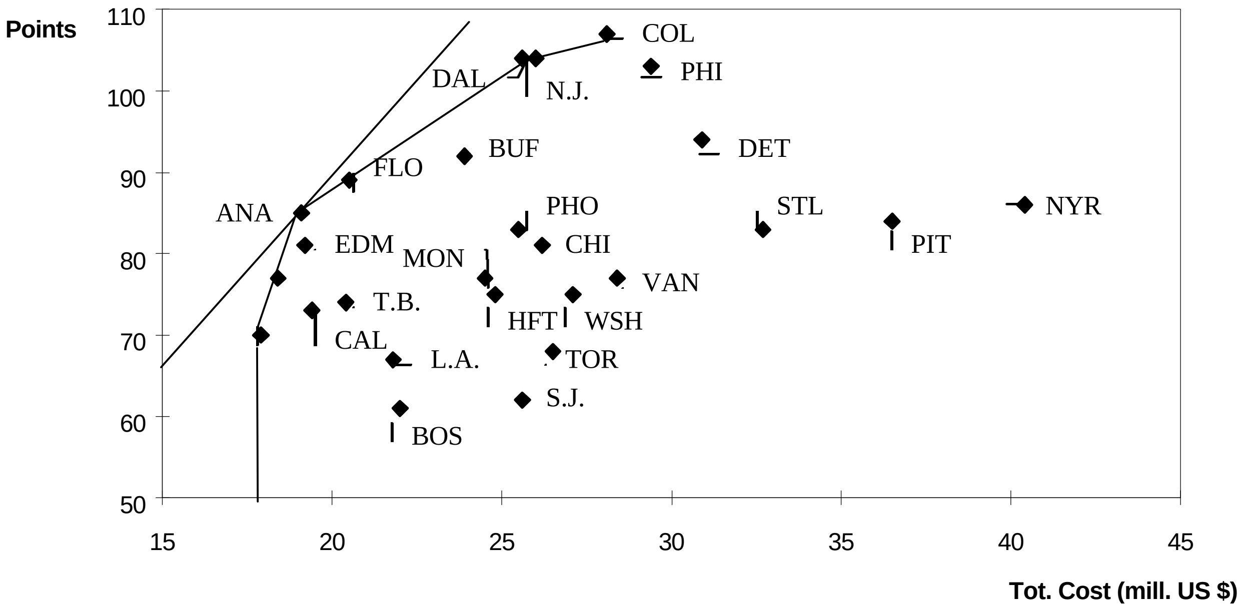

Figure 5.1: Example of DEA frontiers

The straight line passing through Anaheim (ANA) is the CRS reference frontier. Distance between DMU and CRS frontier corresponds to differences in average price of league point. The piece-wise linear curve going through NYI-OTT-ANA-FLO-DAL-N.J.-COL is the VRS frontier. There are seven efficient teams if we assume variable returns to scale. Finally, the NRS reference frontier starts from the origin of the input-output space (not drawn in figure 5.1) and goes through ANA- FLO-DAL-N.J.-COL. Note that NRS reference frontier is combination of both NRS and VRS frontiers. Five teams are efficient if returns to scale are non-increasing. The efficiency score for each unit is calculated as a ratio of the reference output with the given input on the model specific frontier to the actual output of the unit.

5.2 Three-input regular season model

In this section we use DEA to estimate production function (2.3). *Salaries of forwards, defencemen, and goalkeepers*, respectively, were chosen as inputs. Output was measured by *league points*, so we had *three input - single output model*. This takes into account the fact that one dollar invested to goalkeeping may yield different return (in points) than a dollar invested to forward or defence. This model allows us to make conclusions on relative importance of these player positions, and obtain useful information on allocative efficiency of teams.

Table 5.3 summarizes the results the current model. The first two columns report total of player compensation in thousand US dollars[8], and the points achieved during the regular season. Next three columns report the efficiency scores in *constant, non-increasing, and variable returns to scale versions*, respectively. The assumption of constant returns to scale is the tightest one, so naturally the efficiency scores are the lowest in that version.

Whether returns to scale seem to be constant (c), increasing (I) or decreasing (d) for the particular team is indicated in the sixth column. This is simply based on comparison of efficiency scores obtained with different DEA versions. If the efficiency scores are different in CRS and NRS versions, implies that decreasing returns to scale. If the scores are different between NRS and VRS, then returns to scale are increasing. If each version gives the same results, then returns to scale are constant. Those teams operating on the scale of increasing returns would achieve better results by investing more funds to the team than those teams with decreasing returns. However, we note that most teams face constant or decreasing returns to scale, New York Islanders being the only one with increasing returns. Both these efficiency scores and Figure 5.1 support non-increasing returns to scale assumption.

Figure 5.3: Regular Season DEA Summary

Conf./Team	Tot. Salaries (1000 $)	Pts	DEA Scores			Ret. to Scale	Reference Point		
EASTERN			VRS	NRS	CRS		EFF1	EFF2	Rank
NEW JERSEY	26038	104	1	1	1	c	104	90	3
PHILADELPHIA	29356	103	0.99	0.99	0.82	d	105	91	2
BUFFALO	23928	92	1	1	0.99	d	92	80	6
FLORIDA	20394	89	1	1	1	c	89	77	10
NY RANGERS	40414	86	0.81	0.81	0.49	d	106	92	1
PITTSBURGH	36489	84	0.81	0.81	0.63	d	103	90	3
OTTAWA	18413	77	1	1	1	c	77	67	12
MONTREAL	24463	77	0.86	0.86	0.82	d	90	78	9
WASHINGTON	27055	75	0.74	0.74	0.74	c	101	88	5
HARTFORD	24870	75	0.82	0.82	0.81	d	92	80	6
TAMPA BAY	20380	74	0.84	0.84	0.84	c	88	76	11
NY ISLANDERS	17941	70	1	0.92	0.92	i	76*	66	13
BOSTON	22016	61	0.67	0.67	0.67	c	91	79	8
WESTERN									
COLORADO	28059	107	1	1	0.91	d	107	93	1
DALLAS	25567	104	1	1	0.97	d	104	90	5
DETROIT	30868	94	0.90	0.90	0.70	d	105	91	2
ANAHEIM	19122	85	1	1	1	c	85	74	10
PHOENIX	25491	83	0.84	0.84	0.81	d	98	85	8
ST LOUIS	32709	83	0.79	0.79	0.61	d	105	91	2
EDMONTON	19188	81	1	1	1	c	81	70	11
CHICAGO	26227	81	0.78	0.78	0.74	d	104	91	2
VANCOUVER	28370	77	0.80	0.80	0.72	d	96	83	9
CALGARY	19451	73	1	1	1	c	73*	63	13
TORONTO	26463	68	0.66	0.66	0.63	d	104	90	5
LOS ANGELES	21838	67	0.87	0.87	0.86	d	77*	67	12
SAN JOSE	25636	62	0.60	0.60	0.56	d	103	89	7

From the team management's point of view efficiency scores as such are not very useful information. More important question is how many points could have been achieved with the given resources. The last three columns report each team's reference output on NRS frontier. Column *EFF1* reports potential league points with 100% efficient performance when all the other teams maintain the current efficiency level. Note that due to their short resources, New York Islanders, Calgary, and Los Angeles had no chances to qualify in playoffs, even if they

[8] Notice that in the current model, compensation was divided between goalkeeping, defence, and forward as in Figure 4.1.

produced league points relatively as efficiently as New Jersey, Florida, Anaheim, Edmonton, and other efficient ones.[9]

Column *EFF2* reports estimated potential league points if *every team* operated 100% efficiently. They were obtained by re-scaling league points in projection point. This is reasonable since hockey league is a zero-sum game and total sum of points is constant. The last column gives projected league positions for each team if every team produced league points efficiently relative to their investment on players. We conclude that due to inefficiency, Washington, Hartford, and Boston lost their playoff positions for Florida, Ottawa, and Montreal in Eastern Conference. In Western Conference, Toronto and San Jose wasted their playoff positions for Anaheim and Edmonton.

When we estimate the current (NRS) model using multiplier formulation (3.5) we also obtain estimated "shadow prices" (lambdas) for one dollar if invested to goalkeeping, defence, or forward. These marginal contributions are reported in Table 5.3 (multiplied by 1000).

The biggest single problem with number of teams was the lack of good goalkeepers. According to these estimates, Montreal could have yielded one additional league point by investing only additional 2 000 dollars to goalkeeping. Also Los Angeles, New York Islanders, Phoenix, and St. Louis would have desperately needed better goalkeepers. However, there are 26 teams in the league and not all of them are able to hire goalkeepers such as Dominic Hasek, Patric Roy, or Martin Brodeur.

Table 5.3: Estimated contribution of 1000 US $ to league points when invested to following positions

[9] Potential league points for those teams were marked with *.

	Goalkeeping	Defence	Forward
NEW JERSEY	0.04	0.01	**0.06**
PHILADELPHIA	**0.06**	0.02	0.05
BUFFALO	0.00	**0.08**	0.04
FLORIDA	0.05	0.01	**0.07**
NY RANGERS	**0.07**	0.03	0.06
PITTSBURGH	0.00	**0.23**	0.00
OTTAWA	**0.07**	0.02	**0.07**
MONTREAL	**0.53**	0.06	0.00
WASHINGTON	0.05	0.00	**0.09**
HARTFORD	0.05	0.00	**0.09**
TAMPA BAY	0.00	**0.10**	0.06
NY ISLANDERS	**0.36**	0.02	0.04
BOSTON	0.07	0.02	**0.10**
COLORADO	0.00	**0.06**	0.04
DALLAS	**0.24**	0.01	0.03
DETROIT	0.00	**0.08**	0.04
ANAHEIM	**0.07**	0.03	0.06
PHOENIX	**0.31**	0.02	0.03
ST LOUIS	**0.31**	0.02	0.03
EDMONTON	0.05	0.01	**0.08**
CHICAGO	0.06	0.02	**0.07**
VANCOUVER	0.00	**0.25**	0.00
CALGARY	**0.35**	0.02	0.04
TORONTO	0.07	0.01	**0.09**
LOS ANGELES	**0.42**	0.00	0.05
SAN JOSE	**0.09**	0.04	0.08

What comes to skaters, Vancouver and Pittsburgh would have needed reinforcement to their blue line (defenders). However, all teams seem to have taken good care of forward: No substantially high shadow prices (demand) for forwards were found. This is logical, since audience pays to see goals, so very defensive strategy might discourage supporters even if it could yield more points.

5.3. Three input playoffs model

Winning the Stanley Cup is the ultimate goal for each team, and success in the regular season gives just means for it. Thus, the regular season alone does not give the full picture of the team performance as a whole. However, it is not reasonable to conform playoffs to regular season games. Thus, in this section we apply the same DEA model as in the last section to playoff games.

Only difference to the regular season model is that in playoffs, output is not meaningfully measured by league points. Instead, number of games won was chosen to be the output measure, because the more games team wins, the closer it gets to the championship. Furthermore, the more games team plays, the more tickets are sold to home arena. Since playoff matches are never tied, winning games is only way to win the championship. Every team that succeed in winning at least four games qualify to the second round. Teams winning eight games or more qualify to the Conference finals, and with 12 wins to The Stanley Cup final against the Winner of the other conference. Winning Stanley Cup finals require four more wins, so the maximum number of wins is 16.

Table 5.4 summarizes the results. The first four columns report how playoffs were actually played; how many games each team won, what was the resulting position, and against which team each one eventually lost. The next three columns report the DEA scores as in Table 5.2.

Table 5.4: Results of three input playoffs model

	Facts		Drop-	***DEA Eff. Scores***			***Chances to***	
Series	Team	WINS	Ped by	VRS	NRS	CRS	WINS	Qualify to
Stanley Cup	DETROIT	16		100 %	100 %	100 %	16	Stanley Cup
	PHILADELPHIA	12	DET	100 %	98 %	98 %	12	Cup Finals
Conf. Finals	COLORADO	10	DET	100 %	88 %	88 %	10	Conf. Finals
	NY RANGERS	9	PHI	56 %	56 %	46 %	16	Stanley Cup
2nd Round	EDMONTON	5	COL	100 %	65 %	65 %	5	2nd Round
	BUFFALO	5	PHI	74 %	48 %	48 %	7	2nd Round
	NEW JERSEY	5	N.R	65 %	46 %	46 %	8	Conf. Finals
	ANAHEIM	4	DET	100 %	51 %	51 %	4	2nd Round
1st Round	OTTAWA	3	BUF	100 %	42 %	42 %	3	1st Round
	PHOENIX	3	ANA	82 %	35 %	35 %	4	2nd Round
	DALLAS	3	EDM	43 %	32 %	32 %	7	2nd Round
	CHICAGO	2	COL	22 %	17 %	17 %	9	Conf. Finals
	ST LOUIS	2	PHI	17 %	16 %	16 %	12	Cup Finals
	MONTREAL	1	N.J	26 %	13 %	13 %	4	2nd Round
	FLORIDA	1	N.R	17 %	11 %	11 %	6	2nd Round
	PITTSBURGH	1	DET	6 %	6 %	6 %	16	Stanley Cup

In playoffs it is not meaningful to interpret efficiency scores very strictly in traditional way. Rather, efficiency scores tell something of the potential of the team. If efficiency score is one, we can conclude that team could not do any better. If efficiency score is low, we could have expected better results. The last two columns report how many games could each team have won with their salary budget, and to what kind of position that would imply.

We see that the most severe opponents for the champion, Detroit, could have been New York Rangers and Pittsburgh, the two most expensive teams. However, Philadelphia succeeded to drop both of teams out of the playoffs before they met Detroit. On they way to Stanley Cup, Detroit met only one more expensive team (St. Louis), while Philadelphia had to struggle against three strong opponents. Thus the divisions and the Cup system slightly favoured Detroit, considering that Philadelphia did better on regular season achieving nine points more than Detroit.

In addition to New York Rangers and Pittsburgh, also New Jersey, Dallas, Chicago, St. Louis, and Florida had potential to win at least the series in which they were dropped out. Dallas was the biggest disappointment of them, since it lost to Edmonton which was clearly expected to be weaker. In addition to Edmonton and Detroit, also Philadelphia, Colorado, Anaheim, and Ottawa could be happy with their performance.

What comes to improvement of resource allocation in teams, Detroit as the champion (and as the only efficient DMU in NRS and CRS models) is a natural choice for benchmarking. The first three columns in table 5.4 present for each team the sources and the amounts of excess spending (slacks) on NRS frontier. From Figure 4.1 we see that Detroit allocated about 11 per cent of total player salaries on goalkeeping, 14 per cent on defence, and as much as 65 per cent on forward. The last three columns report for each team a new re-allocation that would eliminate output slack and improve production possibilities keeping total expenditure on players at the same level. For example, Colorado has good defence and goalkeeping, but new resources are needed in forward. If benchmarking to Detroit, Colorado could release 2,34 millions dollars from goalkeeping and 1,66 millions from defence by trading with other teams, and invest saved 4 million dollars on new top forwards. Prospective partner could be Anaheim, which would need to shift balance from aggressive forward towards more defensive play.

Table 5.4: Input slacks and optimal reallocation by trades (total salary budget constant)

	Slacks in CRS model (Milj. US $)			Optimal reallocation by trades		
	Goalkeep.	Defence	Forward	Goalkeep.	Defence	Forward
PHILADELPHIA		3.3	2.5	0.63	-1.93	1.31
COLORADO	3	3.1		-2.34	-1.66	4
NY RANGERS	1.2	3.7	4.6	-0.17	-1.46	1.63
EDMONTON	2	2.3		-1.54	-1.29	2.82
BUFFALO	3.1	0.8		-2.68	0.12	2.56
NEW JERSEY	0.1	4.8		0.43	-3.64	3.22
ANAHEIM		0.8	3.2	0.43	0.14	-0.58
OTTAWA		3	1.7	0.51	-1.89	1.38
PHOENIX		3.3	5.4	0.94	-1.25	0.31
DALLAS		2.4	5	0.8	-0.66	-0.14
CHICAGO	0.5	3.5		-0.07	-2.56	2.62
ST LOUIS		3.7	5.6	1	-1.51	0.5
MONTREAL		3.3	6.4	1.05	-1.01	-0.04
FLORIDA	1.1	1.7		-0.8	-1.04	1.84
PITTSBURGH	1		4.6	-0.39	1.32	-0.93
Total	12	39.7	39	-2.2	-18.32	20.5

On the average, most teams spent relatively too much on defence on expense of forward. It seems that the importance of forwards is stressed in playoffs, where every team usually plays with very cautious and defensive tactics, and chances to score are diminished. Thus, teams that can effectively utilize those few opportunities they get during a game are successful.

We also ran a multiplier side formulation (3.5) in order to reveal the optimal weights of goalkeeping, defence, and forward, as reported in Table 5.3 for the regular season. Table 5.5 shows the optimal parameters (multiplied by 1 000) for each team. The higher the multiplier, the larger contribution of investment to the corresponding position to the success. The results of Table 5.5 are highly consistent with Table 5.3. The output variables were different in these models, which explains substantial difference between the multiplier levels. However, relative importance of positions remains with most teams unchanged: Montreal would have needed a top goalkeeper, while Pittsburgh should develop their defence.

Table 5.5: Marginal contribution of Million US $ dollar investment

	CRS			VRS		
	Goalkeep.	Defence	Forward	Goalkeep.	Defence	Forward
NEW JERSEY	0.00	0.00	0.16	0.29	0.00	0.22
PHILADELPHIA	0.40	0.00	0.00	0.20	0.00	0.07
BUFFALO	0.00	0.00	0.16	0.00	0.48	0.14
FLORIDA	0.00	0.00	0.79	**1.54**	0.84	0.97
NY RANGERS	0.00	0.00	0.09	0.00	0.00	0.00
PITTSBURGH	0.00	**2.20**	0.00	0.00	**4.15**	0.00
OTTAWA	**1.60**	0.00	0.00	0.51	0.28	0.32
MONTREAL	**4.80**	0.00	0.00	**8.46**	0.00	0.00
COLORADO	0.00	0.00	0.08	0.00	0.01	0.10
DALLAS	**1.60**	0.00	0.00	**2.74**	0.03	0.00
DETROIT	0.00	0.00	0.05	0.10	0.05	0.06
ANAHEIM	**1.20**	0.00	0.00	0.38	0.21	0.24
PHOENIX	**1.60**	0.00	0.00	**2.82**	0.00	0.00
ST LOUIS	**2.40**	0.00	0.00	**4.23**	0.00	0.00
EDMONTON	0.00	0.00	0.16	0.31	0.17	0.19
CHICAGO	0.00	0.00	0.39	0.72	0.00	0.54

6. CONCLUSIONS

Efficiency of NHL teams was measured using non-parametric DEA method. Salaries of goalkeepers, defenders, and forwards, respectively, were chosen as team inputs. Output was measured by league points in regular season model, and by wins in playoff model.

This particular specification proved to be suitable for this application, but it can also be applied to efficiency analysis of team sports other than hockey. Only necessary requirements are that player markets are competitive, and information on players' salaries is available. However, special characteristics of each particular event should be taken carefully into account. For example, in ice hockey it does not make sense to sum up regular season and playoff games together.

Results show that player salaries do not explain completely the success of teams on the regular season and playoffs. Inefficiency in producing wins and league points with given player material can arise from failures in player selection or coaching. If salaries of coaches had been available, more precise information could have been deducted. In some teams, reallocation of player resources (by trading with other teams) for example from attacking to defence could yield better results.

Quite another question is, whether teams are actually able to negotiate beneficial deals. Team management may well be aware of the need of strengthening in forward, for instance, but proper player type fitting into current line-ups may not be available for reasonable price. On the other hand, we do not know to what extent observed inefficiencies were due to failures in coaching or tactics, and what part was the share of players' mistakes. Furthermore, this type of quantitative analysis is not able to detect which particular players should be kept in team, which ones should be replaced, or who should be hired instead.

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