Referee Analytics: An Analysis of Penalty Rates by National Hockey League Officials

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Abstract

Penalties in ice hockey change the game by reducing the number of players on the ice from the team that committed the infraction. In this analysis, we investigate factors that impact rates of penalties with particular focus on the impact of individual officials. Using play-by-play data collected from NHL.com for the 2008-09 and 2009-10 regular seasons, we develop a logistic regression model to predict the probability of a penalty occurring that accounts for the on-ice officials as well as how close the score is, the period, the time remaining in the period, and the teams playing the game. Our original use of play level data accounts for the amount of action at a given time in a game. This is the first analysis of referees done at the individual play level of which we are aware. We find that no individual referee or linesman differs significantly from the rest. Further we confirm empirically two things that even casual NHL fans have observed. First, the home team is less likely to be called for a penalty than the visiting team and, second, late in close games, the rate at which officials call penalties drops precipitously (and the same is true for overtime games).

1 Introduction

In sports, when a player commits an illegal action against another player, referee or coach, their actions result in a penalty. Penalties differ in each sport ranging from fouls in basketball, warnings cards in soccer, to an addition of yards for a first down in American football. In ice hockey when a penalty is called, a player is designated to sit in a penalty box to serve the allotted time while their team plays with one less skater on the ice. The effect of a team having a penalty can be drastic since the opposing team is almost seven times more likely to score if they have a one-man advantage (power play). Thus penalties influence the outcome of a hockey game. In this paper we analyze play level data from two National Hockey League regular seasons to characterize the rates at which penalties are called with particular interest in the impact of the score, the officials (referees and linesman), the teams involved, the time remaining and the period.

Our interest in this paper is the factors that drive changes in the rates of penalties. One focus of previous work was the impact of home ice on the rates of penalties. Moskowitz and Wertheim persuasively argued that the impact of home ice advantage is through its impact on referees [1]. Similar work, [2], found a home field advantage effect for winning percentages. Other work has involved the question of whether or not referees balance out calls by alternating calls between teams, [3]. During the 1998-99 regular season the NHL randomly determined whether or not there would be one or two referees on the ice. This experiment resulted in two papers [4,5] that look at the impact of an additional referee. As mentioned above the focus of this analysis will be the factors that impact the

rates of penalties in the NHL. We investigated the effect of individual referees, individual linesman, the location of the game (either home or away), the score of the game, the period of the game, and the teams involved in the game. Accounting for the other factors in our model, we found that individual referees and linesman did not have significantly different rates from each other. Additionally we found that the score of the game and the period, particularly overtime led to different rates of overtime. There were also significant differences between teams.

Table 1: Summary of Play-by-Play Events for the 2008-09 and 2009-10 NHL Regular Seasons

Event Abbreviation	Event Description	Event Occurrences, 2008-09	Event Occurrences, 2009-10
FAC	Face-off	70,423	69,806
SHOT	Shot on net	67,847	68,469
HIT	Check/Hit	51,561	54,214
BLOCK	Blocked Shot	32,324	33,452
MISS	Missed Shot	28,577	29,048
GIVE	Give-away	20,546	20,233
TAKE	Take-away	17,022	17,016
PENL	Penalty	13,535	12,330
GOAL	Goal	7,006	7,252

2 Data

To evaluate the factors that impact penalty rates, we will utilize play-by-play files from the 2008-09 and 2009-10 NHL seasons[1]. For each season, there are thirty NHL teams each playing 82 games for a total of 1230 regular season games played. Within those games, the NHL records a series of events for its play-by-play files. An example, play-by-play (PBP) file can be found here [6]. Some of these events were for stoppages or for the beginning or end of games that did not involve game action and so we did not include them in our analyses [2]. Additionally, we eliminated shots and goals from the shootout which is a way of determining a winner for a game that is tied at the completion of overtime. Having eliminated these ancillary events, we analyzed 308,139 events from the 2008-09 NHL regular season and 310,421 events from the 2009-10 NHL regular season. Table 1 has a summary of the analyzed events and their counts. From this table, we can see that there is a regular pattern of PBP events to these two NHL seasons. The rates of each event are nearly the same across these two seasons. In particular, the percent of events that are penalties was 4.39% in 2008-09 and 3.97% in 2009-10.

[1] These data were extracted from NHL.com play-by-play files by Ken Krzywicki and he generously shared these files with us.

[2] Specifically, the events that we excluded were: Stoppage (STOP), Period Start (PSTR), Period End (PEND), Game End (GEND), Shootout Complete (SOC), Goal Called Off (GOFF), Early Intermission End (EIEND) and Early Intermission Start (EISTR).

Table 2: Rates of Penalties Per Event Across Periods

Period	2008-09 NHL Regular Season	2009-10 NHL Regular Season
1	4.29%	3.87%
2	4.78%	4.25%
3	4.19%	3.88%
Overtime	1.89%	2.08%

For our analysis, the response will be whether or not a given event is a penalty (PENL). For this analysis we did not distinguish between types of penalties. We considered several predictors to explain the variability in our response. The first of these is the period in which the event occurred. NHL games are usually composed of three twenty-minute periods, though an overtime period is added if the teams are tied at the end of three periods. Of special interest here will be the rate of penalties during the overtime period. (Note that the overtime period is played with one less player for each team on the ice.) Table 2 has a summary of the probability that a given event is a penalty across the different periods. We can see from this table that the rates of penalties differ across periods. The consistent patterns across these seasons are that the first and third periods had about the same rate of penalties while the second period had about a 0.5% higher rate of penalties and that the overtime period saw a significant drop in penalties such that the rate of penalties for overtime is about half of what it is during other periods.

Two more predictors that we will include are the teams involved in a given event. Certain teams are more likely to be penalized and certain teams are more likely to cause their opponents to be penalized. One of our primary interests is the impact of individual referees and linesman and whether there were differences between these officials in the rates of their penalties. Two referees and two linesmen are assigned to each NHL game. Our primary interest is in referees since they are charged by rule with calling most of the penalties [7]. Since the NHL PBP data does not include the official who made a given call we include all four individuals as possible explanatory variables. Thus we can account for the presence of an individual official on the ice but not individual predilections for making calls. .

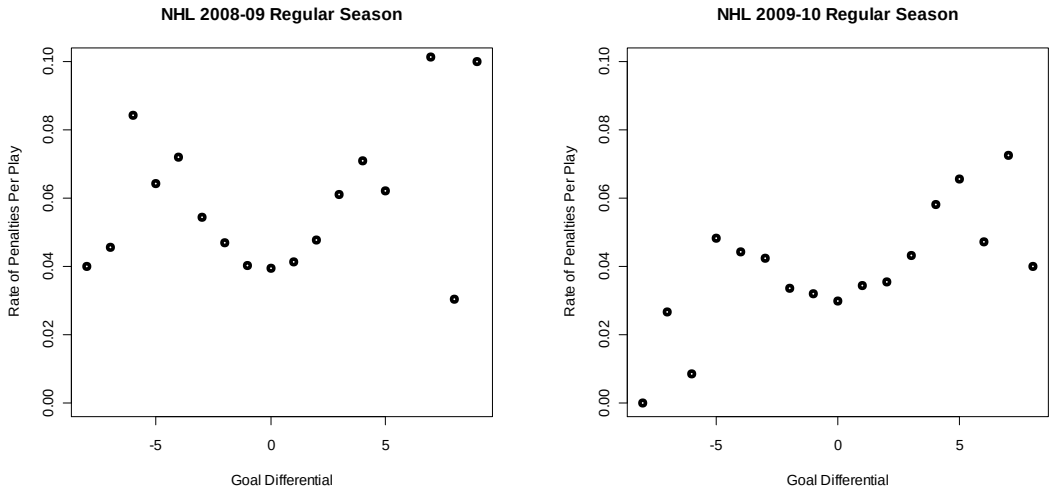

Figure 1: Plots of Penalty Rates by Goal Differential

For the 2008-09 season there were 39 different referees and 35 different linesmen in our data, while the 2009-10 season had the same number of linesman but two additional referees. Teams commit different rates of penalties and draw different rates of penalties so we include both the team initiating an event and the team impacted by a given event as explanatory variables in our model.

Table 3: Probability of Penalty by Team Initiating Event (TeamFor)

TeamFor	2008-09 NHL Regular Season	2009-10 NHL Regular Season
Home	3.83%	3.51%
Away	5.07%	4.53%

The final set of variables that we include in our model focus on the score of the game. The primary variable will be the absolute value of the difference in team's scores under the theory that the closer the score the less likely officials will be to impact the game. Goal differential here is the score of the home team minus the score of the away team for a given event. Figure 1 has graphs plotting the rates of penalties against the goal differential for both of the seasons that we are analyzing here. We can see from these graphs that the relationship between rates of penalties and the goal differential is lowest at zero. Further, the rates of penalties seem to be symmetric about zero for both years until the goal differential is approximately five. As a consequence of this, we will use the absolute value of goal differential as a predictor in our model as well as the squared goal differential. We note that events with goal differentials of more than five make up less than 0.5% of our data for both years. Table 5 in the Appendix gives the percentage of events that occurred at each absolute goal differential. Thus, the additional variability at the extremes of both graphs in Figure 1 is not surprising due to small sample sizes at those goal differentials. Given the hypothesis that referees `swallow their whistles' late in games, we also include predictors for the final ten minutes of the third period and for the final five minutes of the third period. Since this hypothesis seems to be especially supported late in close games, we add a factor that looks at the change in penalty rates for the last five minutes of games where the goal differential is less than 2 goals. Our interest in including all of these explanatory variables is to account for all of the factors that influence penalty rates so that we can isolate the impact of individual referees and linesmen to determine if they have a significant impact on penalty rates.

3 Methodology and Results

To assess the impact of individual on-ice officials (referees and linesman) on the probability that a given event is a penalty, we built and fit a logistic regression model for each of the two seasons for which we have the data described in the previous section. We chose to look at the probability that a given event was a penalty rather than to look at rates of penalties per increment of time was to account for the amount of action in a given game. That is, by using on-ice events we account for the pace of action. Since our response is binary, whether or not a particular event is a penalty, our selection of a logistic regression was the appropriate one. Our resulting coefficients will measure the impact of each factor on the odds that an event is a penalty. Fitting different regression models for each season was done so that we could confirm that our model and our estimates were consistent. We note that there were not substantial rule changes made by the NHL between the 2008-09 season and the 2009-10 season. Below we explicitly state our model and the fitted estimates of the model parameters.

The model for this analysis is that the log-odds of an event being a penalty is a linear function of the following terms:

Referees on the Ice (Referee),
Linesmen on the Ice (Linesman),
Absolute Value of the Goal Differential (GDiff),
Goal Differential Squared (GDiff2),
Team Initiating Event (TeamFor),
Team Taking the Event (TeamAgainst),
Period of the Event (Period),
Home Team Initiated Event (HOME)
Ten Minutes or Less Remaining in the 3rd Period (MIN10),
Five Minutes or Less Remaining in the 3rd Period (MIN5),
Goal Differential Less Than Two (GDiff<2),
Interaction of GDiff<2 & Five Minutes or Less Remaining in the 3rd Period (CLOSE-END).

From the above list, only GDiff and GDiff2 are quantitative variables, the other variables including the interaction term (CLOSE-END) are indicator variables for the presence or absence of a factor. For example, the PERIOD variable is actually comprised of four indicator variables one for each of the three periods and a fourth for overtime. The TeamFor and TeamAgainst variables were comprised of an indicator variable for each team.

Fitting our logistic model to the above list of variables for each season, we found that many of the predictors in the model were statistically significant. Table 4 summarizes the significant coefficients from these models. In that table `N/S' stands for not significant using a significance level of α=0.001 since we are considering models with a large number, over 100, predictors. First, we note that there is strong agreement between the two models in the coefficients that are significant and the terms that are not significant. The one exception is that the absolute value of goal differential, GDiff, had a slightly larger effect during the 2009-10 NHL regular season than during the 2008-09 NHL regular season. In each season there were multiple teams with significantly higher or lower than average rates of being called for penalties and drawing penalties. A list of those teams for each season can be found in Table 6 of the Appendix. The other non-hockey official factors that are significant show remarkable consistency across the two years of our analysis. For all of these factors the differences in the effects of these factors are not significantly different across the years. The change in the odds of a penalty being called during the third period or during overtime relative to the first period is negative. The effect is more pronounced for the overtime period. The greater the value of GDiff, the higher the likelihood that an event will be called a penalty. Finally, there is an additional significant drop in the rates of penalties if a game is close in the last five minutes of the third period.

For the on-ice officials, none of the referees or linesmen significantly impacted the rates of penalties with the exception of two individuals, one referee, Stephane Auger, and one linesman, Tony Sericolo. Both of these individual has predicted rates of penalties that was significantly larger than other referees given the other factors in the model. Since these individual officials appeared as significant in only one season, we attribute this significance to chance.

Table 4: Summary of Model Coefficients By Season

Predictor	2008-09 Season	2009-10 Season
Referee	**N/S**	**Auger, rest N/S**
Linesmen	**N/S**	**Sericolo, rest N/S**
GDiff	**0.0892**	**0.1403**
GDiff2	**N/S**	**N/S**
Period =2	**N/S**	**N/S**
Period =3	**-0.1529**	**-0.1518**
Period =OT	**-0.5675**	**-0.5550**
TeamFor	**Several**	**Several**
TeamAgainst	**Several**	**Several**
Home	**-0.2668**	**-0.2940**
MIN10	**N/S**	**N/S**
MIN5	**N/S**	**N/S**
GDiff<2	**N/S**	**N/S**
CLOSE-END	**-0.4328**	**-0.4630**

4 Discussion

In this paper we have attempted to model the variability in rates of penalties called during two NHL seasons based upon individuals play level data. To our knowledge this is the first play level analysis of officiating that has been done in any sport. Our model assesses the impact of the relative scores of the teams, the teams involved in the action, the officials both linesmen and referees on the ice, the period of the action and the time remaining in the third period. Given that we had only two officials that were significantly different from their peers across these two seasons after accounting for the other factors in our model suggests that there is uniformity among NHL officials. That should be welcome news for the NHL. Given the other factors in our model, we also conclude the following.

1. For each drop in absolute score differential towards zero (i.e. tightening of the score from, say, 4 to 2 to 4 to 3), the odds of a penalty being called drops by 12%.
2. The odds of a penalty being called in the 3rd period is 86% of what it is in the 1st or 2nd period. For overtime, the odds of a penalty being called are 57% of that for the 1st or 2nd period.
3. The home team has odds of an event being called a penalty that are 76% that of the visiting team.
4. In a close game (one goal differential or less) with under than 5 minutes remaining in the 3rd (last) period, the odds of a penalty being called are 64% of what they would be otherwise for a similarly close game.

From this analysis we have confirmed empirically what most hockey fans believe. Further, these findings are strikingly consistent across the two seasons that we analyzed suggesting a persistent regularity to rates of penalties in the NHL.

5 Acknowledgements

We wish to thank Ken Krzywicki for his generosity in making available the NHL play-by-play data in a format that was user friendly. We would also like to thank Chris Wells of St. Lawrence University and Brian Macdonald of West Point for insightful conversations about the content of this paper.

6 References

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[6] National Hockey League. "Play by Play." National Hockey League, 2012. Web. 8 January 2012 <http://www.nhl.com/scores/htmlreports/20112012/PL020612.HTM>.

[7] National Hockey League, National Hockey League Official Rules 2011-2012, Toronto, ON, 2011.

7 Appendix

Table 5: Percent of Events Occurring At Each Absolute Goal Differential

Absolute Goal Differential	Percent of Events from 2008-09 Season	Percent of Events from 2009-10 Season
0	36.43%	36.27%
1	36.22%	35.68%
2	16.68%	16.21%
3	6.80%	7.65%
4	2.36%	3.04%
5	1.06%	0.81%
6	0.31%	0.27%
7	0.09%	0.05%
8	0.04%	0.01%
9	0.01%	-

Table 6: Summary of Differences in Team Rates of Penalties Both Taken and Drawn By*

2008-09 Regular Season
Teams with significantly different rates of being called for penalties (relative to Anaheim)
BOS, CAR, COL, DAL, DET, FLA, MIN, NYI, OTT, SJS, TOR,

Teams with significantly different rates of drawing penalties (relative to Anaheim)
CAR, FLA, NAS, NJD, NYI, TOR, WAS

2009-10 Regular Season
Teams with significantly different rates of being called for penalties (relative to Anaheim)
BOS, BUF, CAR, CHI, DAL, DET, FLA, MIN, NAS, NYI, TOR

Teams with significantly different rates of drawing penalties (relative to Anaheim)
DET, MTL, NAS, NJD, NYI, PHO, SJS, WAS

*Note that for estimation of team coefficients in was necessary to estimate differences from a given team and Anaheim was chosen since it is alphabetically first.