Ball Motion Study: Phase I and II Final Report

Presented by: the USBC Equipment Specifications and Certification Team

Abstract

The United States Bowling Congress, the national governing body of the sport of bowling, aims to ensure the integrity and protect the future of the sport by providing programs and services which enhance the bowling experience. Over the past twenty years, the technological advancements in bowling ball cover stocks and cores, coupled with improved lane surfaces and oiling patterns, have contributed to an increasing rate of honor scores and the overall scoring pace—thereby jeopardizing the credibility of the sport of bowling.

 The Equipment & Specifications Department within the United States Bowling Congress is responsible for setting and governing the specification limits of all equipment and machinery used in the sport. Their research has conclusively shown that increased entry angle into the pins directly relates to better pin carry and, thereby, higher scores. Therefore, in order to achieve the mission of the United States Bowling Congress, one of the department's objectives was defined as understanding which bowling ball properties affect ball motion and whether current or new specifications for bowling equipment need to be modified or developed.

The physics behind ball motion has become increasingly complex, in line with the advances in bowling ball and lane technology. The Equipment & Specifications Department, therefore, initiated a comprehensive study that used multiple regression in order to understand and statistically validate which properties of a bowling ball significantly influence ball motion. Most of the results matched what would be expected by physics, but there were some interesting results with regards to both significant and insignificant variables.

After review of the data with the Equipment & Specifications Committee, along with a majority representation from the major bowling ball manufacturers, the United States Bowling Congress has already proposed new specifications for at least one of the identified significant variables, and has begun investigating possible additional modifications to existing bowling ball, lane conditioner, cleaner and lane specifications.

Introduction

In October of 2005, the United States Bowling Congress along with representatives from the major domestic bowling ball companies formed the Ball Motion Task Force. The task force's goal was to better understand ball motion. Throughout the process, the Ball Motion task force has worked together in order to define the parameters of the testing and to provide USBC personnel with bowling balls for the study and their knowledge base in order to complete the study with accurate and reliable results. Before testing was started in July of 2006, certain things were put into place in order to properly measure ball motion. The Super CATS system was installed on lanes one and eight at the USBC Equipment Specifications and Certifications building. This system is a twenty- three sensor system that measures position, velocity, and vertical angles down a sixty foot lane. The sensors are roughly placed every two feet with a couple of exceptions while starting at eleven feet from the foul line. In addition to the Super CATS system, the task force decided on the test methodology and parameters to carry out the entirety of the testing. The final step was to receive the strongest particle and reactive resin bowling balls from the ball manufacturers. With these balls, USBC personnel started to layout, measure, and drill these for the ball motion Phase I testing.

Test Methodology

Ball manufacturers were asked to send in two samples each of their strongest particle and reactive resin bowling balls for testing. All balls were asked to be fifteen pounds, have between two and two and one-half ounces of top weight, and have a pin to cg distance of between two and three inches. For asymmetrical equipment, the cg was requested to be within one inch of the midline between the pin and the positive spin high RG axis point. The total weight, top weight, diameter, and radius of gyrations were measured before the bowling ball was laid out and drilled.

After the pre-drill measurements were taken, the balls were laid out on a drilling technique agreed upon by the Ball Motion Task Force. The pin to positive axis point distance was three and three-eights of an inch from each other, with a pin to vertical axis line measurement of one and one-quarter inches. Symmetrical bowling balls were laid out with a center of gravity to positive axis point measurement of between three and one-eighth to three and three-eighths inches (depending upon pin to CG distance). Based on the positive spin axis points on the symmetrical bowling balls, asymmetrical equipment was laid out with a positive spin axis to positive axis point measurement of six and one-half inches. This drilling pattern was incorporated for every ball motion test bowling ball.

The Ball Motion Task Force decided that Harry the ball thrower's axis tilt would be thirteen degrees of tilt and his axis rotation would be fifty-five degrees. Based on these two statistics, Harry's positive axis point was determined to be five inches over from his midline by three-eighths of an inch up. The drilling pattern that was used was a span of four and one-half inches from finger cut to thumb cut. The fingers were drilled with a thirteen-sixteenths drill bit three-eighths of an inch apart from one another, two inches

deep. These finger holes are also centered on the midline of the grip. The thumb, also on the centerline of the grip, was drilled using a fifteen-sixteenths inch drill bit two and one-half inches deep. A weight hole was placed on Harry's positive axis point as well. This weight hole was drilled using an eleven-sixteenths inch drill bit two inches deep. Measurements are taken before the weight hole is introduced and after the weight hole is introduced into the ball. These records are kept on paper and then compiled into spreadsheets.

After each ball is drilled, the surface of each ball is taken to 1000 grit by use of abralon pads. The same surface is used on each of the balls because not every ball comes from the factory at the same box finish. The coefficient of friction and oil absorption rate are measured once the ball has the surface put onto it. These measurements were two of the seven post-drill measurements that we measured before the balls were thrown.

The seven post-drilling measurements that were taken on the thirty-two bowling balls are the static variables of our testing. Static variables are variables that are measured before testing occurs. For our testing, these static variables are radius of gyration, spin time, differential ratio, total differential, intermediate differential, coefficient of friction and oil absorption rate. The radius of gyration measurement is actually the low radius of gyration or gyration about the x-axis of a bowling ball. The common place for the x-axis of a bowling ball is where the pin is located. The position is verified using a standard test procedure using a deTerminator. More about the radius of gyration measurement and all the measurements found in this paper can be found at http://www.bowl.com/Downloads/pdf/USBCequipmanual_appendix.pdf. The total differential measurement is found by taking the High radius of gyration minus the low radius of gyration. The high radius of gyration is usually the y-axis of the bowling ball and is either an equator or a spot depending on the type of core in the bowling ball. The intermediate differential of a bowling ball is found by taking the high radius of gyration minus the radius of gyration about the z-axis. The z-axis is perpendicular to both the x and y axes of the bowling ball. The differential ratio is a mathematical calculation by taking the intermediate differential divided by the total differential. The spin time of the bowling ball is found using a MoRich deTerminator. A spot that is both four and one-eighth inches from the low radius of gyration and the high radius of gyration is marked. The time that it takes from this spot to move to the high radius of gyration is measured and the average of three spins is taken. Oil Absorption rate is measured by placing ten microliters of Kegel Offense HV lane conditioner in a two and one-quarter inch circle outside of the ball track on the bowling ball's surface. After the oil has sat on the ball for ten minutes, the remaining oil is absorbed onto a tarred pad. The pad is measured before and after to determine how much oil the pad absorbed. The oil absorption rates are measured in grams per meters squared per minute. The coefficient of friction is measured the standard way as described in the equipment specification manual.

The lanes for the testing were AMF HPL 9000 synthetic lanes. The tests were performed with the Kegel Standard Sanction lane machine using Kegel Defense/C lane cleaner and Kegel Offence HV lane conditioner. The lane pattern applied to the lane surface is comprised of six two to two loads oiled from the foul line to eight feet and then buffed

out until forty-nine feet. What this means is that lane conditioner is applied evenly from the second board on the left to the second board on the right for eight feet and then buffed evenly until forty-nine feet. This means we have thirty units of lane conditioner at eight feet from the foul line, eight units of lane conditioner at thirty-two feet from the foul line, and five units at forty-seven feet which is two feet before the end of the oiling pattern.

Staff performed the experiments using our precision (Robotic) ball thrower which we nicknamed Harry. Harry is named after a former employee here at bowling headquarters, and is our best worker since he is never late, stays here all the time, and rarely complains about his profession. For our testing Harry was set to a "good" bowler's specifications as decided on by the ball motion task force. These specifications were seventeen miles per hour, two hundred and seventy-five revolutions per minute, fifty-five degrees of axis rotation and thirteen degrees of axis tilt. All of these measurements were double checked using video analysis. Harry's positive axis point based on these measurements is five inches over by three-eights of an inch up. There are three laser guides that ensure the technician lines and loads the ball properly inside of Harry. Also a circle is drawn around Harry's positive axis point to ensure proper loading occurs. Harry's consistency is constantly checked in order to maintain proper testing quality is accruing. The standard deviation goals for Harry are measured at eleven feet from the foul line and are approximately one-third of an inch in position and one-tenth of a mile per hour in velocity. Both of which were constantly checked and all tests were conducted within these parameters.

Ball motion can be divided into three distinct phases based on the linearity of the lines. The three phases of ball motion is the skid phase where the ball has not encountered enough friction to begin its hook phase, the hook phase where the ball has encountered enough friction in order to transition from a negative sloped plane to a positive sloped plane going towards the pins, and the backend phase where the ball is traveling on a fairly constant plane towards the pins. The skid and backend phases are determined by the maximum amount of points needed to achieve a ninety-nine percent R-squared in terms of linearity. If the R-squared for a point included in either line falls below this ninety-nine, then it is said that the point is part of the hook phase of ball motion.

In addition to eight static variable staff analyzed, we also analyzed nineteen dynamic or y-variables. These variables were calculations based off the Super CATS data. The first one of these variables is the intended path at forty-nine feet (end of the oil pattern) this measurement measures the difference between the calculated values from the hook and backend equations at forty-nine feet minus the theoretical calculation from the skid phase at forty-nine feet. The intended path at sixty feet variable is the same but is just calculated at sixty feet instead of forty-nine feet. The average path at forty-nine feet calculation is the average position of the Super CATS data at forty-nine minus the theoretical position at forty-nine feet based on the skid phase equation. The average path at sixty feet is the same calculation but based on sixty feet instead of forty-nine feet. The velocity decrease at forty-eight feet is determined by taking the initial velocity minus the average velocity between forty-seven and forty-nine feet. The average velocity decrease at fifty-eight feet is the same calculation but with the average velocity between the last two sensors. The

angle change at forty-eight feet is the angle at forty-eight feet minus the initial launch angle at the first two sensors at eleven and fifteen feet. The angle change at fifty-eight differs only by using the last two sensors as the first part of the calculation. The first transition point is the distance in feet where the ball starts its hook phase. The second transition point is the distance in feet where the ball starts its backend phase. The negative slope is the slope with regards to the horizontal from the skid phase regression line. The positive slope is defined as the slope to the horizontal for the backend phase. The total angle change occurs by taking the inverse tangent of the positive slope line minus the inverse tangent of the negative slope line. The total hook zone length is the second transition point minus the first transition point. An angle per foot calculation can be achieved by taking the total angle change divided by the total hook zone length. The "A" Score is defined as the coefficient of the binomial term that describes the hook zone. The breakpoint is the apex of the hook zone. The first transition to the breakpoint is the length from the breakpoint to the first transition and the breakpoint to the second transition is the second transition point length minus the breakpoint. These variables best describe ball motion, the first eight variables were decided on by the ball motion task force while the other eleven were developed during the ball motion study Phase I.

The task force decided upon bracket testing after their first meeting. These brackets involved ranking a particular static variable from the highest value to the lowest value. Since there are thirty-two balls in the first part of the study, we can setup a bracket pitting the highest ranked ball versus the lowest ranked ball for a particular static variable. We ran five brackets based on the rankings for low radius of gyration, total differential, intermediate differential, differential ratio, and cover stock type. After the first round of these brackets were completed, staff ran a complete bracket on a slightly lower volume oil pattern and a partial bracket on a heavier volume oil pattern than the standard five two to two pattern.

The bracket tests were conducted using an eight shot test with an alternating "ABBABAAB" pattern where ball A was a particular ball and ball B was the corresponding ball according to the bracket. After the raw Super CATS data was taken, our patent pending analysis converted the raw data into the nineteen ball motion variables. In addition to the variables, the ball motion spreadsheet also produces a graph of the two balls versus each other and the shows the three phases for each ball. The example graph and data are shown below.
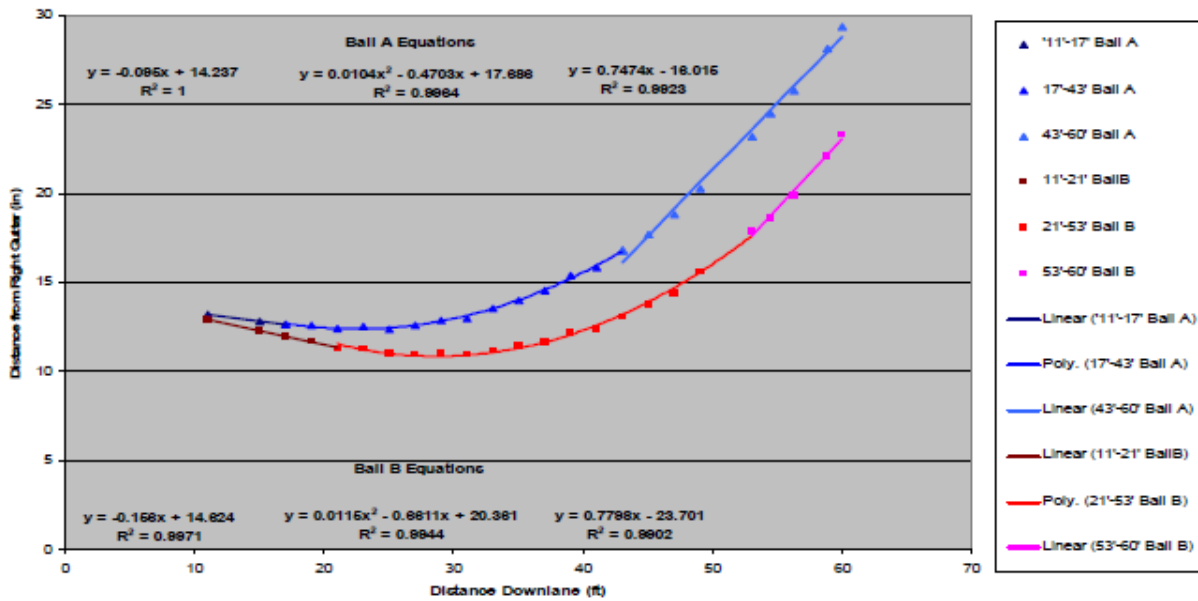
Ball A Equations

$$y = -0.095x + 14.237 \qquad R^2 = 1$$
$$y = 0.0104x^2 - 0.4703x + 17.888 \qquad R^2 = 0.8984$$
$$y = 0.7474x - 16.015 \qquad R^2 = 0.9823$$

Ball B Equations

$$y = -0.158x + 14.624 \qquad R^2 = 0.9971$$
$$y = 0.0115x^2 - 0.6611x + 20.361 \qquad R^2 = 0.8844$$
$$y = 0.7798x - 23.701 \qquad R^2 = 0.8802$$

Legend:
- '11'-17' Ball A
- 17'-43' Ball A
- 43'-60' Ball A
- 11'-21' BallB
- 21'-53' Ball B
- 53'-60' Ball B
- Linear ('11'-17' Ball A)
- Poly. (17'-43' Ball A)
- Linear (43'-60' Ball A)
- Linear (11'-21' BallB)
- Poly. (21'-53' Ball B)
- Linear (53'-60' Ball B)

Axis labels: Distance from Right Gutter (in.) ; Distance Downlane (ft)

Figure 1: Comparative Bracket Parts Chart

This data produced the bracket top performers, which were then analyzed to see any trends. When the first five brackets were done with their first rounds, staff noticed that no significant trends became evident. Another statistic from the first round of tests showed only 23% of balls actually finished their hook phases in the oil pattern. So staff decided to investigate a full bracket with a slightly lower volume oil lane condition pattern. During the lower volume oil bracket, Ball eighteen stood out from all the other thirty-one balls during the bracket. During the testing ninety-one percent of balls finished their motion in the oil pattern. After this testing had completed, staff was curious to see what would happen with a heavier oiled pattern with some of the balls in the study. Due to the heavier oil pattern, no ball fully transitioned in the oil pattern. However, the ball paths were easily modeled and had extremely high R squared values due to the amount of oil.

After the studies were done, Scott Sterbenz, one of our technical advisors and Six Sigma Black Belt, suggested that we perform a multiple linear regression based on the data from the ball motion testing brackets. Multiple linear regression looks at the relationship between one dynamic variable to see which static variables are important to that particular dynamic variable. We can tell which particular variables have the most significance by their low P value. We can also tell which groups of static variables are important by finding the highest R squared value for any equation. The regression analysis was performed on a multitude of brackets included the total differential brackets with five two to twos. Staff examined the top three static variables that had the lowest P values; these static variables were given a score of three, for the most significant down to one for the third most significant variables. Once these scores were given across all the dynamic variables, a tally was made of which predictors were most important to predicting the ball motion variables. The chart below was produced to show which variables were the most significant.
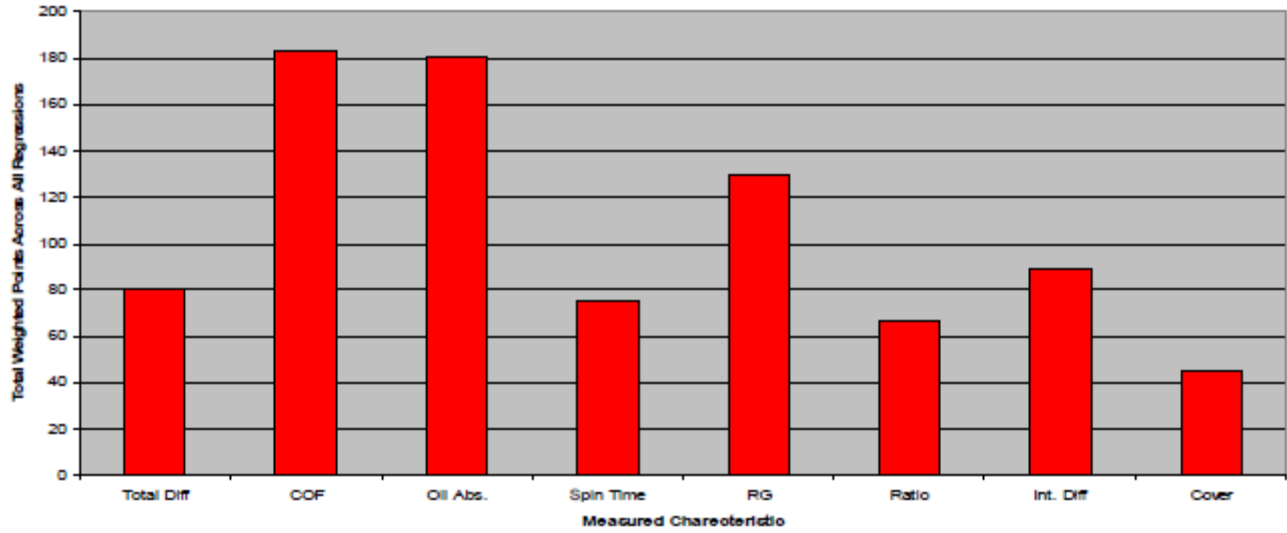
Figure 2: Phase I Significant Variables

Based on the chart above the coefficient of friction, oil absorption rate, and radius of gyration are the three most significant. This data was presented to the ball motion task force at Bowl Expo 2007 in Las Vegas, Nevada. After that meeting a new direction of testing began in the ball motion study. Anything from that point forward became known as Phase II of the ball motion study.

USBC Ball Motion Study:
Final Results - Phase II

During the second of three task force meetings, which was held at Bowl Expo 2007, plans and details for the final phase of the Ball Motion Study were discussed and agreed upon. From a USBC perspective, it was necessary to conduct a Phase II test to place greater detail of the top trends from Phase I and a more in depth testing of additional X-Variables as suggested by the task force. While Phase I concentrated mostly on high performance and aggressive bowling balls, Phase II looked at a more exuberant variety of bowling balls on today's market. These balls ranged from aggressive, particle and resin to less aggressive resin, urethane and plastic. By incorporating a wider range of bowling balls the results in theory would become more accurate. Each manufacturer was asked to submit a highly aggressive, medium aggressive and low level aggressive bowling ball for testing. The test balls were to meet the same submission criteria from Phase I.

Figure 3 below shows how one of the top three trends from Phase I was examined in greater detail by adding additional X-Variables for Phase II. The Coefficient of Friction between a ball and lane surface was now characterized not only by the dry lane COF value (defined in Phase I) but also Surface Roughness – Ra & RS and On-Lane COF.
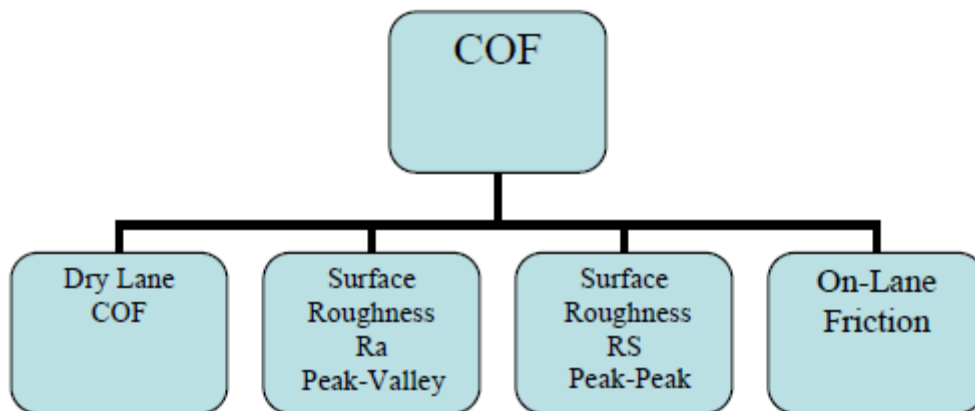

Figure 3: COF Phase II Components

Surface Roughness – Ra is technically defined as the arithmetic mean of the absolute values of the profile deviations from a mean line on a particular surface at a given measurement distance. Simply worded, it is a measurement of how deep or how high (vertically) the microscopic "spikes" or "pores" are on the surface of a bowling ball. Surface Roughness – RS is defined as the arithmetic mean of peak-to-peak distances of the local peaks in the evaluation distance. Basically, it is a measurement to determine the distance between the "spikes" and/or "pores" on a bowling ball's surface. The values of

both Ra and RS can be different from ball to ball even at the same grit due to chemical and porosity differences between cover stocks.

On-Lane Friction is calculated by the change in velocity over a certain distance for each ball. This data was collected via C.A.T.S and in this study the distance being monitored was from the foul line to 38 feet down-lane. This specific distance was chosen due to the friction between a ball and lane approaches zero as the ball reaches it 99% linear "back – end" phase. The earliest ball to reach the "back-end" phase occurred at 39 feet. To fully capture each bowling balls friction value before it approaches zero, one foot before the earliest "back-end" phase was used.

As shown in Figure 4 below, a new and improved oil absorption method was developed for Phase II. In corporation with the task force, USBC staff fine tuned the new method to be more accurate and precise in determining the rate at which different coverstocks absorb lane oil.
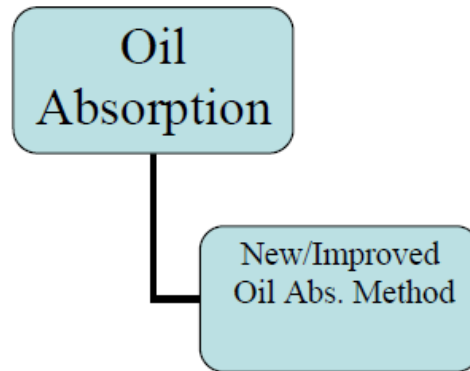

Figure 4: Oil Absorption Phase II

For the new test, a single 0.5ul drop of Kegel Offense lane oil was placed on a single random spot on the bowling ball. As the oil diffuses and/or spreads out due to surface energy and tension, the maximum diameter that the drop becomes was measured in two directions using a micrometer. The time is recorded from the drop touching the surface until it was fully absorb into the ball. A maximum amount of 30 minutes was allowed for the drop of oil to soak into the ball. This procedure was repeated four times on different portions of the ball and the average was taken from the four readings. With the time, surface area, and amount of oil known, mathematically an oil absorption rate was determined for each particular bowling ball.

In addition to the low radius of gyration, the radius of gyration on the positive axis point was added as an X-Variable. Based on the results of the recent axis migration study, USBC research determined that a ball migrates downlane on approximately the same RG profile. Therefore, the RG value on the positive axis point gave a clear representation of the RG value the bowling ball is rotating around during its entire trip toward the pins.

Although initially added as an X-Variable, this value ultimately was removed from analysis consideration because it proved to be statistically insignificant as correlated to the low RG radius of gyration.
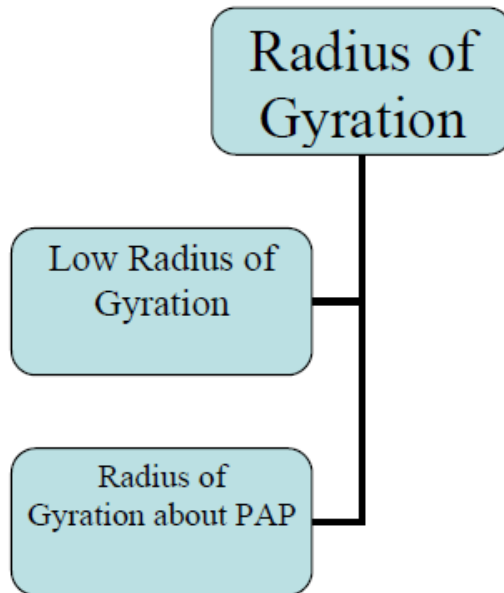

Figure 5: Radius of Gyration Phase II Components

Several more static X-variables were added. Environmental conditions such as air temperature, humidity, and lane temperature were tracked as static inputs to the model. Although these values were intended to be kept controlled with miniscule deviations, it was important to see if the natural variation by small degrees or percent affected the motion of the bowling ball. Average amounts of oil as applied to the lane were also incorporated. The amount of oil in units across the flat pattern was read at eight feet, thirty-two feet, and fifty-one feet (ultimately removed from analysis – directly correlated with On-Lane Friction variable). Static bowling ball weights, such as the amount of top weight, side weight, and thumb weight of the drilled ball were also included. Finally, the diameter of the ball as tested rounded out the new X-Variable list. One X-Variable, differential ratio, was removed since it was a direct mathematical calculation of two other X-Variables don in Phase I. The figure below shows the complete list of X-Variables used in Phase II analysis.

X-Variables
SR- Ra
On-Lane COF
SR- RS
Dry Lane COF
Oil Absorption
RG
Total Differential
Spin Time
Diameter
Side Weight
Int.-Diff
Oil @ 32'
Room Humidity
Oil @ 8'
Top Weight
Room Temp.
Thumb Weight
Lane Temp.

Figure 6: Ball Motion Study Phase II X-Variables

Next, the procedure was also revamped for Phase II. Balls were no longer thrown in a bracket head to head match-up due to the changes during Phase I. Instead, they were thrown four consecutive shots, followed by a single shot of a "standard" ball, and then four additional shots of the test ball. C.A.T.S. data from a total of 8 test shots were averaged for the ball path and the twenty Y-Variables were calculated. The "standard" ball was used as a visual double check to ensure the oil pattern and "Harry" were optimally configured. The test balls were thrown in a random order. The following figure displays the range of certain Y response values that the test balls produced. Due to the wider range in data collected, Phase II fulfilled one of the goals set forth from the beginning of the project which was to evaluate most levels of today's performing bowling balls.

	Low Value	High Value
Intended Path @ 49' (in)	5.83	14.03
Velocity Decrease @ 49' (mph)	1.31	2.53
Angle Change @ 49' (°)	2.06	4.89
A Score	0.0100	0.0165
Breakpoint (ft)	28.80	39.83
Angle/Foot (°/ft)	1.95	3.04
Average Path @ 60' (in)	13.98	24.58

Figure 7: Example showing Y-Variable Values

Once all tests were completed a chart of each X and each Y response for every test ball was configured. As discussed previously, the USBC patent pending process of multiple linear regression analysis was used to relate multiple X-Variables to each Y-Variable. As in Phase I, the goal of multiple linear regression analysis was again to determine how significant each X-Variable is to each Y-Variable. This process was able to be completed by evaluating the statistical P-Value that is reported for each X-Variable after each regression was run. Remember that each regression could have had up to all of the 18 X-Variables as being statistically significant to yield the particular Y-Variable that was regressed. The P-Value reported with each X-Variable on each regression signified how important that particular X-Variable was in relation to the other X-Variables in that regression. The smaller the associated P-Value the more significant the particular X-Variable influenced the predicted Y-Variable. An example of a regression analysis result is shown in the figure below. In the example, RG followed by SR-Ra and On-Lane Friction were the top three contributing X-Variables to the regression based upon the P-Value.

	Coefficients	Standard Error	t Stat	P-value
Intercept	101.8280041	21.24732062	4.792510356	0.004916017
Friction @ 38'	16.21334739	4.299483968	3.770998453	0.013009568
RG	-35.68695537	7.707155923	-4.630366341	0.005681898
SR- RA	0.195178074	0.046165344	4.227804988	0.00826565
SR- RS	-0.002643291	0.000823152	-3.211182545	0.023697459
i-Diff	72.08905934	48.99944958	1.471221819	0.201199672

Figure 8: Sample Regression Analysis

After each regression was complete, based on the P-Value, an 18 point score or tally system was used to determine the overall order of significance that each X-Variable had on the ball path. For example, assume that the figure above is an actual part of a regression analysis used in this study. A total of 18 X-Variables were regressed for the 18 point scale to apply. Since RG has the lowest or smallest P-Value, RG was given a score of 18 points. The next smallest P-Value occurred with the X-Variable SR-Ra, therefore, SR-Ra was given a score of 17. This sequence of points continued for each X-Variable in each regression. At the completion of the numerous regressions that were analyzed, the scores for each X-Variable were added together to determine the overall effect. The following graph shows the final results of the Ball Motion Study. The higher the bar on the graph, the more significant that particular X-Variable relates to the overall ball path.
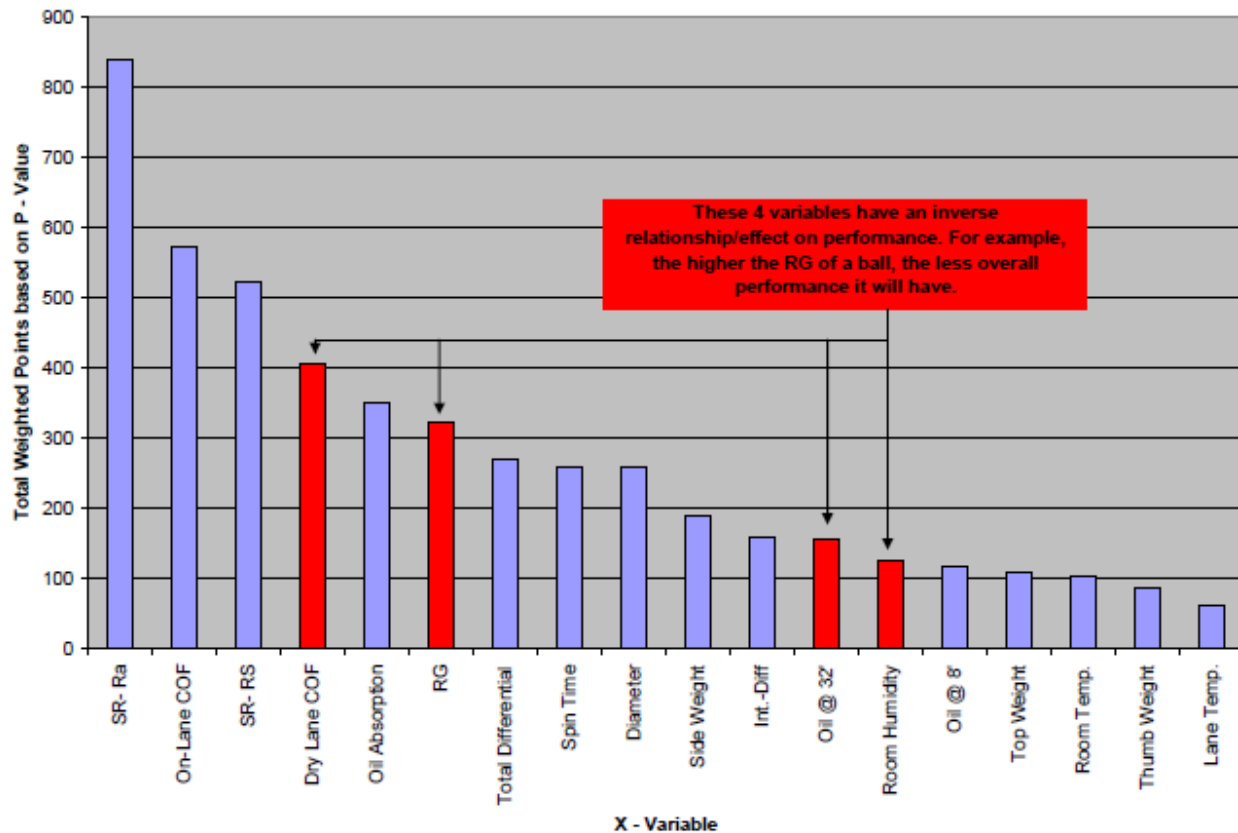
Figure 9: Ball Motion Study Results

As shown, the top 5 factors affecting the ball path are related to coverstock. SR-Ra, On-Lane Friction, SR-RS and the ball's ability to absorb oil affect the ball path in a direct form. For example, the greater the surface roughness of a bowling ball or the greater on-lane friction that a ball has will yield higher values in intended path, sooner transitions in the phases of ball motion, and thus be considered to be more aggressive. The next few factors that affect the ball path are related to core properties such as RG and Total Differential. Finally, the lesser contributing factors to the ball path are diameter, static weights, intermediate differential (Mass Bias Strength), and the controlled environmental conditions. Another important value to take away from the X-Variable chart is the four variables (Dry Lane COF, RG, Oil at 32', Room Humidity) which produce an indirect affect on the ball path. For example, the higher the RG of a bowling ball the less effect on intended path, later transitions in the phases of ball motion, and therefore is considered to be a less aggressive ball. The same applies to the other three inverse factors.

The next step was to perform a validation check on the modeling capabilities and trends that have been analyzed. All testing thus far was completed using Kegel offense oil and an AMF HPL lane surface. If a different oil and different lane surface was used, would the new generated data lead to the same resulting trends? Further testing was conducted on several bowling balls using a Brunswick lane surface and a different lane conditioner.

The following figure shows that despite a difference in the hard values, the overall trend for the following balls was the same. The order in performance both in intended path at 49' and 60' remained the same. Therefore, if a full test was completed the same trends would occur and the previously described results would be valid.

Lane 1 with Offense	Intend @ 49'	Intend @ 60'
EV10	14.03	24.2
NE21	13.28	23.45
IC16	11.29	21.32
PC23	9.37	18.9
Lane 8 with Authority 22	Intend @ 49'	Intend @ 60'
EV10	14.19	25.16
NE21	9.7	19
IC16	7.28	14.69
PC23	5.77	12.1

Figure 10: Data from Different Surface/Different Oil Test

With the Ball Motion Study complete and the results finalized, the top trends could now be evaluated to determine if any additional specifications were needed or, on the contrary, if current specifications needed to be relaxed or repelled. To preserve the balance of player skill and success in the sport, USBC could take measures on any important areas of ball motion/ball path that are not being adequately controlled. For example, there are two specifications currently on a bowling ball's coverstock, dry lane COF and Mohs Hardness. However, as indicated by the testing results, surface roughness and on-lane COF are extremely important to the ball path. Recently, USBC investigated the possible need for a surface roughness specification and in the upcoming year will investigate the need for a reduction in the static weight specification. Another important trait that has an effect on the ball path is the amount of oil that a coverstock absorbs. This characteristic will be analyzed in greater detail over the next year for a possible specification as well.

Concerning Surface Roughness - Ra, several tests have been conducted on a range of bowling balls from several companies on the market today. Balls were tested at various Abralon grits (180, 360, 500, 1000, 2000, 4000) along with a polished finish. The idea was to get a graphical representation of how surface chemistry reacts at different grits. Basically, of a majority of the balls on the market today, what is the average surface roughness value(s)? The figure below shows the Surface Roughness – Ra values for several bowling balls across several grits.
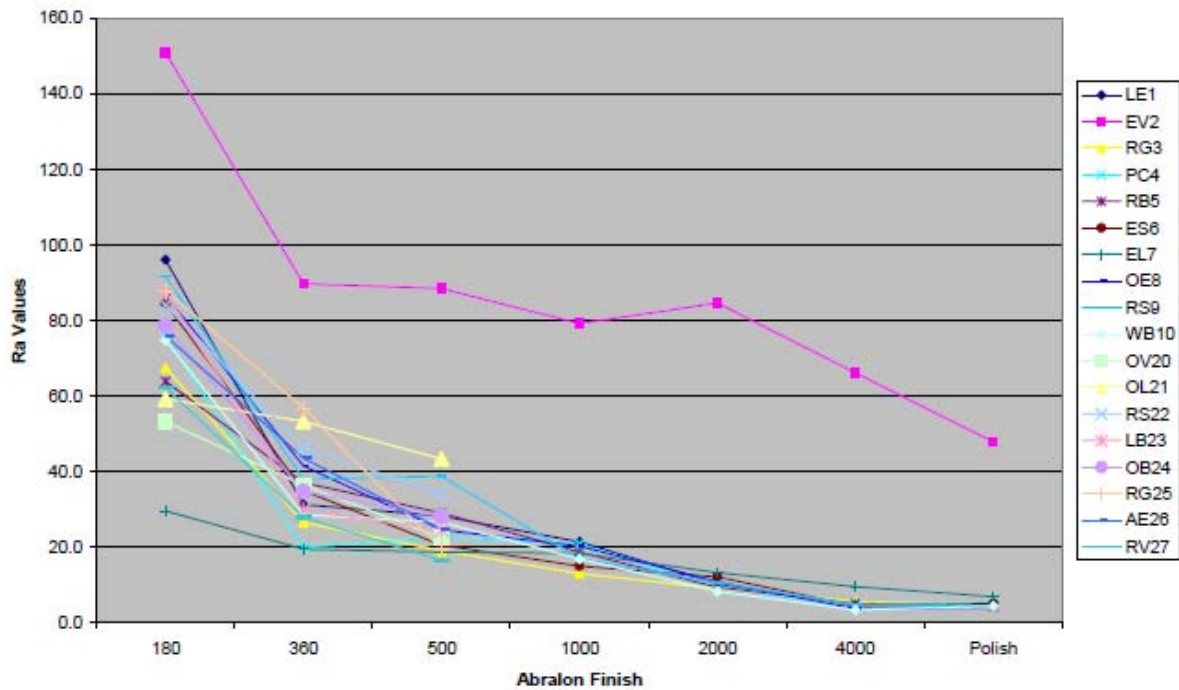
Figure 11: Surface Roughness – Ra Samples

Using a statistical analysis, the average and standard deviations for the wide range of balls tested was calculated at various Abralon finishes. Due to the significance to ball motion and lack of current specification on surface roughness, it was suggested that a specification on surface roughness occur. It was agreed upon by the task force and USBC to look closer at the 500 Abralon finish. It was at this grit that the balls begin to show a difference in surface roughness due to shell chemistry and this particular grit is common out in the "real-world". Using the 99% Upper Bound statistical method, the following figure displays the suggested specification.

Ra Data @ 500 Abralon

Average:	26
Stdev:	8
2Sigma:	15
3Sigma:	23
Specification @99% Upper Bound:	50
8 Additional Samples Required if Ra > :	35

EV2 value removed due to normality constraints

Figure 12: Ra Data at 500 Abralon

Based upon the data, USBC and the task force have moved forward in implementing a surface roughness specification at 500 Abralon. All Bowling balls submitted for

approval after 4/1/09 must be below a maximum average Ra Surface Roughness of 50 u-in. Balls above this value will not be approved, however, if the initial test results are between 35 and 65 u-in, the manufacturer will be required to submit 8 additional samples for re-testing to verify the overall average is below 50 u-in. (* *please see below*)

In summary, Phase I testing examined high end aggressive bowling balls and it was determined the top three factors affecting the ball path were Dry Lane COF, Oil Absorption, and Low RG. Phase II began by expanding the range of performance bowling balls for testing to get a more accurate and precise model on factors affecting the ball path. Also, Phase II incorporated greater detail on COF by using not only Dry Lane COF values, but On-Lane Friction measurements, two variations of Surface Roughness, and a new improved oil absorption test method. An additional RG test was also included. After close scrutiny and analysis, Phase II ultimately supported Phase I trends. Overall, the most significant factors that contribute to the ball path were determined to be Surface Roughness – Ra, On-lane COF, Surface Roughness – RS, Dry Lane COF, Oil Absorption, and Low RG. Basically, coverstock chemistry and porosity had greater influence on the ball path followed by certain core properties and finally static weights. In conclusion, the Ball Motion Study was a success at meeting its main objective: "To Better Understand Ball Motion". Due to the results of the study, a new specification on Surface Roughness – Ra has been approved by the Equipment Specification Committee and will take effect on April 1, 2009. Tests on static weights, Surface Roughness – RS, and Oil Absorption will be evaluated during the 2008 calendar year with a possible specification(s) later in 2009 or 2010.

*Note: Due to further testing and statistical analysis, in October of 2008 it was proposed to and accepted by the Equipment Specifications Committee that the point at which 8 additional bowling balls were to be requested for approval be adjusted from 35 u-in to 42 u-in. If a bowling ball submitted for approval has a surface roughness- Ra of over 42 u-in, 8 additional samples will be required for re-testing to verify the overall average is below the specification of 50 u-in.