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EVALUATION OF THE UNIFORMITY OF HARDWOOD ATHLETIC FLOOR SYSTEMS USING A GIS

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Summary:

Field testing of safety and performance characteristics was conducted on several different athletic floor systems. An overall performance ranking was given to each floor system, based on measured characteristics. The data from these tests were used to develop maps within a GIS. The spatial statistics capabilities of the GIS were used to analyze the spatial uniformity of the floor system properties. The results from the uniformity analysis were used to assign a uniformity ranking to the floor systems. The uniformity rankings and the performance rankings were examined for similar trends. Two floors were ranked in the top three in both rankings, and two floors were ranked in the bottom three of both rankings. This indicates that in general there is a tendency for floor systems with higher performance evaluations to be more uniform. The GIS was found to be a valuable tool for analyzing the uniformity of athletic floor systems.

Keywords:
DIN Testing, Moran Coefficient, Basketball

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1: INTRODUCTION

During recent years dramatic improvements have been made in the design of hardwood athletic floor systems. Floor systems have been designed so that they cushion during landings, reducing impact forces, and still provide the characteristics required for playing several sports. These improvements are commonly quantified by using mechanical tests. The tests examine the cushioning or shock absorbing properties, the ball rebound properties, and the deflection characteristics of the floors under impact. Current testing standards define recommended average values, but do not address the spatial uniformity of these characteristics over the playing surface. This study conducted field testing to generate maps of playing surface characteristics, which were then used to examine the uniformity of the playing system.

1.1: Biomechanical Considerations

Several authors (Hamil and Knutzen, 1995; Cavanagh and Lafortune, 1980; Nigg, 1983) have found that the vertical Ground Reaction Force (GRF) curve commonly has two noticeable peaks. Figure 1 is a recreation of a common vertical GRF curve From Nigg, (1993). The first peak is commonly referred to as the ‘passive peak’ or ‘impact peak’ (Hamil and Knutzen, 1995). This refers to the fact that this phase of the landing is not under neuro-muscular control. This first peak occurs during the heel-strike. The ‘passive peak’ is usually present about 10 ms after ground contact. Shock absorption measurements are intended to represent the ability of the floor system to reduce the ‘passive peak’ force load during landings.

The second peak in the vertical GRF curve is commonly referred to as the ‘active peak’ (Frederick and Hagy, 1986), because this phase of the landing is under the muscular control of the athlete. The magnitude of the ‘active peak’ is generally greater than the ‘passive peak’ (Hamil, and Knutzen, 1995). The active peak normally occurs after a period of approximately 40 ms. The typical duration for the total contact time during running is slightly less than 300 ms (Nigg, 1983). Measurements related to the deflection characteristics of the floor system are intended to examine the effects of the ‘active’ portion of the loading curve on the floor system.

Figure 1: Common vertical ground reaction force curve versus time (Nigg, 1983).

1.2: Basic Floor Geometry

Hardwood athletic flooring systems are composed of combinations of up to four basic layers. Figure 2 contains a schematic view showing the locations of these four basic layers. The Hard Maple playing surface is usually composed of tongue and groove jointed boards with lengths randomly distributed between 0.45m and 2.4 m. The sleeper layer, when present, is oriented 90^o to the boards in the playing surface layer. The sub-floor is most often composed of plywood. Resilient pads support the floor system above what is most commonly a concrete floor. The material properties and geometry of the resilient pads can be varied to obtain different system characteristics.

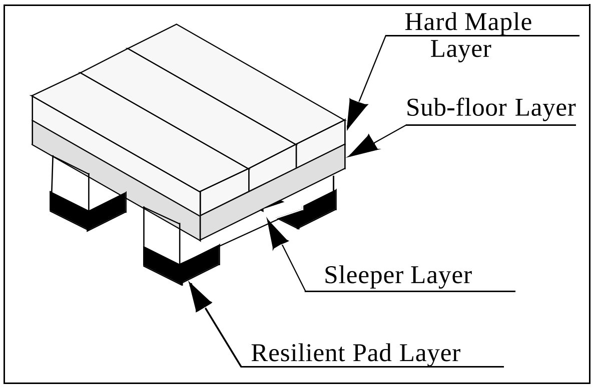

Figure 2: Schematic showing general components of a hardwood athletic floor system.

2: METHODS

Six floors in high-school and college gymnasiums were evaluated in this study. The floors contained a variety of different constructions, and resiliency levels. Each floor was tested using the same test pattern and the data was used to generate grid maps within a GIS. These maps were then evaluated using spatial statistics to examine the uniformity of each data layer. This section outlines the methods and materials used throughout this study.

2.1: Mechanical Testing

Evaluation of floor system performance characteristics was conducted according to standard 18032 part II (DIN, 1991) from the German Institute of Standardization (hereafter referred to as DIN standard 18032). The methods will be summarized in this report for the purpose of brevity, but a full explanation of the procedures can be found in the DIN standard 18032.

One of the first things noticed when players walk onto a floor system ball bounce behavior. The ball bounce property is evaluated by comparing rebound heights on concrete to those of the floor systems. There are two primary variables in determining ball rebound height on concrete: ball inflation pressure and concrete stiffness properties. It was assumed that inflation pressure was the dominating variable when obtaining the rebound height on concrete at each floor site. This assumption is supported by the fact that the floor systems, which are highly resilient compared to concrete, normally produce less than a 10% change in the rebound height compared to concrete.

Ball reflection is expressed as a percent of the rebound height obtained on concrete. The equation below shows how ball reflection, which is the term used in the DIN standard, is calculated. A ball reflection value of greater than 90% is required to be considered acceptable within the DIN 18032 standard guidelines.

$$\text{Ball Reflection} = \frac{\text{Rebound Height}_{?floor?}}{\text{Rebound Height}_{?concrete?}} ? 100 \qquad [1]$$

This test uses a tripod to release the ball. A rendering of this tripod is shown in Figure 3. This study measured height by using an ultrasonic distance sensor, with a range of 0 m to 6.0 m.

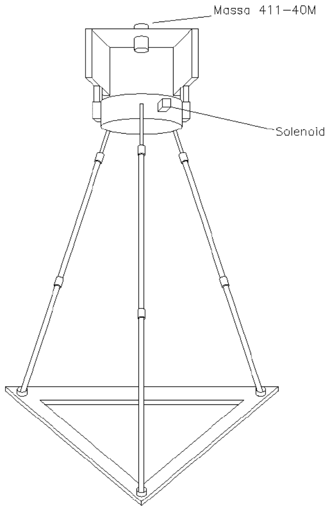

Figure 3: Rendering of ball drop test apparatus.

Shock absorption, the next performance characteristic measured, was obtained by comparing the peak force which occurs during an impact on the floor system to the peak force which occurs during a similar impact on concrete. In this test, a 20 kg mass is released from a height of 55 mm and allowed to impact a housing containing a spring with a 2,000 kN/m stiffness. The housing also contains a 20 kN load-cell to record the impact force generated during impact. Figure 4 shows a schematic drawing of the test apparatus used to impact the floor and determine the shock absorption characteristics. Three drops are required to characterize the response of a particular point. The spring is present to attenuate the impact so that it more closely resembles the impact of an athlete during the early, or passive, portion of a landing. The shock absorption (*SA*) characteristic of the floor system, in percent, is given by the following equation when the stiffness of the test attenuation spring is between 1975 and 2025 kN/m

$$SA = {}^{?}_{?}1 - \frac{F_{\text{max, gym floor}}}{F_{\text{max, rigid floor}}}{}^{?}_{?} ? 100 \qquad [2]$$

where

$F_{max,gym\ floor}$ = Maximum force from a floor system

$F_{max,rigid\ floor}$ = Maximum force from a rigid surface

A shock absorption value of 53% or greater was considered acceptable by the DIN standard 18032.

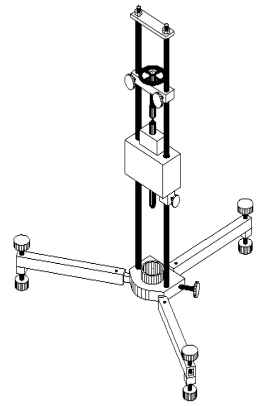

Figure 4: Schematic of the Shock Absorption test apparatus.

A device similar to the one used to determine the shock absorption properties of the floor system was used to examine floor system deflection characteristics. The primary differences between the two devices were an increase in drop mass, to 50 kg, and a reduction in the stiffness of the force attenuation spring to, 50 kN/m. Floor system deflections were recorded using linear-velocity-displacement-transducers, or LVDT’s. The locations of the LVDT’s are shown in Figure 5.

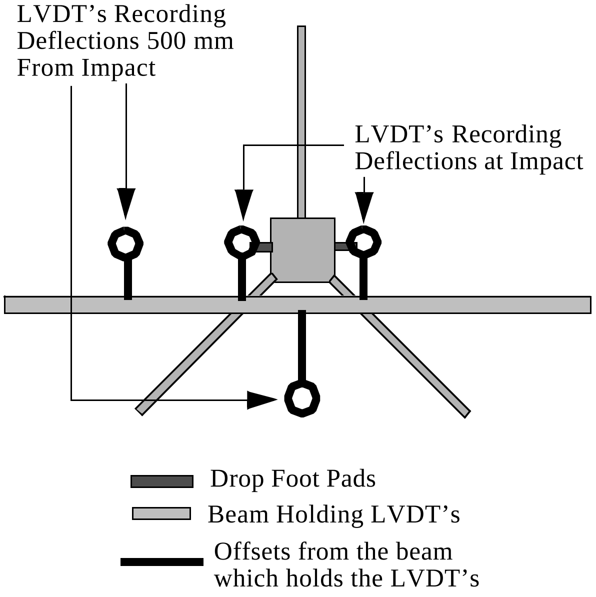

Figure 5: Schematic top view of the test setup used to examine the deflection characteristics of hardwood athletic floor systems.

As the impact occurs the maximum value from four time-domain signals were recorded: i) impact force, ii) floor system deflection at impact, iii) floor system deflection 500 mm from the impact parallel to the boards in the maple playing surface, and iv) floor system deflection 500 mm from the impact perpendicular to the boards in the maple playing surface.

The values obtained during testing are then used to compute two normalized parameters which can be used to evaluate the deflection characteristics of the floor system. The first deflection characteristic parameter used from the DIN standard 18032 was the standard vertical deflection, (*StVv* for short). The equation for *StVv* is given below and is in units of millimeters. It represents the deflection expected during an impact of 1500 N. A value of 2.3 mm or greater is recommended by the DIN standard.

$$StVv = 1500\frac{f_{1max}}{F_{max}} \qquad [3]$$

where

f_{1max} = Maximum deflection at impact

F_{max} = Maximum force of impact

The second parameter calculated is the area indentation, or *AI* for short. Area indentation is the ratio of the magnitude of the deflection which occurs 500 mm from the impact point to the deflection which occurs at the point of impact. It is presented in units of percent, and shown in the equation below.

$$AI = \frac{f_{500}}{f_{1max}}100 \qquad [4]$$

where

f_{500} = Maximum deflection 500 mm from impact

Area indentation is calculated for the deflection obtained parallel to the maple surface boards and perpendicular to the maple surface boards. The average value is also calculated and presented. The DIN standard 18032 recommends area indentation values below 15%.

In order to reduce the number of points that would be tested to characterize a floor, it was assumed that symmetry of the court and style of play would allow one end to be used to evaluate the entire floor. The final layout of points to be tested is shown in Figure 6. The locations of the points which were tested needed to be consistent for all floors. It was desired to have some points in high use areas, and some points in relatively low use areas. The point which is in a very high use area during a basketball game is directly beneath the goal. The location of this point is centered between the sidelines, and 1.5 m from the baseline. In order to determine test point locations easy, it was decided that a box which was 1.5 m from the sidelines, baseline, and time-line should be used. The points at all corners on this box were used as test locations (Points 1, 3,7, and 9 in Figure 6). Next a line midway between the sidelines was constructed, and the points at the intersection of this line and the 'box' were used as test locations (Points 2 and 8 in Figure 6). Finally a line parallel to the baseline was placed on the box at the top of the three-point arc, and the points at the intersections between this line and the box, as well as the intersection of this line and the line bisecting the court were used (Points 4, 5 and 6 in Figure 6).

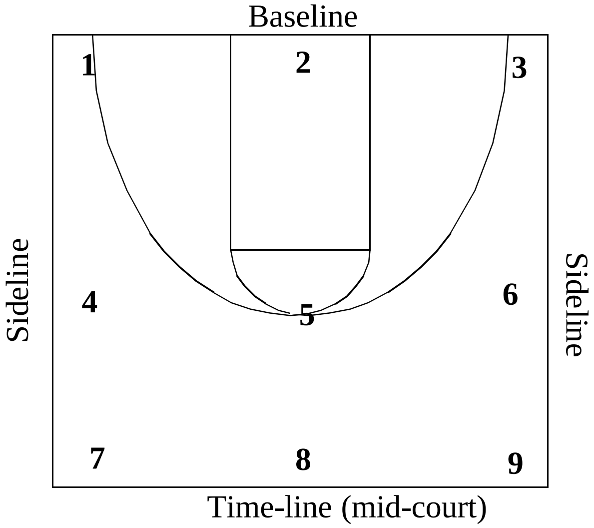

Figure 6: Schematic of points to be tested during field data collection

2.2: GIS Uniformity Evaluation

Grid maps of the raw data layers were generated within the ARC™ Geographic Information System (GIS). The raw data layers were then manipulated to obtain the ball reflection, shock absorption, standard vertical deflection, and area indentation maps. The uniformity or similarity of the data within these maps was then statistically evaluated using the Moran coefficient. The following equation yields the Moran coefficient (*I*) (Goodchild, 1986).

$$I = \frac{\sum \sum w_{ij} m_{ij}}{\sum \sum w_{ij} \left(\frac{\sum (z_i - z_m)^2}{n} \right)} \qquad [5]$$

where

n = total number of cells in the grid

i, j = any two cells

z_i = the value of the attribute of cell i

z_m = the mean cell value for the grid

m_{ij} = the similarity of i's and j's attributes

w_{ij} = the similarity of i's and j's locations ($w_{ij} = 1$ if cells i and j are directly adjacent, 0 otherwise)

and

$$m_{ij} = (z_i - z_m)(z_j - z_m) \qquad [6]$$

z_j = the value of the attribute of cell j

Table 1 shows the interpretations of the results from the Moran coefficient. The coefficient has values which correspond to similar/uniform data sets, independent/uncorrelated data sets, and dissimilar/non-uniform data set. The overall uniformity of each floor system was evaluated by simply counting the number of layers which were indicated to be similar by the Moran Coefficient. Layers producing Moran coefficient values between -0.1 and 0.1 were considered independent and added one half to the number of uniform data layers.

Table 1: Interpretations of Moran Coefficient

Moran Coefficient Value	Interpretation
I > 0	Similar, regionalized, smooth, clustered
I = 0	Independent, Uncorrelated, random
I < 0	Dissimilar, contrasting, checkerboard

3: RESULTS AND DISCUSSION

3.1: Field Testing

Figures 7 - 9 contain sample data sets collected during this study to evaluate ball reflection, shock absorption, and the deflection characteristics, respectively.

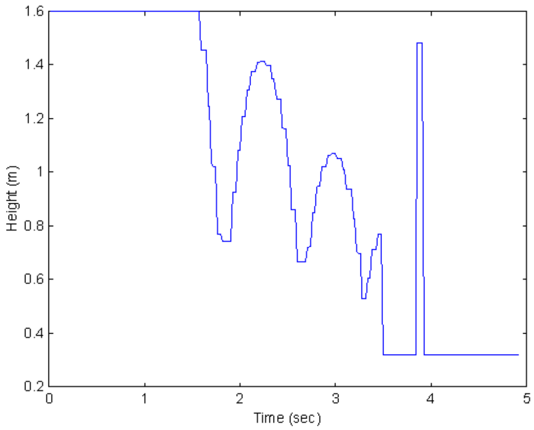

Figure 7: Sample of ball height versus time, from a ball reflection test.

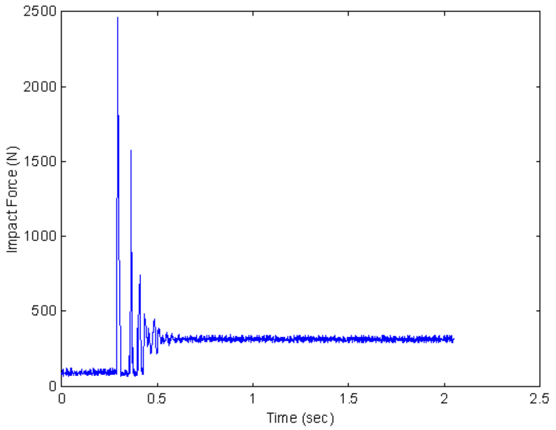

Figure 8: Sample force versus time curve generated during a shock absorption test.

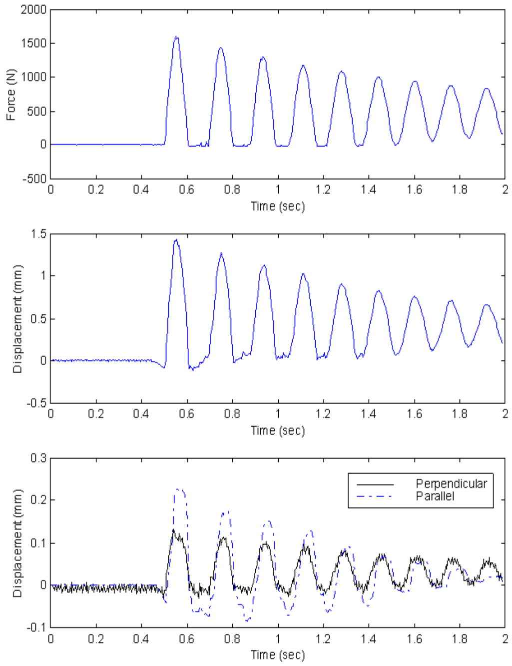

Figure 9: Sample data set collected during field testing.

Table 2 contains the data collected from one of the floor systems tested. The trends shown in Table 2 were representative of the trends present in each floor. Each of the parameters measured varies significantly within a floor. Area indentation and standard vertical deflection contained largest amounts of variation within floors, and between floors.

Table 2: DIN testing results summary

Floor Characteristic	Mean	Max	Min	Stnd Dev
Ball Reflection (%)	97.1	98	96	0.6
Shock Absorption (%)	52.4	56	46	2.4
Stand. Vert. Defl (mm)	2.20	2.60	1.89	0.2
Area Indentation (%)	25.1	27	19	2.9

3.2: GIS Uniformity Evaluation

The spatial data sets used to develop the table presented in section 3.1 were used to create maps within ARC™. A sample map obtained from the evaluation of the shock absorption properties is shown in Figure 10. Figure 11 contains a map of the standard vertical deflection for the same floor. The shock absorption map contains five cells with the same value, 64%, and appears to contain more uniform data than the map representing the standard vertical deflection. The Moran coefficient was computed for every layer, and every floor to allow uniformity to be quantitatively examined.

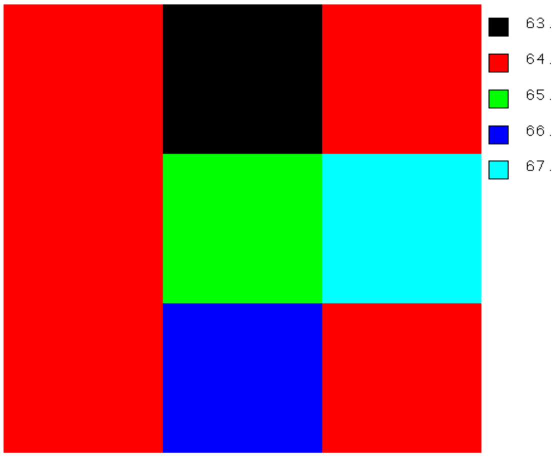

Figure 10: Shock absorption map created from data collected on floor ‘C’.

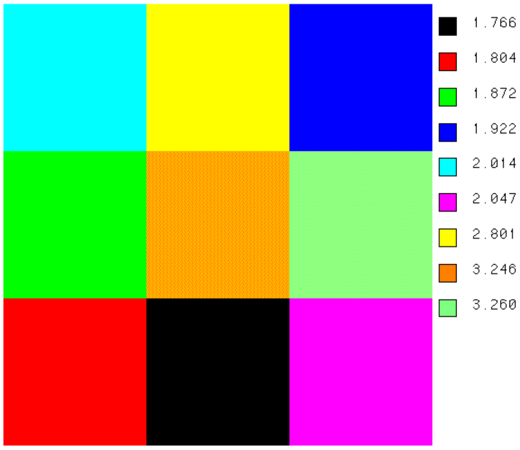

Figure 11: Map of the standard vertical deflection characteristics of floor ‘C’.

The Moran coefficients were computed and evaluated to determine if they indicated uniform or nonuniform data layers. Tables 3 contains the results of this process for the floor used to obtain the maps in Figures 10 and 11. Tables 3 also contains the total number of uniform data layers indicated for the floor system.

Table 3: Moran coefficients and their meanings for A Sample Floor

Floor Property	Moran Coefficient and Meaning
Ball Reflection	-0.06 (SS/R)
Shock Abs	0.05 (SS/R)
Area Indentation	-0.07 (SS/R)
Standard Vertical Defl	0.08 (SS/R)
Total Uniform Layers	2
(D) = Dissimilar, Contrasting, Checkerboard (SS/R) = Slightly Similar to independent, Random (S) = Similar, Regionalized Smooth, Clustered	

The number of uniform data layers can be used to order the floors from most to least uniform. This uniformity order is presented in Table 4. Increasing numbers in the uniformity ranking column indicate less uniform floor systems, and floors with the same uniformity ranking were considered equally uniform. Floor systems were also ranked based on the evaluated performance characteristics. Ball reflection, shock absorption, and standard vertical deflection are ranked highest (1) to lowest (6), as the DIN standard considers higher numbers in these categories to indicate superior floor systems. The area indentation is ranked from lowest (1) to highest (6) because the DIN standard considers superior floors to have lower values in this category. Finally, an overall performance ranking, as shown in Table 4, was determined by computing the average rank of the four performance characteristics. The floor with the best overall performance ranking was assigned 1, and the floor with the poorest overall performance ranking was assigned 6.

Table 4: Uniformity and performance characteristic rankings.

Floor	Uniformity Ranking	OVerall Ranking Using Average Performance Characteristic Rank
A	4	6
B	4	2
C	2	1
D	3	3
E	1	5
F	4	4

Table 4 shows that two of the floors, ‘C’ and ‘D’ rank in the upper half for uniformity and performance, and that two of the floors ‘A’ and ‘F’, rank in the lower half for uniformity and performance. This indicates that there is at least a tendency for the floors which rank higher in performance testing to be more uniform than those which perform poorly during performance evaluation.

4: CONCLUSIONS

This study found that a GIS can effectively be used along with collected field data to produce maps illustrating the performance characteristics of hardwood athletic floor systems. The GIS allows the computation of several standard spatial statistics such as mean, maximum, minimum and standard deviation, as well as the evaluation of spatial parameters such as similarity or uniformity. The GIS was found to provide a tool by which the uniformity of a floor system could be numerically evaluated. It was also determined that performance rankings are somewhat related to floor system uniformity. This relationship is not consistent, and some rank high in one type of evaluation and low in another type of evaluation. This means that neither performance characteristics or uniformity evaluations should be used alone to classify floor systems, both should be presented to more fully convey the properties of the floor system.

5: ACKNOWLEDGMENTS

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6: REFERENCES

[1] Cavanagh, P. R. and M. A. Lafortune, 1980. Ground reaction forces in distance running. Journal of Biomechanics v. 15 pp 397-406.

[2] DIN Standard 18032 part 2 (1991). Sports halls, halls for gymnastics and games sports floors requirements, testing.

[3] Frederick, E. C. and J. L. Hagy. 1986. Factors affecting peak vertical ground reaction forces in running. International Journal of Sport Biomechanics, v 2 pp 41-49.

[4] Hamill, J. and K. M. Knutzen, 1995. Biomechanical Basis of Human Movement, Williams and Wilkins, Media, PA.

[5] Nigg, B. M. 1983. External force measurements with sports shoes and playing surfaces. Biomechanical Aspects of Sports Shoes and Playing Surfaces, Nigg and Kerr Editor. University of Calgary, pp 11-23.