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Improving the Serving Motion in a Volleyball Game: A Design of Experiment Approach

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Abstract

The statistical design of experiment (DOE) is a procedure of planning controlled experiments for investigating the effect of some process on some experimental units. Although the DOE method has a wide range of applicability in various scientific areas, the DOE application in sport science has been received less consideration. Similarly, this study tries to determine the most significant factor in hitting the ball to a desirable distance in Volleyball serve motion. To conduct the experiments four factors were identified, which are "start angle of arm", "stop angle of arm", "the required force for striking the ball", and "the arm length of the server". The experiments were conducted according to the design of experiment (DOE) with the help of Design Expert software, and the results were statistically evaluated using analysis of variance (ANOVA). The findings of the study show that "force" has the most significant effect on the objective of experiments.

Keywords: *Design of Experiment (DOE), Volleyball Serve, Full Factorial Design, Analysis of Variance (ANOVA), Optimization.*

1. Introduction

A server in a volleyball game stands behind the inline and hit the ball, in an attempt to drive it into the opponent's court. Basically, the server objective is to make the ball landed inside the court; Further it would be more desirable if the ball's direction, speed and acceleration to be arranged, so that the receiver faces difficulty in handling the ball properly. The procedure of hitting the ball in a volleyball serve is illustrated in Figure 1.

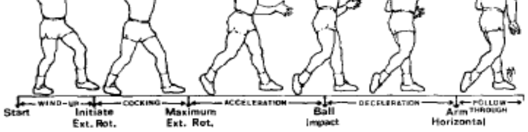

Fig. 1 The six steps of volleyball serve.

Angle of arm, force of hitting the ball and length of the player arm represent elements in determining the ball flight distance for a volleyball serve. To have a competitive level of proficiency, the player should come up with the appropriate level of applied force as well as a proper angle of arm while striking the ball. Hence, this study will investigate the effect of different factors on the flight distance of the ball in serve motion in order to determine the significant factors that affect this distance.

2. Literature Review

2.1 Volleyball Serve

Volleyball game is a competitive and refreshing game which came into being for almost one century. Despite the lengthy period of its existence, the biomechanical aspect of it has been received inadequate attention [1]. There are five factors of "digitization", "velocities", "trajectory angles", "performance mechanics", and "correlation" that are applied to study the volleyball serve motion biomechanically [2]. These factors can be measured by various methods, which will evaluate the effectiveness of serve motion accurately [3].

Making fewer errors than competitors will improve the chance of winning the game which causes enhancing the serve motion as a priority in game of volleyball [4]. Serving is an important time of scoring in the game since it is the only skill that put the ball into play; furthermore, the player has a total control over it during the execution [5]. Velocity, movement and placement are among the factors that are denoted as vital features of an offensive serve [6]. In addition, Rugosi [7] believes that serve placement has the most significant role in creating a good serve since a strategic location of it can disturb the offensive options of the receiving team. So, serve can be considered as one of the most important skills in winner determination process of volleyball game.

2.2 Design of Experiment (DOE)

Design of Experiment (DOE) is a structured and organized method to determine the relationship between different factors, which have influence on the process and its output [8]. The DOE method dates back to the beginning of the last century worked by Fisher [9]. He developed the basic principles of factorial design and the associated data analysis known as ANOVA during research in improving the yield of agricultural crops [10]. DOE can either be very simple or very complicated according to the number of factors studied and formulated assumptions [11].

In this method, an experimentalist changes one or several process variables (factors) in order to observe the effect that the changes have on one or several response variables [8]. DOE starts with determining the objectives of an experiment and selecting the process variables for the study. There are many different DOE methods, and the best choice depends on the objectives of the analysis and the number of factors to be investigated [12]. There are four interrelated steps, which should be considered for conducting DOE. First of all, the objective should be defined; then the number and nature of design variables should be determined, and finally by defining the nature of the responses and the number of experimental runs, the number of standard designs will be available. The best design would be the most compatible one with the objectives, number of design variables, precision of measurement and reasonable cost [13].

The DOE associated data should be analyzed by ANOVA method. The analysis of variance (ANOVA) is a commonly used tool to study and estimate the factor influences on a process. It is also utilized in order to determine whether these effects are significant or are only the expression of the system variability due to the uncontrolled factors. Analysis of the variance enables the determination of the point starting from which, an effect threshold can be regarded as significant [11].

One of the considerable DOE applications is in research and development studies when a large amount of resources should be used to solve an optimization problem. In these cases DOE will minimize the costs by conducting as few experiments as possible; hence, it will be highly cost effective. A common experimental design is one with all input factors set at two levels each. These levels are called 'high' and 'low' or '+1' and '-1', respectively. A design with all possible high/low combinations of all the input factors is called a full factorial design in two levels [11] which this study uses it to conduct the experiment.

In addition, the results of study are summarized with ANOVA tables to ease the process of determination the significant factors.

3. Methodology

3.1 Research Instruments

Three volleyball players were selected to execute our experiments. The start and stop angle were measured by using two ropes. The distance was calculated by meter, and a camera was used to film each of the trials of serves performed by the servers for measuring the time.

3.2 Research Procedure

The participants were filmed during executing the serve motion to determine the time duration of arm movement between start and stop angle. Each server was told to perform sixteen overhand serves as he would execute the skills in the course of a volleyball game. As shown in Figure 2, the serving zone was limited to 18 meters (60 feet) long by 9 meters (30 feet) wide, and the passer was placed at the beginning of this zone. The server was awarded according to where the ball falls into the ground.

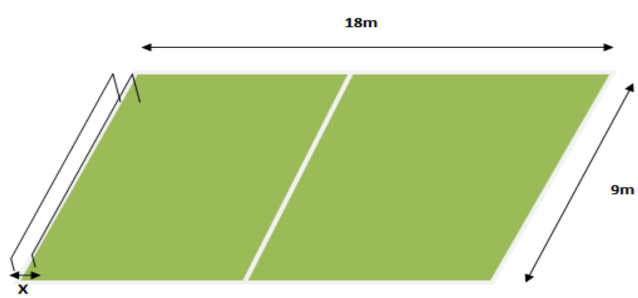

Fig. 2 Volleyball ground and its dimensions.

- Measuring start and stop angle:

Two ropes were utilized for measuring start and stop angle. Server was asked to locate his hand at the place of first rope and hit the ball at the place of second rope. Desirable start and stop angle can be achieved by changing the place of the player between two ropes and different distances of these ropes.

- Measuring force:

Force is the most critical factor that must be measured in this experiment. The amount of force can be controlled by the time in which the player must react and hit the ball, and this time would be restricted by height of the ball from the ground. If the player wants to move his arm faster between two ropes, he must exert more amounts of force; so controlling this time leads to a controlled amount of force that player should exert. Hence, in this experiment, the reaction time is controlled by the height of the ball from the ground. The used Physic's law in this experiment is shown in Figure 3.

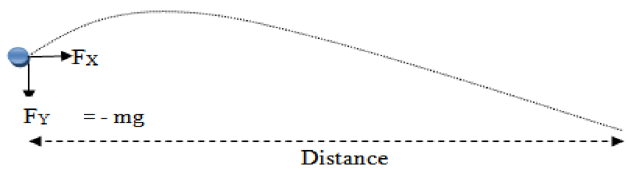

Fig. 3 Ball flight distance.

In this experiment, the highest and lowest level of force is considered as 10N and 6N respectively. To insure the amount of force which is 10N the player should move his arms between two ropes as fast as 3.019 m/s^2, which is calculated according Eq. (1).

'm_{Arm}' is equal to 3.216 Kg, and 'g' is considered 10 m/s^2.

$$F_{Player} = m_{Arm} * a_{Arm} \quad (1)$$
$$10N = 3.216\ Kg * a_{Arm}$$
$$a_{Arm} = 3.109\ m/s^2$$

$$X = 1/2 * a * t^2 + V_0 * t + X_0 \quad (2)$$

Where;
X : The space between two ropes, which here is equal to 0.5 m.
V_0 : Horizontal velocity of the arm at the place of the first rope, which here is equal to 0.
$X_0 = 0$

So;
t = 0.576 sec

$$Y = 1/2 * g * t^2 \quad (3)$$

So;
Y = 1.61 m

If the ball has fallen from 1.61 m, it will take 0.576 sec. Therefore, it will take 0.576 sec for the player to react in order to apply 10N force. The same procedure based on Eq. (1), Eq. (2), and Eq. (3) was done to determine the reaction time for the force of 6N, which is the low level of force. The results are as follow;

$a_{Arm} = 1.866\ m/s^2$
t = 0.732 sec
Y = 2.68 m

3.3 Data Analysis Method

To analyze the data, total of five variables were taken into consideration namely distance, start angle, force, arm length and stop angle. Data were analyzed using Design Expert software V8. Results are presented through frequency counts and other descriptive statistics.

4. Research Design

4.1 Research Design Variables

The design variables are described into two main groups, which are response parameter and volleyball serve parameters.

- Response parameter:

The distance from the player to the spot where the ball lands directly onto the court or travels outside the court after being touched by an opponent (Y = distance).

- Volleyball serve parameters:

The experiment has four factors that might affect the distance that ball travels in volleyball serve. The variables are as follow:

1. Factor 1: start angle (location of the arm when the player starts the forward motion of the arm – levels are 10 and 50 degrees with a center point level of 30 degrees).

2. Factor 2: force (the player is asked to hit the ball with approximately 10 N and 6 N).

3. Factor 3: arm length (distance the arm is extended – levels are 60 and 70 cm with a center point level of 65 cm).

4. Factor 4: stop angle (location of the arm where the forward motion of the arm is stopped and the ball starts flying – levels are 0 and 20 degrees with a center point level of 10 degrees).

4.2 Experimental Design

In this study, randomizations of the run order and analysis sequences were carried out according to the run order by Design Expert software. Full factorial design of four factors with two levels and three replicates was conducted, which consist of 48 runs plus four center points that resulted in a total number of 52 trials. The response (distance) that was calculated by measuring different amounts of each factor and combination of them is shown in Appendix.

5. Results and Analysis

As mentioned earlier, Design Expert software was used to analyze the data in order to identify the significant factors and interactions between the studied factors. Analysis of variance (ANOVA) table is utilized to summarize the experimental results.

5.1 Normal Probability

Normal probability plot is used to show the significance of factors. As it is clear from Figure 4, points A (start angle), B (force), C (length) and BC (force and arm length) are the significant factors due to their distance from the straight line. These factors are both in single and interactions way. 'B' is the farthest from the line supporting the main effect plot that indicates force as the main factor.

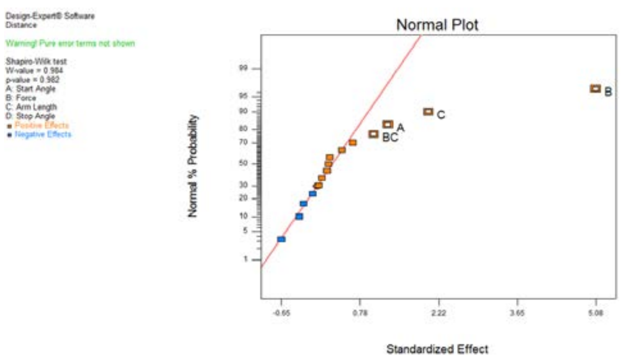

Fig. 4 Normal plot.

5.2 Results Analysis for Distance Parameter in Volleyball Serve

In this section, the results of the experiments are summarized by ANOVA tables. Based on Figure 5, there are four significant effects which are 'A', 'B', 'C', and also interaction between 'B' and 'C'. The rest of the factors are not significant, as they just appeared to complete the hierarchy. The ANOVA summary indicated in Figure 6 implies that the model term is significant, and the curvature is not significant. Model summary is shown in Figure 7.

Selection: Manual   Order: Modified

	Term	Stdized Effects	Sum of Squares	% Contribution
	Intercept			
M	A-Start Angle	1.29	20.02	4.46
M	B-Force	5.08	310.08	69.07
M	C-Arm Length	2.03	49.61	11.05
e	D-Stop Angle	0.18	0.40	0.090
e	AB	0.46	2.52	0.56
e	AC	0.092	0.10	0.022
e	AD	0.66	5.20	1.16
M	BC	1.03	12.81	2.85
e	BD	0.23	0.65	0.15
e	CD	0.033	0.013	2.970E-003
e	ABC	-0.24	0.70	0.16
e	ABD	0.21	0.52	0.12
e	ACD	-0.075	0.068	0.015
e	BCD	-0.65	5.07	1.13
e	ABCD	-0.32	1.27	0.28
M	Curvature	0.28	0.80	0.18
e	Lack Of Fit		0.000	0.000
e	Pure Error		39.11	8.71
	Lenth's ME	0.63		
	Lenth's SME	0.97		
	Pure Error			

Fig. 5 Factor effect estimates and sum of squares for the 2^4 factorial.

	Adjusted Model		Unadjusted Model	
	F-value	p-value	F-value	p-value
Model	81.14	< 0.0001	81.72	< 0.0001
Curvature	0.66	0.4190		
Lack of Fit	1.34	0.2428	1.29	0.2666

Fig. 6 ANOVA summary.

	Adjusted Model		Unadjusted Model	
	Coefficient		Coefficient	
Factor	Estimate	p-value	Estimate	p-value
Intercept	10.16		10.19	
A	0.65	0.0002	0.65	0.0002
B	2.54	< 0.0001	2.54	< 0.0001
C	1.02	< 0.0001	1.02	< 0.0001
BC	0.52	0.0021	0.52	0.0020
Center Point	0.47	0.4190		

Fig. 7 Model summary.

The following ANOVA is for a model that adjusts to curvature. This is the default model used for the diagnostic plots.

ANOVA for selected factorial model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	392.53	4	98.13	81.14	< 0.0001	significant
A-Start Angle	20.02	1	20.02	16.55	0.0002	
B-Force	310.08	1	310.08	256.39	< 0.0001	
C-Arm Lengtl	49.61	1	49.61	41.02	< 0.0001	
BC	12.81	1	12.81	10.59	0.0021	
Curvature	0.80	1	0.80	0.66	0.4190	not significant
Residual	55.63	46	1.21			
Lack of Fit	16.52	11	1.50	1.34	0.2428	not significant
Pure Error	39.11	35	1.12			
Cor Total	448.97	51				

Std. Dev.	1.10	R-Squared	0.8743
Mean	10.19	Adj R-Squared	0.8636
C.V. %	10.75	Pred R-Square	0.8459
PRESS	69.20	Adeq Precisior	24.745

Fig. 8 ANOVA results.

As shown in Figure 8, the Model F-value of 81.14 implies that the model is significant. There is only a 0.01 percent chance for occurring "Model F-Value" due to noise with the specific size. The Curvature F-value of 1.34 indicates that there is no significant curvature (as measured by the difference between the average of the center points and the average of the factorial points) in the design space.

The "Pred R-Squared" of 0.8459 is in a reasonable agreement with the "Adj R-Squared" of 0.8636. Although the "Adeq Precision" greater than 4 is desirable, the ratio of 24.745 indicates an adequate signal which leads to the conclusion that the model is proper enough to navigate the design space.

5.3 Regression Model and Response Surface

Final equation in terms of coded factors is shown in Eq. (4);

$$Distance = +10.19 + 0.65 * A + 2.54 * B + 1.02 * C + 0.52 * B * C \quad (4)$$

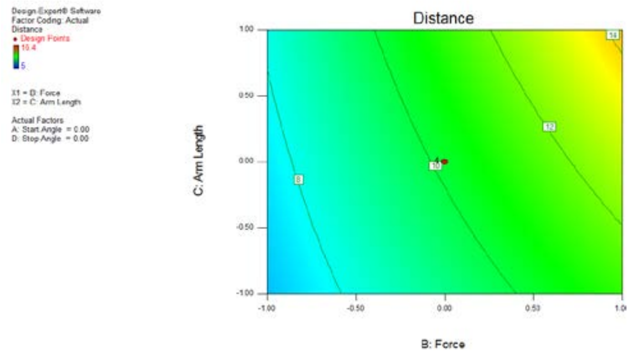

Fig. 9 The contour plot.

Figure 9 indicates the contour plot for distance response. Because the model contains interaction, the contour lines are curved. The figure illustrates that the distance increases as both force and arm length increase. It also shows that several combinations of force and arm length will satisfy the objective of hitting the desirable distance of the struck ball.

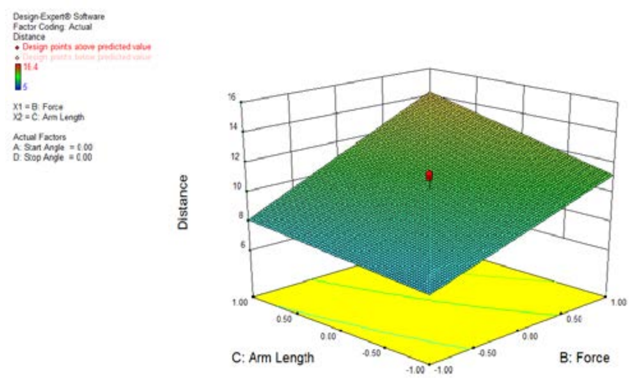

Fig. 10 3D response surface for BC interaction.

Figure 10 presents the three-dimensional response surface graph of distance response. Due to the interaction between force and arm length, our model is a second order one; therefore, fitted response surface is a curve (twisted plane). But as mentioned earlier, there is no evidence of the second-order curvature in the response because the curvature was not significant.

5.4 Optimization

For maximizing the distance that ball travels in volleyball serve, Design Expert 8 software was utilized. Figure 11 shows twenty-three best solutions in order to maximize the distance.

Number	Start Angle	Force	Arm Length	Stop Angle *	Distance	Desirability	
1	50.00	10.00	70.00	10.00	14.9151	0.559	Selected
2	49.79	10.00	70.00	10.00	14.9082	0.558	
3	49.16	10.00	70.00	10.00	14.8879	0.555	
4	50.00	10.00	69.90	10.00	14.8856	0.555	
5	50.00	9.98	70.00	10.00	14.8808	0.554	
6	48.61	10.00	70.00	10.00	14.8702	0.553	
7	50.00	9.96	70.00	10.00	14.8463	0.549	
8	50.00	9.98	69.69	10.00	14.7976	0.543	
9	46.23	10.00	70.00	10.00	14.7934	0.542	
10	50.00	9.86	70.00	10.00	14.6971	0.528	
11	42.72	10.00	70.00	10.00	14.6801	0.526	
12	41.33	10.00	70.00	10.00	14.6352	0.519	
13	40.05	10.00	70.00	10.00	14.5936	0.513	
14	39.32	10.00	70.00	10.00	14.57	0.510	
15	48.04	9.80	70.00	10.00	14.5507	0.507	
16	31.08	10.00	70.00	10.00	14.3041	0.472	
17	28.91	10.00	70.00	10.00	14.2342	0.462	
18	50.00	10.00	67.77	10.00	14.23	0.461	
19	50.00	9.53	69.98	10.00	14.1887	0.456	
20	25.33	10.00	70.00	10.00	14.1185	0.445	
21	21.91	10.00	70.00	10.00	14.0078	0.430	
22	19.81	10.00	70.00	10.00	13.94	0.420	
23	18.62	10.00	70.00	10.00	13.9018	0.415	

Fig. 11 Best solutions for maximizing ball distance.

5.5 Confirmation Run

In order to verify the adequacy of the model that was developed in section 5.3, four confirmation runs were performed. Using the point prediction tool of the software, the distances of the selected experiments were predicted by the confirmation runs.

Figure 12 demonstrates an example of the output by using the point prediction tool based on the models that were developed by the software. The predicted and the actual values from confirmation runs were compared by calculating the residuals and percentage of error. These values are presented in Table 1.

Factor	Name	Level	Low Level	High Level	Std. Dev.	Coding
A	Start Angle	30.00	10.00	50.00	0.000	Actual
B	Force	8.00	6.00	10.00	0.000	Actual
C	Arm Length	65.00	60.00	70.00	0.000	Actual
D	Stop Angle	10.00	0.000	20.00	0.000	Actual

Response	Prediction	Std Dev	SE (n=1)	95% PI low	95% PI high
Distance	10.1942	1.09581	1.1063	7.96865	12.4198

Fig. 12 An example output from the prediction tool.

Table 1: Analysis of confirmation experiment for ball distance

No	Factor1 A:Start Angle	Factor2 B:Force	Factor3 C:Arm Length	Factor4 D:Stop Angle	Predicted Distance	Actual Distance	Residual	%Error
1	50	10	70	10	14.915064	14.5	-0.41506	-2.86251
2	50	8	65	20	10.840064	11.1	0.259936	2.341765
3	30	10	70	10	14.269231	14.3	0.030769	0.215169
4	30	8	70	20	11.210897	11.5	0.289103	2.513935

6. Conclusions

Volleyball refers to a game where a ball has to be hit over a net. It is a team sport, and the aim of this game is to ground the ball in the court of the opponent team. The serve in volleyball is one of the most important actions, which can be considered as the team competitive advantage over its rivals. Without the proper techniques and timing, the serve cannot reach to the opponent ground effectively. So, different factors such as start and stop angle of arm, force and arm length influence the flight distance of the struck ball. There are deeply correlations between these factors and applying them appropriately will result in success of serve.

The purpose of this study was to investigate the significant factors that may affect the flight distance of the ball, which was hit in volleyball serve in order to maximize the distance to a proper length and accordingly pass the net. The study used three cases to gather the raw data and conduct the experiment.

The results of the study show that some specific strength and physical characteristics were correlated considerably to enhance the ball flight distance in volleyball serve which are start angle, force and arm length. While, to gain the best result in serve, it is required to analysis all the contributory factors, the above-mentioned factors have more significant effect on the traveled distance of the ball after hitting in the volleyball serve motion.

Our optimization point occurred when start angle, force, arm length and stop angle were 50 degree, 10 N, 70 cm and 10 degree respectively.

Although the study has determined the most significant factor in the volleyball serve motion, it should be of benefit to take other factors such as “initial ball height”, “the angle of body twist” and the “player jumping height” into consideration. On the other hand, the level of force was roughly estimated; so, for the future research, it is recommended that scholars use appropriate instruments for measuring this metric in order to reach to a more accurate conclusion.

Appendix

Appendix 1: Experimental results for distance.

Std	Run	Factor 1 A:Start Angle	Factor 2 B:Force	Factor 3 C:Arm Length	Factor 4 D:Stop Angle	Response 1 Distance
1	17	-1.00	-1.00	-1.00	-1.00	6.3
2	27	-1.00	-1.00	-1.00	-1.00	7.4
3	45	-1.00	-1.00	-1.00	-1.00	8.3
4	32	1.00	-1.00	-1.00	-1.00	7.2
5	47	1.00	-1.00	-1.00	-1.00	7.5
6	9	1.00	-1.00	-1.00	-1.00	8.2
7	5	-1.00	1.00	-1.00	-1.00	9.6
8	15	-1.00	1.00	-1.00	-1.00	10.1
9	36	-1.00	1.00	-1.00	-1.00	11.3
10	11	1.00	1.00	-1.00	-1.00	10.6
11	51	1.00	1.00	-1.00	-1.00	11.1
12	39	1.00	1.00	-1.00	-1.00	11.2
13	12	-1.00	-1.00	1.00	-1.00	6.7
14	34	-1.00	-1.00	1.00	-1.00	7.2
15	44	-1.00	-1.00	1.00	-1.00	8.8
16	48	1.00	-1.00	1.00	-1.00	7.5
17	6	1.00	-1.00	1.00	-1.00	8.2
18	42	1.00	-1.00	1.00	-1.00	8.4
19	41	-1.00	1.00	1.00	-1.00	13.1
20	22	-1.00	1.00	1.00	-1.00	14.3
21	7	-1.00	1.00	1.00	-1.00	13.9
22	4	1.00	1.00	1.00	-1.00	13.7
23	28	1.00	1.00	1.00	-1.00	14.6
24	19	1.00	1.00	1.00	-1.00	16.4
25	29	-1.00	-1.00	-1.00	1.00	5
26	49	-1.00	-1.00	-1.00	1.00	6.8
27	1	-1.00	-1.00	-1.00	1.00	7.4
28	35	1.00	-1.00	-1.00	1.00	5.2
29	3	1.00	-1.00	-1.00	1.00	7.9
30	30	1.00	-1.00	-1.00	1.00	8.2
31	23	-1.00	1.00	-1.00	1.00	9
32	16	-1.00	1.00	-1.00	1.00	10.3
33	43	-1.00	1.00	-1.00	1.00	11
34	21	1.00	1.00	-1.00	1.00	12.3
35	18	1.00	1.00	-1.00	1.00	13.1
36	40	1.00	1.00	-1.00	1.00	14.4
37	13	-1.00	-1.00	1.00	1.00	6.6
38	26	-1.00	-1.00	1.00	1.00	7.2
39	24	-1.00	-1.00	1.00	1.00	8.7
40	10	1.00	-1.00	1.00	1.00	8.6
41	52	1.00	-1.00	1.00	1.00	9
42	8	1.00	-1.00	1.00	1.00	10.5
43	46	-1.00	1.00	1.00	1.00	11.7
44	50	-1.00	1.00	1.00	1.00	12.5
45	20	-1.00	1.00	1.00	1.00	15.1
46	37	1.00	1.00	1.00	1.00	14.7
47	25	1.00	1.00	1.00	1.00	15.3
48	33	1.00	1.00	1.00	1.00	15.5
49	2	0.00	0.00	0.00	0.00	9
50	31	0.00	0.00	0.00	0.00	11
51	14	0.00	0.00	0.00	0.00	11.2
52	38	0.00	0.00	0.00	0.00	11.3

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