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APPLICATION OF TRUNCATED SPLINE NONPARAMETRIC REGRESSION FOR MODELING THE HEIGHT OF YEOP CHAGI KICKS OF TAEKWONDO ATHLETES IN SAMARINDA CITY

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ABSTRACT

Nonparametric regression is a model approach method that is used when the shape of the regression curve between the response variable and the predictor variable is assumed to have an unknown shape or pattern. One of the estimators in the nonparametric regression approach is the truncated spline which has the ability to handle data whose behavior changes at certain sub intervals. The purpose of this study was to obtain the estimated value of the parameters of the nonparametric regression model with a truncated spline approach at one knot point, two knot points, and three knot points for kick height data of yeop chagi taekwondo athletes in Samarinda City. The results showed that the truncated spline nonparametric regression model was the best in modeling kick height data for yeop chagi taekwondo athletes in Samarinda City with three knot points. This model has the minimum Generalized Cross Validation (GCV) value of 7.94 with an R^2 value of 94.72% and a Mean Square Error (MSE) value of 2.62. Based on the results of the model parameter significance test, it was concluded that the factors that influence the kick height of the yeop chagi taekwondo athlete in Samarinda City are flexibility, leg power, leg length, and waist circumference.

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1. INTRODUCTION

Regression analysis is a statistical method that studies a model from a set of data that relates between variables in explaining causal or interrelationships. Regression analysis method is used to measure the effect of predictor variables on response variables and can predict response variables using predictor variables [1]. Nonparametric regression is a model approach method that is carried out without assumptions from the shape of the regression curve where the regression curve is only assumed to be smooth, meaning that it is contained in a certain function space so that nonparametric regression has high flexibility because the data is expected to find its own estimated form of the regression curve without being influenced by the subjectivity factor of the researcher [2].

Spline is a form of estimator that is quite popular, often used in nonparametric regression because it has a good visual interpretation, is flexible, and is able to handle smooth function characteristics [3]. The truncated spline regression model does not provide assumptions about the shape of the regression curve or is assumed to be smooth. The advantages of this method occur because in nonparametric regression the truncated spline has a knot point, which is a joint point that indicates a change in data behavior patterns. In addition, truncated spline nonparametric regression can model data on data patterns that change at certain intervals. This method is a type of polynomial section, namely polynomials that have segmented properties. The shape of the truncated spline nonparametric regression estimator is also influenced by the location and number of knot points [4]. The method used for selecting smoothing parameters is the GCV method. In selecting knots, the GCV method is the best because this method has asymptotically optimal properties [4]. The optimum knot point is obtained from the minimum CGV value.

Several previous studies using truncated spline nonparametric regression, among others. [5] Conducted a multivariable truncated spline regression modeling on the factors that influence poverty in districts/cities in East Java. [1] Conducted a truncated spline nonparametric regression modeling on the crude birth rate in Surabaya. [6] Doing fourier series and spline truncated regression modeling in multivariable nonparametric regression on poverty data in Papua Province.

Taekwondo is a branch of martial arts that uses hands and feet to be packaged properly using self-discipline rules and ethics, so that taekwondo is of great benefit in social life. Taekwondo originates from Korea and is headquartered in Kukkiwon Seoul, Korea. The organization for taekwondo in Indonesia is the Indonesian Taekwondo Executive Board (PBTI) [7]. The sport of Taekwondo is also influenced by various elements of physical condition to achieve victory in a match, one of which is flexibility, leg power, leg length, and good waist circumference. To achieve victory in a match, each athlete is fast and high in kicking the opponent in a Kyorugi Taekwondo competition, which is a one-on-one fight in the arena using permitted techniques. The kick that is often used and is more effective and must be mastered by taekwondo-in which is a basic kick is the yeop chagi kick [8].

In another previous study conducted by [9] with the title "Effectiveness of Dolyo Chagi and Idan Dolyo Chagi in Opening Attacks at Taekwondo Competition Kyorugi National Student Championship Rector's Cup Surabaya November 2012 Institute of Technology". The results of this study can be concluded that the kick technique of male and female senior taekwondo athletes that is most effectively used to open attacks is dolyo chagi. Therefore, because the method is the most appropriate method based on references and relevant previous scientific works, the authors are interested in conducting scientific research with the title "Application of Truncated Spline Nonparametric Regression for Modeling the Height of Yeop Chagi Kicks of Taekwondo Athletes in Samarinda City".

2. RESEARCH METHODS

This study used a truncated spline nonparametric regression method with data on kick height of Yeop Changi taekwondo athletes in Samarinda City. Data and information about kick height are obtained by direct measurement of taekwondo athlets in Samarinda City.

2.1 Regression Analysis

Regression analysis is data analysis used to determine the relationship between the response variable (x) and the predictor variable (y) [10]. Regression analysis is conducted to determine the effect or impact between the predictor variable on the response variable, so in using this analysis in taking research samples from the large population there must be a sample size. In addition, in testing or using this regression analysis, you must go through the requirements of the regression analysis, which is often referred to as the "Classical Assumption Test". This classic assumption test consists of normality, linearity, multicollinearity, and homoscedasticity [10].

2.2 Truncated Spline Nonparametric Regression

One of the existing methods in nonparametric regression is the spline nonparametric regression method. Spline nonparametric regression has high flexibility where the data is expected to find its own estimated form of the regression curve. The truncated spline function is obtained by adding the polynomial function to the truncated function. In general, a truncated spline function can be written as follows [4]:

$$y_i = \beta_0 + \sum_{p=1}^{L}\sum_{k=1}^{m}\beta_{Lm}x_{Li}^{m} + \sum_{p=1}^{L}\sum_{h=1}^{r}\beta_{L,m+r}\,(x_{Li} - k_{Lr})_{+}^{m} + \varepsilon_i$$

Where, y_i is respon variable on the i-th $i = 1,2,\dots,n$, β_{Lm} is parameter regression for polynomial functions on the k-th is orde $k = 1,2,\dots,m$ and p is number that the predictor variables $p = 1,2,\dots,L$, x_{Li}^{m} is predictor variable on the p-th and observation on the i-th $p = 1,2,\dots,L$; $i = 1,2,\dots,n$; $k = 1,2,\dots,m$, $\beta_{L,m+r}$ is truncated component from nonparametric truncated spline regression on the p-th, where h is knot point $h = 1,2,\dots,r$ and m is the number orde, k_{Lr} is knot on the h-th $h = 1,2,\dots,r$ and p is number that the predictor variables $p = 1,2,\dots,L$, ε_i is error on the i-th and assumed to be indentical, independent and distributed normal as stated in $\varepsilon_i \sim IIDN(0,\sigma^2)$ [11][12][13].

2.3 Generalized Cross Validation (GCV)

GCV is one method that can be used to select the optimal knot point, here is the formula for finding the GCV value [1][14][15].

$$GCV(K_1,K_2,\dots,K_r) = \frac{MSE(K_1,K_2,\dots,K_r)}{(n^{-1}trace[\mathbf{I} - \mathbf{A}(\boldsymbol{K_1},\boldsymbol{K_2},\dots,\boldsymbol{K_r})])^2} \quad (1)$$

with

$$MSE(K_1,K_2,\dots,K_r) = n^{-1}\sum_{i=1}^{n}(y_i - \hat{f}(x_i))^2 \quad (2)$$

where

$\mathbf{I}$: Identity Matrix of size $n\ x\ n$

$\boldsymbol{A(K_r)}$: Diagonal Element of Matrix **A(K)** of size $n\ x\ n$

2.4 Best Model Selection Criteria

The method that is often used in selecting the best model is the Mean Square Error (MSE). MSE is a good condition of the model that has a non-negative value. A good model comes from the smallest MSE value produced by the model [10]. The following is the equation for calculating the MSE value in the truncated spline regression model [16][17].

$$MSE = \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)}{n} \quad (3)$$

The coefficient of determination can be used to measure the strength of a model in explaining the response variable. The value of the coefficient of determination ranges from zero to one [18]. The following is the equation used to calculate the coefficient of determination.

$$R^2 = \frac{SSR}{SST} \quad (4)$$

SSR is Sum Square Regression and SST is Sum Square Total. $SSR = \sum_{i=1}^{n}(\hat{y}_i - \bar{y})^2$ and $SST = \sum_{i=1}^{n}(y_i - \bar{y})^2$ where y_i is the observation of the ith response variable, $\hat{y}_i$ is the estimated value of the ith response variable and $\bar{y}$ is the average of y_i [19][20][21].

2.5 Multicollinearity Test

The multicollinearity test is a test used to determine whether there is a high correlation between variables Multicollinearity is a condition where there is a correlation between predictor variables when the regression model uses more than one predictor variable. A good regression model should not have a correlation between the predictor variables. If collinearity occurs, the estimation results from the coefficients become invalid. VIF values can be seen as follows [22].

$$VIF = \frac{1}{1 - R_p^2}; p = 1,2,\dots,L \quad (5)$$

2.6 Research Variables

The variables used are research variables consisting of response variables (y) and predictor variables (x). The response variable of this study was Yeop Chagi's Kick Height of a Taekwondo Athlete in Samarinda City. The predictor variables of this study were Flexibility, Leg Power, Leg Length, and Waist Circumference. Variable notations, definitions, and units can be seen in the following **Table 1.**

Table 1. Research Variables

Notation	Operational Definition	Data Source
y	The height of the yeop chagi kick, which is an important indicator in building the quality of performance of taekwondo athletes in Samarinda city	Observation
x_1	Flexibility scores of taekwondo athletes in Samarinda city	Observation
x_2	Leg power scores of taekwondo athletes in Samarinda city	Observation
x_3	The length of the limbs measured from the base of the waist to the tip of the feet of taekwondo athletes in Samarinda city	Observation
x_4	Waist circumference scores of taekwondo athletes in Samarinda city	Observation

2.7 Stage of Analysis

The stages of analysis in this study are as follows.

1. Make a descriptive statistical analysis of each variable.
2. Make a scatterplot between the response variables and each variable that is suspected to influence to find out the data pattern.
3. Determine the knot point in the truncated spline nonparametric regression model with 1 knot point.
4. Determine the knot point in the truncated spline nonparametric regression model with 2 knot point.
5. Determine the knot points in the truncated spline nonparametric regression model with 3 knot points.

6. Parameter estimation of the truncated spline nonparametric regression model using Equation.
7. Selecting the optimum knot point with the GCV method to obtain the best model. The formula used to calculate the GCV value is the formula in equation.
8. Perform simultaneous hypothesis testing for the parameters of the truncated spline nonparametric regression model.
9. Perform a partial hypothesis test to test the significance of the parameter parameters of the truncated spline nonparametric regression model.
10. Conclusion

3. RESULTS AND DISCUSSION

In this chapter an analysis and discussion will be carried out that are adapted to the objectives previously described, namely regarding data modeling of the height of the kick of the yeop chagi athlete in Samarinda City taekwondo along with the factors that are thought to have an influence using descriptive statistical analysis and modeling the height of the athlete's yeop chagi kick. Taekwondo Samarinda City with a truncated spline nonparametric regression approach where the nonparametric regression curve uses a linear function.

3.1 Descriptive Data Analysis

The variables for analyzing descriptive data consist of the variables Yeop Chagi's Kick Height, Flexibility, Leg Power, Leg Length, and Waist Circumference in taekwondo athletes in Samarinda City in 2023. The research data consisted of 40 samples with 21 male athletes and 19 female athletes.

Table 2. Descriptive Data Analysis

Variable	Minimum	Maximum	Mean	Variance
Yeop Chagi Kick Height	154 cm	184 cm	170.68 cm	50.99 cm
Flexibility	9.5 cm	28.6 cm	21.81 cm	21.98 cm
Leg Power	25 cm	79 cm	45.55 cm	213.59 cm
Leg Length	85 cm	110 cm	99.48 cm	48.05 cm
Waist Circumference	58 cm	96 cm	73.18 cm	84.84 cm

In **Table 2** it can be seen that the average value of the yeop chagi kick height of taekwondo athletes in Samarinda City in 2023 is 170.68 cm with a variance value of 50.99 cm. cm and the minimum value of the yeop chagi kick height is found in Athlete 3, male, 154 cm. The average flexibility value for Samarinda City taekwondo athletes in 2023 is 21.81 cm with a variance value of 21.98 cm. The maximum flexibility value is found in Athlete 24, female, with 28.6 cm of flexibility. and the minimum flexibility value is found in Athlete 3, male, with 9.5 cm of flexibility.

The average leg power value of taekwondo athletes in Samarinda City in 2023 is 45.55 cm with a variance value of 213.59 cm. The maximum value of leg power is found in Athlete 19, male, of 79 cm and the minimum value of leg power is found in Athlete 10, female, of 25 cm.

The average value of the leg length of taekwondo athletes in Samarinda City in 2023 is 99.48 cm with a variance value of 48.05 cm. The maximum value of leg length is found in Athlete 37, male, of 110 cm and the minimum value of leg length is found in Athlete 22, female, of 85 cm.

The average value of the waist circumference of taekwondo athletes in Samarinda City in 2023 is 73.18 cm with a variance value of 84.84 cm. The maximum value of waist circumference is found in Athlete 11, male, of 96 cm and the minimum value of waist circumference is found in Athlete 2, female, of 58 cm.

3.2 Relationship Pattern of Predictor Variables with Response Variables

Pattern of relationship between each predictor variable with the response variable using a scatter plot.

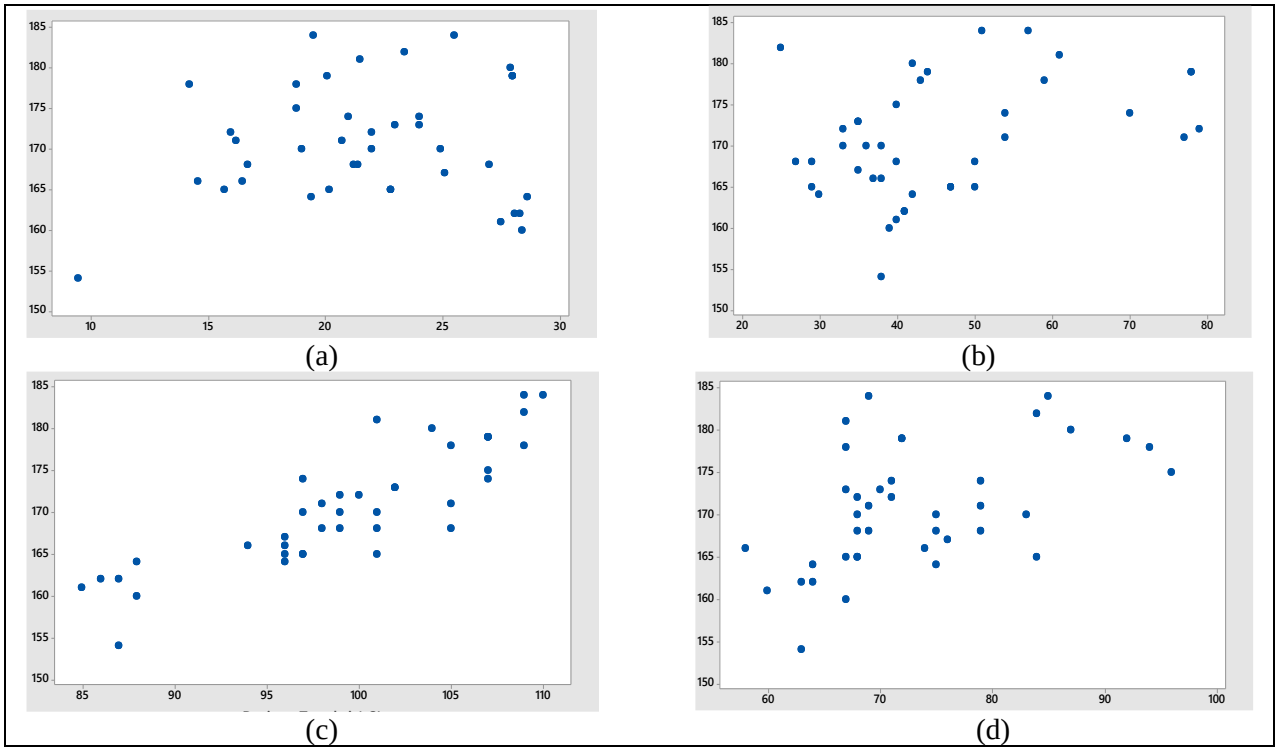

Figure 1. (a) Data Pattern of variables y and x_1, (a) Data Pattern of variables y and x_2, (a) Data Pattern of variables y and x_3, (a) Data Pattern of variables y and x_4.

Based on **Figure 1**, the relationship between each independent variable does not show a tendency to pattern or the shape of the regression curve is not known to the dependent variable. Therefore, the truncated spline nonparametric regression method can be used.

3.3 Multicollinearity

Multicollinearity detection aims to test whether a regression model has a correlation between predictor variables. A good regression model should not have a correlation between the predictor variables. The results of the multicollinearity test can be seen in **Table 3**.

Table 3. Multicollinearity Detection Using the VIF Method

Variable	x_1	x_2	x_3	x_4
VIF	1.021558	1.194375	2.119418	2.039560

From **Table 3** which has been shown the VIF values for all predictor variables are < 10. So, it can be concluded that there is no high correlation in each predictor variable.

3.4 Selection of Optimal Knot Points Using the GCV Method

The knot point is the point of convergence where there is a change in the data pattern. The best truncated spline nonparametric regression model is obtained from the optimal knot point. To determine the optimal knot point, the GCV method is used in linear truncated spline nonparametric regression. The following is the selection of optimal knot points with one knot point, two knot points, and three knot points.

Table 4. Comparison of GCV Knot Points

Knot Point(s)	GCV Value
1 Knot Point	11.91
2 Knot Points	10.95
3 Knot Points	7.94

Based on **Table 4**, the minimum GCV value is at knot 3, so the optimal knot point is knot 3. The estimation results of the nonparametric spline truncated regression parameter using knot 3 can be seen in **Table 5**.

Table 5. Optimum Knot Point Parameter Estimation GCV Method

Variable	Parameter	Estimation
x_1	$\hat{\beta}_{11}$	0.21
	$\hat{\beta}_{12}$	19.94
	$\hat{\beta}_{13}$	-40.60
	$\hat{\beta}_{14}$	25.47
x_2	$\hat{\beta}_{21}$	0.16
	$\hat{\beta}_{22}$	-0.41
	$\hat{\beta}_{23}$	-7.17
	$\hat{\beta}_{24}$	13.73
x_3	$\hat{\beta}_{31}$	0.85
	$\hat{\beta}_{32}$	11.94
	$\hat{\beta}_{33}$	-11.86
	$\hat{\beta}_{34}$	-6.54
x_4	$\hat{\beta}_{41}$	-0.05
	$\hat{\beta}_{42}$	-13.32
	$\hat{\beta}_{43}$	16.51
	$\hat{\beta}_{44}$	8.25

Based on **Table 5**, the linear truncated spline nonparametric regression model with three knot points is obtained as follows:

$$\begin{aligned}\hat{y} = {} & 77.61 + 0.21x_1 + 19.94(x_1 - 15.35)_+ - 40.60\,(x_1 - 19.63)_+ \\ & + 25.47(x_1 - 23.53)_+ + 0.16x_2 - 0.41(x_2 - 41.53)_+ \\ & - 7.17(x_2 - 53.65)_+ + 13.73(x_2 - 64.67)_+ + 0.85x_3 \\ & + 11.94(x_3 - 92.65)_+ - 11.86(x_3 - 98.27)_+ - 6.54(x_3 \\ & - 103.37)_+ - 0.05x_4 - 13.32(x_4 - 69.63)_+ + 16.51(x_4 \\ & - 78.16)_+ + 8.25(x_4 - 85.92)_+\end{aligned}$$

selecting the optimal knot point using the GCV nonparametric regression spline truncated linear method is obtained using three knot points with an R2 value of 94.72% and an MSE value of 2.62 (Appendix 11). This shows that the variables flexibility, leg power, leg length, and waist circumference have a large effect of 94.72% on the kick height of yeop chagi taekwondo athletes in Samarinda City in 2023 while the remaining 5.28% is influenced by other variables.

3.5 Parameter Significance Testing of Truncated Spline Regression Model

After obtaining the best estimated model parameter values, a significance test of model parameters was carried out which aims to find out whether the predictor variables significantly influence the height of the yeop chagi kick of the Samarinda City taekwondo athlete in 2023 or not. Testing the significance of parameters is done simultaneously first. If the results of the simultaneous parameter significance test show that there is at least one significant parameter, then the test can be continued partially.

1. Testing the Simultaneous Significance of Model Parameters

Following are the results of the analysis of the variety of truncated spline nonparametric regression models presented in **Table 6**.

Table 6. Analysis of Variance for Simultaneous Spline Regression Models

Source of Variance	Df	Sum of Squares	Total Squares	F_{count}	*p-value*
Regression	16	1763.39	110.21	19.56	1.033×10^{-09}
Error	23	225.38	5.63		
Total	39	1988.78			

Based on the simultaneous test, it can be seen from **Table 6** that the value $F_{count} = 19{,}56$ and $P - value = 0{,}00$ with $F_{0,05(16;23)} = 2.10$ and significance level of 0,05 show F_{count} = 19.56 greater than F_{Table} = 2.10 and $p - value$ less than the significance level so it was decided to reject H0 which means that simultaneously the variables flexibility, leg power, leg length, and waist circumference affect the kick height of yeop chagi taekwondo athletes in Samarinda City in 2023.

2. Testing the Partial Significance of Model Parameters

Partial parameter testing was carried out aiming to find out the variables that significantly influence the kick height of yeop chagi taekwondo athletes in Samarinda City in 2023.
The following is **Table 7** which shows the partial test results for each parameter.

Table 7. Partial Testing of Regression Model Parameters

Variable	Parameter	Estimation	*p-value*	t-count	Decision
Constant	$\hat{\beta}_0$	77.61	0.00	8.78	Significant
x_1	$\hat{\beta}_{11}$	0.21	0.02	1.79	Significant
	$\hat{\beta}_{12}$	19.94	0.05	2.33	Significant
	$\hat{\beta}_{13}$	-40.60	0.21	-2.07	Not Significant
	$\hat{\beta}_{14}$	25.47	0.03	1.31	Significant
x_2	$\hat{\beta}_{21}$	0.16	0.00	3.60	Significant
	$\hat{\beta}_{22}$	-0.41	0.89	-0.13	Not Significant
	$\hat{\beta}_{23}$	-7.17	0.31	-1.02	Not Significant
	$\hat{\beta}_{24}$	13.73	0.07	1.88	Not Significant
x_3	$\hat{\beta}_{31}$	0.85	0.00	7.14	Significant
	$\hat{\beta}_{32}$	11.94	0.00	3.01	Significant
	$\hat{\beta}_{33}$	-11.86	0.02	-2.42	Significant
	$\hat{\beta}_{34}$	-6.54	0,02	-2.44	Significant
x_4	$\hat{\beta}_{41}$	-0.05	0.51	-0.66	Not Significant
	$\hat{\beta}_{42}$	-13.32	0.19	-1.34	Not Significant
	$\hat{\beta}_{43}$	16.51	0.17	1.40	Not Significant
	$\hat{\beta}_{44}$	8.25	0.17	1.40	Not Significant

Based on **Table 7**, there are 17 parameters in the truncated spline nonparametric regression model that are formed with a 95% confidence level if the p-value is less than α, which is 0.05, then the estimated parameters are significant. A total of 17 parameters in the truncated spline nonparametric regression model, there are 9 parameters that are significant and there are 8 parameters that are not significant, so that all variables are suspected to have an effect, the four variables include flexibility (x_1), leg power (x_2), leg length (x_3), and waist circumference (x_4).

3.6 Interpretation of Truncated Spline Nonparametric Regression Models

The best truncated spline nonparametric regression model is the first order truncated spline or linear spline using the GCV method with three knot points. After the partial parameter significance test was performed, a truncated spline nonparametric regression model was obtained which was interpreted as follows:

$$\hat{y} = 77.61 + 0.21x_1 + 19.94(x_1 - 15.35)_+ - 40.60\,(x_1 - 19.63)_+ + 25.47(x_1 - 23.53)_+ + 0.16x_2 - 0.41(x_2 - 41.53)_+ - 7.17(x_2 - 53.65)_+ + 13.73(x_2 - 64.67)_+ + 0.85x_3 + 11.94(x_3 - 92.65)_+ - 11.86(x_3 - 98.27)_+ - 6.54(x_3 - 103.37)_+ - 0.05x_4 - 13.32(x_4 - 69.63)_+ + 16.51(x_4 - 78.16)_+ + 8.25(x_4 - 85.92)_+$$

4. CONCLUSIONS

Based on the results of the analysis and discussion, it can conclude that the best truncated spline nonparametric regression model is with three knot points. Third model has the minimum GCV value which is 7.94. Here is the best spline model:

$$\hat{y} = 77.61 + 0.21x_1 + 19.94(x_1 - 15.35)_+ - 40.60\,(x_1 - 19.63)_+ + 25.47(x_1 - 23.53)_+ + 0.16x_2 - 0.41(x_2 - 41.53)_+ - 7.17(x_2 - 53.65)_+ + 13.73(x_2 - 64.67)_+ + 0.85x_3 + 11.94(x_3 - 92.65)_+ - 11.86(x_3 - 98.27)_+ - 6.54(x_3 - 103.37)_+ - 0.05x_4 - 13.32(x_4 - 69.63)_+ + 16.51(x_4 - 78.16)_+ + 8.25(x_4 - 85.92)_+$$

Based on the parameter test, it can be seen that all variables have a significant effect on the height of the yeop chagi kick. The variables are flexibility, leg power, leg length, and waist circumference. By obtaining the highest score on each variable, it is possible to get the maximum kick height.

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