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Paper Title : **Modelling The Relationship Between Vehicle Speed and Road Radius, Degree of Curved, and Grade in Wringin Highway Bondowoso**

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Modelling The Relationship Between Vehicle Speed and Road Radius, Degree of Curved, and Grade in Wringin Highway Bondowoso

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Abstract. Road geometric are the component design of the road. Road geometric design has provisions such as road classification, design criteria, road components, cross section, visibility, vertical alignment, and horizontal alignment. Based on Bina Marga (1997), the design speed on the horizontal alignment is influenced by road's radius (R), degree of curved (D), the coefficient of friction (F), superelevation (e), and the level of attainment of road crossing (Ls). In the research of Fitzpatrick (2000), it was explained that the grade affected of vehicle speed on thecurved. This research was conducted to find out the modeling the relationship between vehicle speed and road,s radius, degree of curved, and grade in Wringin Highway Bondowoso. This research uses a non linear regression analysis method. Primary and secondary data include vehicle speed, road's radius, degree of curved, and grade. In this research, vehicle speed as the dependent variable and road's radius, degree of curved, and grade as the independent variable. The analysis results obtained a grade of -10% <g <-12% and 10% <g <12% which is the best result for the model relationship vehicle speed with radius. At a grade of -10% to -12%, get the value R^2 = 0.933 and Y = -0.024x2 + 1.802x + 5.165 using the polynomial regression model. R^2 values indicate grade and radius affect the amount of vehicle speed by 93.3%, while 6.7% is influenced by other factors. The 10% to 12% grade gets the value R^2 = 0.993 and Y = 0.043x2 - 3.139x + 91.65 using the polynomial regression model. This value indicates grade and radius affect the amount of vehicle speed by 99.3%, while 0.7% is influenced by other factors.

INTRODUCTION

Road geometric are the component in designing a road. Some road components are designed based on the completeness of basic data obtained from the results of field surveys and analyzed based on applicable design requirements. Determinate for geometric design include road classification, planning criteria, road parts, cross section, visibility, vertical alignment, and horizontal alignment.

Horizontal alignment is a straight line that is connected with a curved line. Horizontal alignment is divided into simple circular arc arches, spriral arches - circles - spirals, and spiral-spiral arches. Road geometric on curved component is designed to compensate for the centrifugal force received by the vehicle that runs at the speed of design. Speed is one the essential parameters for determining the quality of road service. [1] Speed design is the speed used for design every component of the highway. The speed design on curved is influenced by road,s radius (R), degree of curved (D), the coefficient of friction (F), superelevation (e), and the level of achievement of changes in road crossing (Ls). In the research of Fitzpatrick [2], it was explained that of grade affected the vehicle speed on the curved. Meanwhile, Tarris [3] and Krammes [2] stated that the most influential factor of causing the changing of speed in horizontal curves is the radius of curve. Another study conducted by Bassani [4] indicated that lane width and speed limit are the most effective variables.

Some previous studies indicated that there are still debates in terms of variables influencing the speed. Furthermore, study about the modelling the relationship between road geometric design and speed is still limited in

Indonesia. Therefore, this study was trying to fill the gap of the lack of appropriate model related to road geometric parameters and speed, especially in two-lane rural road in Indonesia. This research conducted a modeling of the relationship between vehicle speed with road's radius, degree of curved, and grade in Wringin Highway Bondowoso, which has a length of 16.8 km (STA 166 + 600 - STA 183 + 700).

METHODS

This research was conducted at Jalan Diponegoro and Wringin. The road is a connecting road Bondowoso - Besuki in length of 16.8 km (STA 166 + 600 - 183 + 700 STA). Pictures of Jalan Diponegoro and Wringin can be seen in Figure 3.1.

FIGURE 1. Diponegoro and Wringin Road

Research Data

This research uses primary data and secondary data. Primary and secondary data includes vehicle speed, road,s radius, degree of curved, and grade. The following are the stages of data collection:

1. Survey of Vehicle Speed
   Survey of vehicle speed using a speed gun. The following are the steps to determine the vehicle speed:
   a) Preparation of equipment such as Speed gun and stationery;
   b) Placement of the surveyor at the midpoint of curved to shoot the vehicle at the starting, middle and end points;
   c) Speed gun tool is directed at the vehicle that is observed then automatically read the vehicle speed;
   d) Record vehicle speed from speed gun readings based on vehicle classification.

2. Calculation of Road's Radius and Degree of Curved
   Following are the steps to determine bend radius and curvature with the help of google maps:
   a) Download the bend map on google maps;
   b) Input map to Autocad 2007;
   c) Change maps to original scale;
   d) Determination of important points in curved such as straight parts, beginning of curved, and end of curved;
   e) Withdrawing a perpendicular line from the starting point of the bend to cutting both lines, so that road,s radius and degree of curved.

3. Grade
   In this study to retrieve data grade extends the road using a GPS (Global Positioning System). The following are the steps in taking data on slope extending the road:
   a. Preparation of equipment such as GPS and stationery;

b. Placement of surveyors at the starting point of curved for determination of coordinates, then records the height of the starting point of curved obtained from GPS;
c. Placement of surveyors at the end point of curved to determine coordinates, then record the height of curved endpoint obtained from GPS;
d. Calculation of the height difference of coordinates to get the value of grade extends the road.

Data Analysis

The purpose of data analysis is to find out the best relationship model between the vehicle speed, road's radius, degree of curved, and grade. In analyzing the relationship using regression analysis. The stages of analysis are as follows:

a. Calculation of the average vehicle speed / moving speed obtained from direct surveys on the field / curved;
b. Determination of grade on each curved;
c. Calculation of road's radius values and curvature on maps obtained from google maps;
d. Statistical analysis of regression equations to determine the modeling relationship between the vehicle speed with road's radius, degree of curved, and grade.

DISCUSSION

Grade

Grade is the slope of the road obtained from the elevation of the starting point of curved and the end point of the curved divided by the distance between points. Data for calculating grade extending the road can be seen in table 1.

TABLE 1. Calculation of Grade

Num	Curved	Early elevation curved (m)	End elevation curve (m)	Distance (m)	Grade %	
					(+)	(-)
1	Curved 1	155	160	50	10	-10
2	Curved 2	181	185	43,5	9	-9
3	Curved 3	189	191	36,8	5	-5
4	Curved 4	188	191	66,9	4	-4
5	Curved 5	204	208	71,8	6	-6
6	Curved 6	212	214	28,6	7	-7
7	Curved 7	228	231	60	5	-5
8	Curved 8	230	234	54,9	7	-7
9	Curved 9	240	242	37	5	-5
10	Curved 10	249	252	34	9	-9
11	Curved 11	254	255	30,2	3	-3
12	Curved 12	252	254	35	6	-6
13	Curved 13	254	256	42	5	-5
14	Curved 14	256	258	43	5	-5
15	Curved 15	261	267	60	10	-10
16	Curved 16	277	278	32	3	-3
17	Curved 17	273	276	43	7	-7
18	Curved 18	276	280	61	7	-7
19	Curved 19	283	287	54	7	-7
20	Curved 20	288	291	46	7	-7
21	Curved 21	298	300	57	4	-4
22	Curved 22	303	305	42	5	-5

Num	Curved	Early elevation curved (m)	End elevation curve (m)	Distance (m)	Grade %	
					(+)	(-)
23	Curved 23	313	314	39	3	-3
24	Curved 24	318	319	27	4	-4

From table 1, it is explained that in corner 1 the initial elevation of curved = 155 m is obtained, the end elevation of curved = 160 m, distance = 50 m, and grade = 10%.

Next, the grade grouping process is divided into 7 parts / classes of grade which can be seen in table 2.

TABLE 2. Grouping Grade

No	Grade class	Class Limit	Middle class limit	frequency
1	1 - 2	0,5 - 2,5	1,5	2
2	2 - 4	2,5 - 4,5	3,5	29
3	4 - 6	4,5 - 6,5	5,5	23
4	6 - 8	6,5 - 8,5	7,5	18
5	8 - 10	8,5 - 10,5	9,5	11
6	10 - 12	10,5 - 12,5	11,5	4
7	12 - 14	12,5 - 14,5	13,5	3
Total frequency				90

From table 2 the number of curved in grade class is 1% - 2% = 2 curved, 2% - 4% = 29 curved, 4% - 6% = 23 curved, 6% - 8% = 18 curved, 8% - 10% = 11 curved, 10% - 12% = 4 curved, 12% - 14% = 3 curved with a total sample of 90 curved.

Road's Radius and Degree of Curved

The radius is a line formed by drawing a straight line from the center of the curved. The degree of curved is an angle formed by two curved lines. The radius and degree of curved on the Jalan Diponegoro and Wringin sections can be seen in Figures 2.

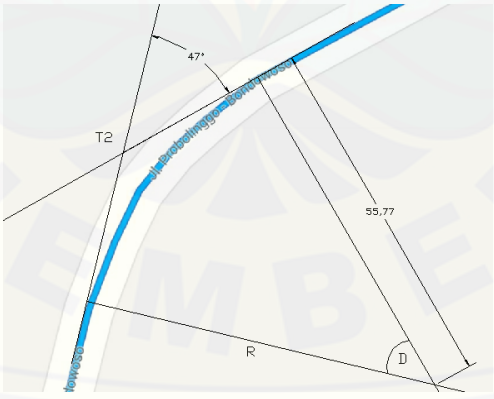


FIGURE 2. Road's Radius and Degree of Curved in curved 1

Vehicle Speed

Vehicle speed is the rate of movement of a vehicle that passes early curved, the middle of curved, and the end of curved, which uses a speed gun. The following is a sample calculation for the average vehicle speed on Diponegoro and Wringin road:

$$V = \frac{V1+V2+V3}{n}$$
$$V = \frac{V1+V2+V3}{n}$$
$$V = 38{,}67\ km/jam$$

Next, calculate the value of the V85 percentile speed from the average speed data of lane vehicles by grouping the velocity data. The following grouping speed of lane vehicles can be seen in table 3.

TABLE 3. Data grouping of vehicle speed

Num	Speed (km/jm)	Median (x)	Frequency (f)	Percentage	Cumulative Percentage Frequency	f.x
1	23-26	24,50	7	7	7	171,5
2	26-29	27,50	14	14	21	385
3	29-32	30,50	28	28	49	854
4	32-35	33,50	26	26	75	871
5	35-38	36,50	17	17	92	620,5
6	38-41	39,50	7	7	99	276,5
7	41-44	42,50	1	1	100	42,5

Table 3, is the data of average vehicle speed at the grade of 8% - 10% in curved 1 and obtained 7 classes of grouping. Next, make graph the V85 percentile speed by connecting the middle value with the cumulative percentage frequency. V85 percentile speed can be seen in Figure 3.

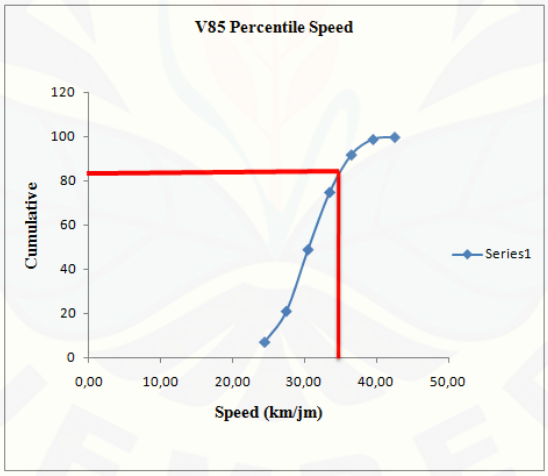


FIGURE 3. Graph V85 percentile Speed Grade 8% - 10%

From Figure 4.4, the V85 percentile speed is 8% - 10% grade at curved 1 of 35 km / hour. This speed is used to find the relationship between speed and radius and the degree of curved.

Regression Analysis

Regression analysis is an analysis of whether or not there is a relationship between one or several X variables with Y variables. If the value of R2 approaches 1, the relationship between variables is declared good, while the

value of R2 is away from number 1, the relationship between variables is declared bad. The Y variable of this researc is vehicle speed, while the variable X includes the road's radius, degree of curved, and grade.

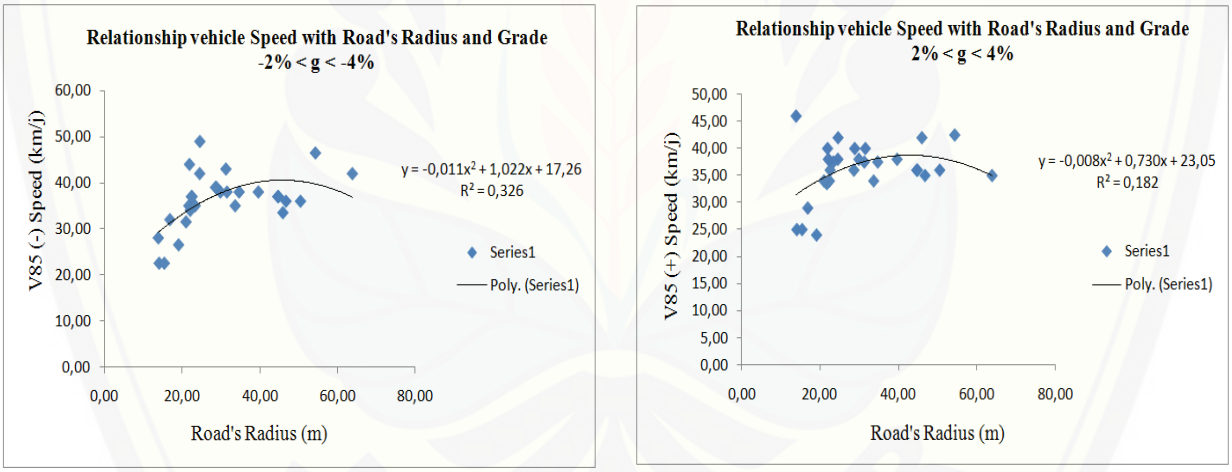
a) Relationship of vehicle speed with radius in grade -2% < G <-4% and 2% < G <4%

The data used for the relationship of vehicle speed with radius in grade -2% < G <-4% and 2% < G <4% can be seen in table 4.

TABLE 4.V85 percentile Speed Data, Radius, and Grade -2% < G < -4% and 2% < G <4%

Num	Grade	Curved	Radius	V85 Speed	
				(-)	(+)
1	-2% < G < -4% and 2% < G < 4%	4	13,99	22,50	25,00
2		11	16,77	32,00	29,00
3		16	21,65	35,00	33,50
4		21	15,33	22,50	25,00
5		23	19,02	26,50	24,00
6		24	24,46	42,00	38,00
7		25	54,34	46,50	42,50
8		26	46,74	36,00	35,00
9		28	33,62	35,00	34,00

From table 4, then a graph is made of the relationship between V85 percentile speed and radius and grade of -2% < G <-4% and 2% < G <4% with the help of Microsoft Excel software. This graph can be seen in Figures 4.



(a) (b)

FIGURE 4. Relationship V85 speed with radius in grade -2% < G <-4% (a) and 2% < G < 4% (b)

From Figure 4, it is explained that in grade - 2% < G <- 4% the R2 value is 0.326 with the type of polynomial regression. This value indicates that grade and radius affect the amount of vehicle speed by 32.6%, while 67.4% is influenced by other factors. The vehicle speed increases from 22.5 km / h to 46.5 km / h at the radius of 55 m, then decreases or is constant after passing the value of the radius above 55 m caused by several other factors. Whereas, it is explained that in grade of 2% - 4%, the R2 value is 0.182 with the type of polynomial regression. This value shows that grade and radius affect the amount of vehicle speed by 18.2%, while 81.8% is influenced by other factors. Vehicle speed increases from 24 km / h to 42 km / h at the radius of 44 m, then decreases or constant after passing the radius above 44 m caused by several other factors.

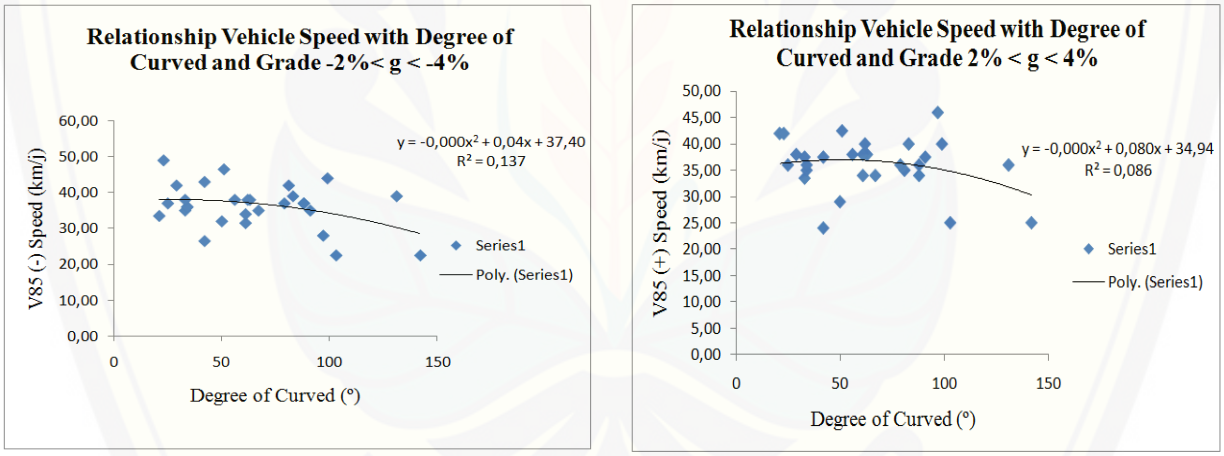
b) Relationship of vehicle speed with degree of curved in grade -2%< G < -4% dan 2% < G < 4%

The data used for the relationship of vehicle speed degree of curved radius in grade -2% < G <-4% and 2% < G < 4% can be seen in table 5.

TABLE 5. V85 percentile Speed Data, degree of curved, and Grade -2% < G < -4% and 2% < G <4%

Num	Grade	Curved	Degree of Curved	V85 Speed	
				(-)	(+)
1	-2% < G < -4 and 2% < G < 4%	4	142	22,50	25,00
2		11	50	32,00	29,00
3		16	33	35,00	33,50
4		21	103	22,50	25,00
5		23	42	26,50	24,00
6		24	29	42,00	38,00
7		25	51	46,50	42,50
8		26	34	36,00	35,00
9		28	67	35,00	34,00

From the data in table 5, a graph is then made of the relationship between the V85 percentile speed and the degree of curved and grade of -2% < G <-4% and 2% < G <4% with of Microsoft Excel software. This graph can be seen in figures 5.



(c) (d)

FIGURE 5. Relationship V85 speed with degree of curved in grade -2%< G < -4% (c) and 2%< G < 4% (d)

From Figure 5, it is explained that in grade of -2% <G < -4%, the R2 value is 0.137 with the type of polynomial regression. This value indicates that the grade and degree of curved affect the vehicle speed by 13.7%, while 86.3% is influenced by other factors. Vehicle speed tends to be constant up to 21 degrees due to grade and several other factors. Then, the vehicle speed decreases to the limit of 142 degrees. Whereas, it is explained that in grade of 2% - 4% the R2 value is 0.469 with the type of polynomial regression. This value indicates that the grade and degree of curved affect the amount of vehicle speed by 46.9%, while 53.1% is influenced by other factors. Vehicle speed tends to be constant up to a limit of 51 degrees caused by grade and several other factors. Then, the vehicle speed decreases to the limit of 142 degrees. The following results from the relationship of speed, radius, curved can be seen in table 4.6.

TABLE 6. Recapitulation of equation and modeling relationship of speed, radius, degree of curved, and grade

Num	Relationship	Grade	Coefficient Of Determination (R^2)	Equation	Regression
1	Speed, Radius, and Grade	-2% < G < -4%	0,326	Y= -0,011x2 + 1,022x + 17,26	Polinomial
		2% < G < 4%	0,185	Y= -0,008x2 + 0,730x + 23,05	Polinomial
		-4% < G < -6%	0,663	Y= -0,008x2 + 0,948x + 16,11	Polinomial
		4% < G < 6%	0,675	Y= -0,007x2 + 0,888x + 15,78	Polinomial
		-6% < G < -8%	0,223	$Y= 18,66X^{0,180}$	Power
		6% < G < 8%	0,260	$Y= 17,30X^{0,200}$	Power
		-8% < G < -10%	0,546	Y= -0,016x2 + 1,46x + 10,35	Polinomial
		8% < G < 10%	0,636	Y= -0,026x2 + 2,484x - 13,51	Polinomial
		-10% < G < -12%	0,933	$Y= -0,024x^2 + 1,802x + 5,165$	Polinomial
		10% < G < 12%	0,993	Y= 0,043x2 - 3,139x + 91,65	Polinomial
2	Speed, Degree of curved, and Grade	-2% < G < -4%	0,137	Y= -0,000x2 + 0,04x + 37,40	Polinomial
		2% < G < 4%	0,086	Y= -0,000x2 + 0,080x + 34,94	Polinomial
		-4% < G < -6%	0,22	Y= 0,000x2 - 0,208x + 47,20	Polinomial
		4% < G < 6%	0,109	Y= 0,000x2 - 0,107x + 41,4	Polinomial
		-6% < G < -8%	0,266	Y= 0,001x2 - 0,237x + 44,36	Polinomial
		6% < G < 8%	0,289	Y= 0,001x2 - 0,250x + 44,77	Polinomial
		-8% < G < -10%	0,045	Y= 0,001x2 - 0,184x + 43,29	Polinomial
		8% < G < 10%	0,143	Y= 0,001x2 - 0,178x + 42,77	Polinomial
		-10% < G < -12%	0,351	Y= 0,010x2 - 0,711x + 46,82	Polinomial
		10% < G < 12%	0,581	Y= -0,007x2 + 0,722x + 19,63	Polinomial

CONCLUSION

The results calculation and regression analysis relationship between vehicle speed with road's radius, degree of curved, and grade inWringin Highway Bondowoso, it was concluded that the closest relationship was the relationship of vehicle speed with radius in grade -10% < G <-12% and 10% <G <12%. At a grade of -10% to -12%, get the value R2 = 0.933 and Y = -0.024x2 + 1.802x + 5.165 using the polynomial regression model. This value indicates grade and radius affect the amount of vehicle speed by 93.3%, while 6.7% is influenced by other factors. The grade 10% to 12% shows the value of R2 = 0.993 and Y = 0.043x2 - 3.139x + 91.65 using the same regression model. This value indicates grade and radius affect the amount of vehicle speed by 99.3%, while 0.7% is influenced by other factors. The results coefficient of determination (R2) from grade -10% <G <-12% and 10% <G <12% are the best of the other grade due to the influence of the size of the grade it self. The greater the value of grade then the speed decreases, while the smaller the grade the speed is constant or normal.

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