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# THE BEST LOCATION FOR SPEED BUMP INSTALLATION USING EXPERIMENTAL DESIGN METHODOLOGY

## ABSTRACT

*Speed bumps, as traffic calming devices, have been extensively used to reduce traffic speed on local streets. This study represents a unique application of experimental design methodology where the effects of some controllable factors in determining the best location for installing speed bumps before stop points (e.g. entry gates, road junctions) were investigated. Through Classical Design of Experiments (DOE), the optimum location of the speed bump was obtained based on the graphical plots of the significant effects. The speed at the stop point was treated as the response and minimum speed is desirable. Design-Expert® software was used to evaluate and analyze the results obtained. The suggested mathematical model effectively explains the performance indicators within the ranges of the factors. The car speed is the most significant factor that affects the distance-time in comparison with other factors, which provides secondary contributions.*

## KEY WORDS

*speed bump location, Classical Design of Experiments (DOE), full-factorial design, distance-time, local optimum point*

## 1. INTRODUCTION

In order to control vehicle speeds in local areas traffic calming measures are exploited to reduce the vehicle speed when passing through critical areas [1, 2, 3]. According to [2, 4, 5] speed bumps, also known as road bumps, are widely utilized for controlling vehicle speed and enhancing traffic safety on secondary roads, especially in residential areas. Speed bumps

can be regarded as the best choice for deployment on local streets with posted speed limit of 40 km/h or lower. The above mentioned devices are meant to reduce the speed to as low as 8 km/h. Consequently, they are most suitable for critical areas that have low speed limits [4, 6, 7].

A study by Chadda and Cross [8] assessed the views of traffic professionals on some issues relating to the effectiveness and safety of speed road bumps by conducting a survey. In this survey, some traffic professionals supported the use of speed bumps. There are, however, some others who oppose the use of these devices on public right-of-way because of safety and liability problems. The majority of studies over the last two decades propose that speed bumps as traffic calming technique have limited effects on reducing traffic speed. The scientists recommend using the appropriate devices like humps or cushions, which are flatter and more effective than speed bumps [9, 10, 11]. In some studies, there is a comparison between three types of traffic calming techniques; speed bumps, speed humps and speed cushions. They also discuss the impact of these speed control devices on speed reduction on public streets and investigate their effectiveness and liability for use in local areas [4, 12]. Pau [9] presents the research carried out which concentrated on a case study in Italy. This study revealed that when approaching the speed bumps the cars and two-wheel vehicles generally attempt to avoid the vibration and undulation effect which is caused when passing over these speed control devices. This may induce improper drivers' behaviour to undertake manoeuvres or reduce speed suddenly, which can be

the main reason of some accidents. Shao et al. [13] investigated the relationship between the dimensions of speed bumps and the force applied to road surface and inside the vehicles using a simulation method. Finally, it was concluded that when installing speed bumps on highways, some improvements should be done on its width and vertical height in order to reduce its negative effects on vehicles and pavements.

There are only policies and engineering guidelines for the design and application of speed control devices which are published by the Institutes of Transportation Engineers (ITE) and most of the engineers follow them [6]. However, there are few studies and regulations about locating the most proper and safest places for installing these devices before a stop point. Therefore, this study concentrates on the effects of some design variables in determining the best location for setting up a speed bump and optimizing the distance from bump to stop point so that the minimum speed at that point can be obtained. If the bumps are installed properly, it is expected that the bumps can reduce the speed of traffic in the area before the stop point and help drivers reduce the speed effectively. Based on ITE standards, a speed bump is typically 12 to 36 inches in width (1 to 3 feet) with a rounded section of pavement, approximately 3 to 6 inches in height [6]. The vibration generated as a result of driving over the speed bumps would make drivers go through the critical areas at proper speed; for instance, before an entry gate or a road junction, in order to avoid taking the risk or discomfort caused by bumps vibration. Different kinds of variables or factors are involved in the issue mentioned above which have tangible or intangible effects on the process. The variables could include car speed, car weight, road inclination, distance from bump to stop point, road friction, car braking capability, climatic conditions and so on.

Classical Design of Experiment (DOE) is a practical statistical method which is done under controllable conditions to determine the unknown effects and to evaluate which process inputs have significant effect on the process output so that the systems performance optimization with known input variables can be done quickly [14]. Some of the previous experiments have been done by experimenters to formulate certain hypotheses about a particular process. Hambli et al. [15] found that the design of experiment technique is an efficient and cost-effective way to model and analyze the interactions which indicate process variations. DOE also has wide application in the improvement of new processes in such a way that processes can be defined based on several controllable variables. With the application of designed experiments, engineers can make sure which subdivision of the process variables has the most significant influence on the process performance [16].

The factorial experimental design is an effective method used for experiments that comprise two or more factors [14, 17]. In factorial experiments where numerous independent sources of variation may be presented, Analysis of variance (ANOVA) is a highly effective technique to analyse experimental data that involves quantitative measurements [18].

## 2. EXPERIMENTAL DETAILS

The ultimate objective of classical experimental design is to specify the best location for installing a speed bump before a stop point (e.g. before an entry gate or a road junction). Montgomery [17] provided guidelines for designing an experiment. Amongst others, the *factors* or inputs of the process are classified as either controllable or uncontrollable variables (noise factors), the *levels* or subdivisions of each factor and the *response* or experimental result need to be determined. To clarify the process, it is necessary to indicate the four controllable affecting factors, namely: car speed before bump, number of passengers, surface inclination and distance from bump to stop point. In the current experimental design, road friction which depends on various types of material used for covering the road, the climate condition and the car brake quality were considered as uncontrollable variables, which were totally disregarded in this experiment. To examine the impacts of controllable factors, according to the above mentioned explanations, the factors have been organized into various levels as the following:

- The number of passengers (A), which includes two levels; 1 passenger and 5 passengers.
- The car speed before bump (B), which includes two levels; 10 km/hr and 30 km/hr.
- The distance from bump to stop point (C), that consists of two levels; 10 m and 20 m.
- The road surface inclination (D), which encompasses two levels; flat surface (zero percent) and seven percentage of surface inclination.

In this study, the speed at the stop point is considered as the response in order to determine the effect of bump location on a convenient stop and to optimize the distance from bump to stop point to obtain the minimum speed at this point. Due to the lack of necessary instruments for speed measurement at the stop point, the criterion for measuring the response factor was considered to be the distance-time between starting point after bump to the stop point and the minimum speed at stop point is changed in order to maximize this span of time. This experiment was used to determine which adjustments of these critical variables are required to enhance the process.

One experiment was planned based on the full factorial design and according to the above mentioned levels, there are  $2^4$  possible treatment combinations.

On the other hand, three observations from each treatment combination were taken into consideration, which means that  $2^4 \times 3$  experimental trials or runs were performed at all combinations of factors levels. To enhance the factorial experiment and due to shortage of time for running a complete replicate of factorial design under homogeneous experimental conditions, a period of two days was allocated to the experiment and each day was considered as one block. Also, to validate the assumption that the relationships of factors and their effects are linear, two centre points (CP) were added to each block of the design. These centre points were set at 3 passengers, 20 km/hr car speed, 15 m distance from bump to stop point and 3.5% of road surface inclination. Eventually,  $(2^4 \times 3) + 2 + 2$  which is 52 runs were performed in the experimental design.

After setting up the factorial experiment, the experiments were actually performed by utilizing one unit of 'Proton Saga Iswara 1.3S Sedan' and specifying three roads with totally homogeneous situations of asphalt

type and speed bumps shape and type; however, the conditions of these roads are different regarding the surface inclination (0%, 3.5% and 7%). In this case, the speed bump dimension was  $36'' \times 6'' (3' \times 0.5')$ . Based on previous considerations, the actual experiment was carried out in two days, which was considered as two blocks. Meanwhile, during the whole pe-

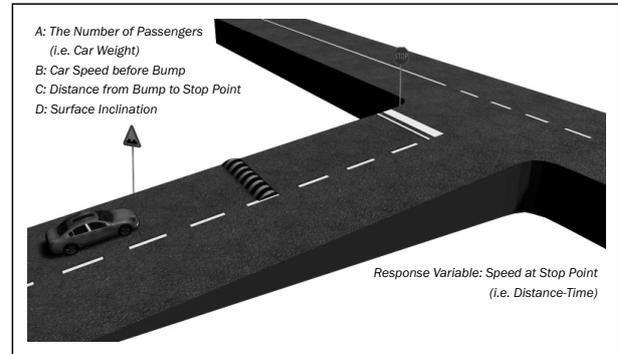


Figure 1 - The graphical experimental design of dependent and independent variables

Table 1 - Experimental design blocks

Day 1 [-]	a	b	c	d	abc	acd	abd	bcd	CP.	CP.
Day 2 [+]	(1)	ac	ab	bc	ad	cd	bd	abcd	CP.	CP.

Table 2 - Response factors, which were measured in the performed actual experimental design

Std.	Treatment Combination	ABCD Factorial Effect	Factors				No. of replicates (Time (Sec.))			Total	Average	Standard Deviation
			A: Car weight (No. of Passengers)	B: Car Speed (km/hr)	C: Distance (m)	D: Surface Inclination (%)	R1	R2	R3			
1	(1)	+	1	10	10	0	2.18	4.90	3.26	10.34	3.45	1.37
2	a	-	5	10	10	0	3.05	3.69	3.35	10.09	3.36	0.32
3	b	-	1	30	10	0	1.20	1.35	1.68	4.23	1.41	0.24
4	ab	+	5	30	10	0	1.36	1.26	1.71	4.33	1.44	0.24
5	c	-	1	10	20	0	4.31	7.76	6.56	18.63	6.21	1.75
6	ac	+	5	10	20	0	4.41	7.95	7.72	20.08	6.69	1.98
7	bc	+	1	30	20	0	3.08	3.05	3.29	9.42	3.14	0.13
8	abc	-	5	30	20	0	3.13	3.16	3.37	9.66	3.22	0.13
9	d	-	1	10	10	7	4.34	2.79	3.91	11.04	3.68	0.80
10	ad	+	5	10	10	7	3.53	4.27	3.87	11.67	3.89	0.37
11	bd	+	1	30	10	7	1.65	1.66	1.96	5.27	1.76	0.17
12	abd	-	5	30	10	7	1.70	1.58	2.14	5.42	1.81	0.30
13	cd	+	1	10	20	7	8.12	8.42	8.64	25.18	8.39	0.26
14	acd	-	5	10	20	7	5.71	8.93	10.28	24.92	8.31	2.35
15	bcd	-	1	30	20	7	3.45	3.18	3.05	9.67	3.22	0.20
16	abcd	+	5	30	20	7	3.20	3.24	3.46	9.90	3.30	0.14
17	CP.	0	3	20	15	3.5	2.79	3.41	3.44	9.64	3.21	0.37
18	CP.	0	3	20	15	3.5	3.46	5.13	4.29	12.88	4.29	0.84
19	CP.	0	3	20	15	3.5	3.05	3.41	3.14	9.59	3.20	0.19
20	CP.	0	3	20	15	3.5	4.53	3.41	2.96	10.89	3.63	0.81

Table 3 - Design summary

Name	Units	Type	Low (-1)	High (+1)	Mean	Std. Dev.
A: No. of Passengers	(No.)	Factor (Numeric)	1	5	3	-
B: Car Speed	(km/hr)	Factor (Numeric)	10	30	20	-
C: Distance	(m.)	Factor (Numeric)	10	20	15	-
D: Surface Inclination	(%)	Factor (Numeric)	0	7	3.5	-
Time	(Sec.)	Response (Numeric)	1.2	10.28	3.92	2.26

riod of the experiment, the driver was the same. Other equipment such as chronometer, clinometer and measuring tape were used while doing the experiment. As the experiment was being performed, to ignore the effect of driving force on the car speed after passing the bump, the driver shifted the vehicle gear in the normal position in the freewheel condition. Figure 1 shows graphically the experimental independent variables as input factors and dependent variable as an output or response factor.

Table 1 clearly illustrates that 'Day 1' and 'Day 2' were considered as two blocks in the experimental design. Also, Table 2 presents the results of the experimental data collection from the performed actual experimental design.

### 3. DATA ANALYSIS

After data collection, in order to develop an experimental design and to evaluate and analyze the results, version 8 of the Design-Expert® software was deployed. The design summary presents brief information about the raw data in the software (Table 3).

Initially the factorial model was adopted and two factor interactions (2FI) were selected. This resulted in

all main effects and two factor interactions to be considered for the model. Results of the design evaluation vividly illustrate that the model has efficient unique design points and well-organized replicates because of the six degrees of freedom available to evaluate the lack of fit and 34 degrees of freedom for the evaluation of pure error.

Initially the type of model transformation is fitted to none. In order to find the significant estimated effects of the model, the Half-Normal plot of effects was

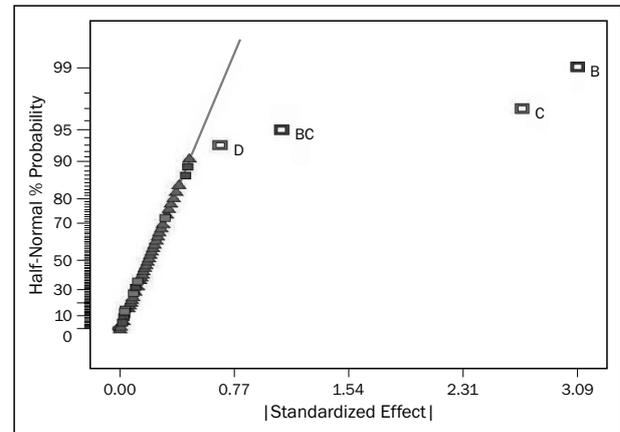


Figure 2 - Half-Normal plot

Table 4 - ANOVA Table [Partial sum of squares - Type III]

Source	Sum of Squares	d.f.	Mean Square	F-Value	p-value (Prob. > F)	
Block	0.067	1	0.067			
Model	222.39	4	55.60	64.82	< 0.0001	significant
B - Car Speed	114.25	1	114.25	133.21	< 0.0001	significant
C - Distance	88.25	1	88.25	102.90	< 0.0001	significant
D - Surface Inclination	5.53	1	5.53	6.45	0.0146	significant
BC	14.35	1	14.35	16.74	0.0002	significant
Curvature	0.51	1	0.51	0.59	0.4445	not significant
Residual	38.60	45	0.86			
Lack of Fit	6.64	11	0.60	0.64	0.7800	not significant
Pure Error	31.95	34	0.94			
Cor. Total	261.56	51				
Std. Dev.	0.92	R <sup>2</sup>	0.8505			
Mean	3.93	Adj. R <sup>2</sup>	0.8375			
C.V. %	23.48	Pred. R <sup>2</sup>	0.8072			
PRESS	50.42	Adeq. Precision	20.909			

Table 5 - Post ANOVA Table

Factor	Coefficient Estimate	d.f.	Standard Error	95% CI (Low)	95% CI (High)	VIF
Intercept	3.927	1	0.13	3.67	4.18	
Day 1	-0.036	1				
Day 2	0.036					
B - Car Speed	-1.543	1	0.13	-1.81	-1.27	1
C - Distance	1.356	1	0.13	1.09	1.62	1
D - Surface Inclination	0.339	1	0.13	0.07	0.61	1
BC	-0.547	1	0.13	-0.81	-0.28	1

selected. The main effects of B, C and D and the BC interaction terms were selected as the significant main effects and two factor interaction effect and these will be assigned to the ANOVA model (Figure 2).

The ANOVA Table (Table 4) vividly reveals that, the model F-value of 64.82 indicates that the model is significant. Values of 'Prob. > F' less than 0.05 show that the model terms are significant [19]. In this study, B, C, D and BC are significant model terms; the model centre points and consequently, the model curvature are not significant. The 'Lack of Fit F-value' of 0.64 indicates the lack of fit is not significant. Non-significant lack of fit is desirable as the model is fitted into the data perfectly. The Predicted R-Squared indicates how well the model predicts the response value and with a value of 0.8072 it is in reliable conformance with the Adjusted R-Squared of 0.8375 due to the less than approximately 0.2 difference from each other. Adequate precision which measures the range predicted response related to its relevant error, in other words, a signal to noise ratio, equalling 20.909 indicates an adequate signal. Ratios of more than 4 imply adequate model distinction [20, 21]. In this specific case, the value is well above four.

According to the post ANOVA (Table 5) 95% of Confidence Interval (CI) High and Low range signifies that the true coefficient estimates should be found in 95% of the occasions. In this case, almost all the CIs indicate that the factors have a statistically significant effect on the response. The Variance Inflation Factor

(VIF) which is equivalent to the value of one presents an ideal correlation amongst the regression coefficients.

The predictive models are listed in both actual and coded terms. The coded equation is suitable to identify the relative significant factors by comparison of the factor coefficients. This comparison cannot be designed with the actual equation because the coefficients are scaled to adopt the units of each factor. The equations give similar predictions; these equations used in the prediction have no block effects. Blocks are only to accommodate the observed experiments, not to make predictions. The following equations are the final empirical model in terms of coded factors (Equation (1)) and in terms of actual factors (Equation (2)) for the time (the experiment response):

$$\text{Time} = +3.93 - 1.54 * B + 1.36 * C + 0.34 * D - 0.55 * B * C \tag{1}$$

$$\text{Time} = -0.67632 + 9.77829E-003 * \text{Car Speed} + 0.48993 * \text{Distance} + 0.045264 * \text{Surface Inclination} - 0.010937 * \text{Car Speed} * \text{Distance} \tag{2}$$

The next step is to proceed with the diagnostic plots. Normal probability plot of residuals (Figure 3(a)) indicates that the residuals pursue a straight line except for some moderate scatter even with normal data.

Box-Cox Plot (Figure 3(b)) offers a guideline for choosing the correct power law transformation. A recommended transformation is listed based on the best

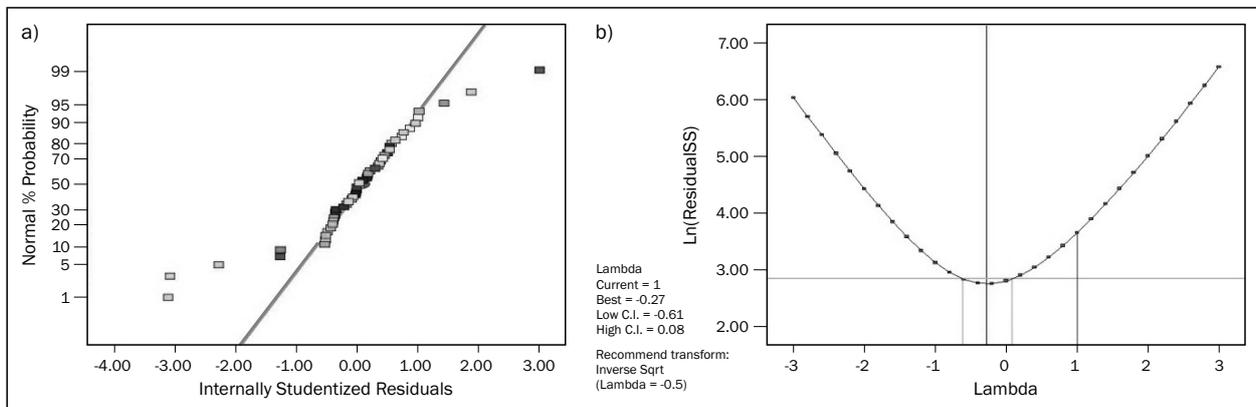


Figure 3 - (a) Normal probability plot of residuals, (b) Box-Cox plot

lambda value found at the minimum point of the curve generated by the natural log of the residuals sum of squares. If the 95% Confidence Interval around this lambda includes 1, then the software will not propose a specific transformation; however, currently this plot shows asymmetry. The transformation type which is recommended by the software for solving this issue is Inverse Square with -0.5 Lambda. Thus, the transformation of the response may provide a better analysis. To implement the new transformation, Inverse square was chosen as a new type of transformation. After that, Half-Normal plot of effects was chosen to find new significant estimated effects of the model. The main effects of B, C and D and the BC interaction terms, in order to enter the ANOVA model were selected once more as significant main and two-factor interaction effects (Figure 4). The ANOVA Table is presented to confirm statistically the significant effects and summarize the test performed (Table 6).

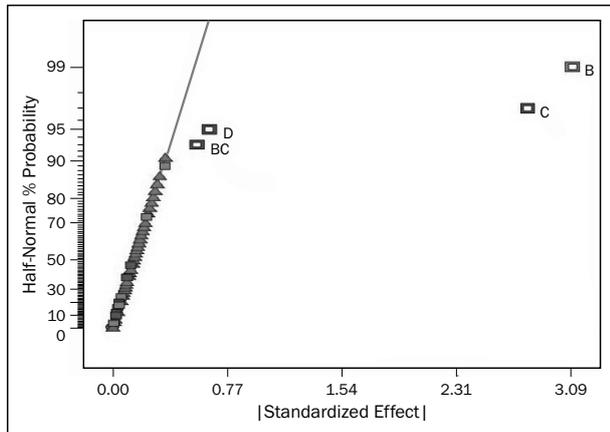


Figure 4 - New Half-Normal probability plot

Based on the data shown in ANOVA Table, the model F-value of 118.03 indicates the model is significant and there is only a 0.01% possibility that the 'Model F-Value' as large as 118.03 could happen because of the noise. Significant model terms which are newly introduced in this case are, again, B, C, D and BC; however, the model centre points and consequently, the model curvature are not significant. 'Lack of Fit F-value' of 0.44 specifies a lack of fit, which is not significant and there is a 92.60% probability that this 'Lack of Fit F-value' could emerge because of the noise. The Predicted R-Squared of 0.8840 is in reliable conformity with the Adjusted R-Squared of 0.9015, which is caused by about 0.2 differences from each other. Adequate Signal is indicated by adequate precision of 28.174. Ratios more than 4 suggest an adequate model distinction [20, 21]. The value is ideally above 4 in the specific case. In the post ANOVA (Table 7), statistically significant effect of factors on the response is indicated by 95% Confidence Interval.

The new predictive models are presented in both actual and coded terms. The final empirical models in terms of coded factors (Equation (3)) and in terms of actual factors (Equation (4)) for the time (the experiment response) are as follows:

$$1/\text{Sqrt}(\text{Time}) = +0.56 + 0.11 * B - 0.100 * C - 0.023 * D - 0.020 * B * C \quad (3)$$

$$1/\text{Sqrt}(\text{Time}) = +0.54379 + 0.017176 * \text{Car Speed} - 0.011835 * \text{Distance} - 3.10876\text{E-}003 * \text{Surface Inclination} - 4.07165\text{E-}004 * \text{Car Speed} * \text{Distance} \quad (4)$$

To perform the process with new data, new normal probability plot of the residuals and new Box-Cox plot are shown in Figure 5. In the holistic perspective re-

Table 6 - New ANOVA Table [Partial sum of squares - Type III]

Source	Sum of Squares	d.f.	Mean Square	F Value	p-value (Prob. > F)	
Block	5.37E-05	1	5.368E-05			
Model	1.11	4	0.28	118.03	< 0.0001	significant
B - Car Speed	0.59	1	0.59	249.45	< 0.0001	significant
C - Distance	0.48	1	0.48	203.16	< 0.0001	significant
D - Surface Inclination	0.026	1	0.026	11.07	0.0018	significant
BC	0.020	1	0.020	8.44	0.0057	significant
Curvature	4.768E-03	1	4.77E-03	2.02	0.1619	not significant
Residual	0.11	45	2.36E-03			
Lack of Fit	0.013	11	1.20E-03	0.44	0.9260	not significant
Pure Error	0.093	34	2.73E-03			
Cor. Total	1.22	51				
Std. Dev.	0.049	R <sup>2</sup>	0.9094			
Mean	0.56	Adj. R <sup>2</sup>	0.9015			
C.V. %	8.70	Pred. R <sup>2</sup>	0.8840			
PRESS	0.14	Adeq. Precision	28.174			

Table 7 - New Post ANOVA Table

Factor	Coefficient Estimate	d.f.	Standard Error	95% CI (Low)	95% CI (High)	VIF
Intercept	0.56	1	6.81E-03	0.55	0.58	
Day 1	1.02E-03	1				
Day 2	-1.02E-03	1				
B - Car Speed	0.11	1	7.09E-03	0.10	0.12	1
C - Distance	-0.100	1	7.09E-03	-0.11	-0.086	1
D - Surface Inclination	-0.023	1	7.09E-03	-0.04	-9.05E-03	1
BC	-0.020	1	7.09E-03	-0.03	-6.10E-03	1

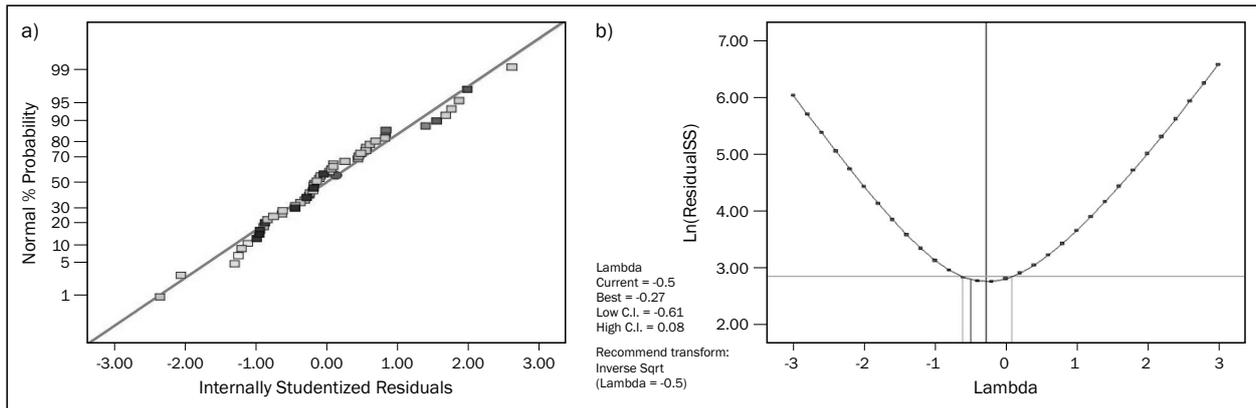


Figure 5 - (a) New Normal probability plot of residuals, (b) New Box-Cox Plot

Regarding Figure 5(a), it can be understood that the residuals generally fall on a straight line indicating the errors that are distributed normally. Moreover, Figure 5(b) vividly shows that lambda is within the 95% Confidence Interval and therefore, the software does not recommend adjustment of a new specific transformation. Meanwhile, the Box-Cox plot of the new transformation of the responses shows symmetry. Thus, the whole model statistics and diagnostic plots seem to be in accordance with the expected hypothesis; therefore, the process of data analysis can be finalized.

The two-factor BC interaction plot (Figure 6) clearly shows when the car speed is at the low level to provide

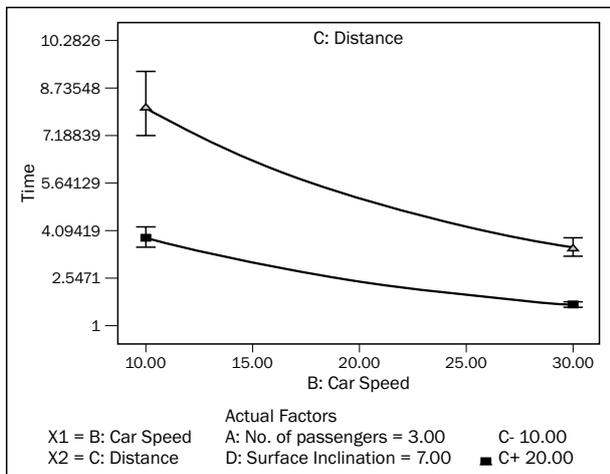


Figure 6 - BC Interaction plot

maximum time (8.13 sec) and consequently, minimum speed at stop point, the large positive effect of the distance occurs. The number of passengers due to the insignificant effect does not have any effect on this plot and is set at the highest level of the surface inclination (7%) in order to gain maximum response.

Additionally, 3D surface plot demonstrates this object through 3D figure. At the highest level of the surface inclination (7%) in Figure 7, the maximum time is achieved at the lowest level of the car speed (10 km/hr) and the highest level of the distance (20 m) based

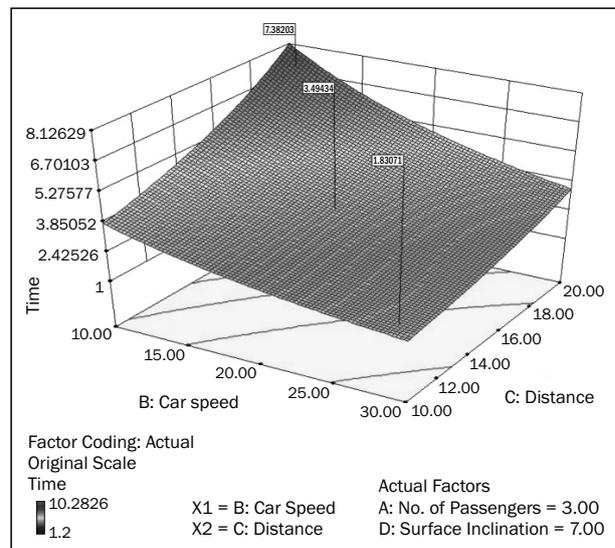


Figure 7 - 3D Surface plot

on the time contours trend. In this plot, the maximum time occurs at the peak of the curvature.

Ultimately, the optimum point within the range of the model with the value of 8.12629 Seconds, after analyzing the experimental model, is gained at the B<sup>-</sup>, C<sup>+</sup> and D<sup>+</sup> corner of the cube plot (Figure 8). This value is the maximum time between the starting point after speed bump and the stop point. Based on the main objective of this experimental design and the local optimum point of the model, the best and safest location for setting up a speed bump is at 20 metres prior to stop point in order to achieve the minimum speed and the convenient stop at the stop point. Meanwhile, the interconnectivity of the critical variables (B, C and D) remains so important for achieving this aim.

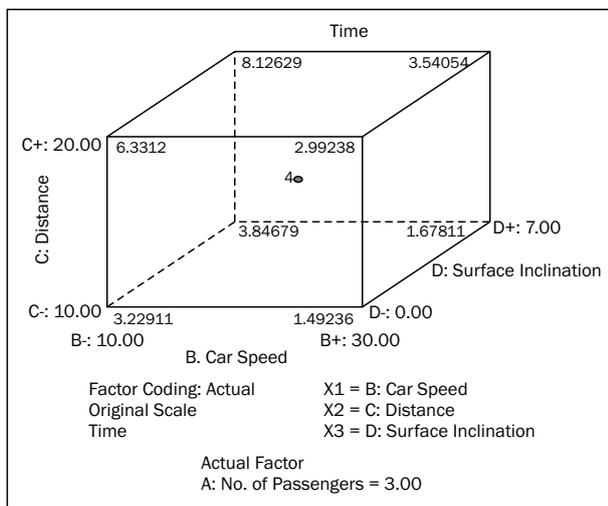


Figure 8 - Cube plot

#### 4. CONFIRMATION TEST

Eight confirmation run experiments were performed in order to confirm the adequacy of the model developed (Tables 8 and 9). The test conditions for the first two verification run experiments were among the treatment combinations that were performed previously, while the remaining six verification run experiments were in conditions that have not been used previously, but they were within the range of the levels which were identified prior to the experiment (Table 8). By the use of confirmation capability of the software, the response of the selected experiments was predicted with the 95% Prediction Interval (PI) and the number of trials in the confirmation experiment was considered to be three times (Table 9). The general conditions of predicted value and the related Prediction Interval are based on the model developed previously. The predicted value and the actual experimental value were compared and the residual absolute value which is the subtraction of the value of the actual one from the one predicted and the percentage error which

is the value of dividing the residual by the actual values were calculated. All these values are presented in Table 9. The range of the percentage errors for time is as follows: Time ~ 0.06% to 11.53%.

Based on the results yielded from the confirmation test, the developed experimental model is reasonably accurate. The actual confirmation run responses are within the 95% Prediction Interval range. The 95% Prediction Interval is the range in which any individual value is expected to fall into 95% of occasions.

#### 5. CONCLUSION

The effectiveness of speed bumps as a speed deterrent device for controlling vehicle speed and improving traffic safety on local streets had been established previously. This paper presents an experimental investigation in determining the effects of some controllable factors, i.e. car weight (A), car speed (B), distance from bump to stop point (C) and surface inclination (D), on the distance-time from the starting point after bump up to the stop point. In the current study, the speed at the stop point is treated as response and it is desirable to optimize the distance from bump to stop point in order to obtain the minimum speed at the stop point. Classical DOE technique is selected to specify the percentage contributions of these factors on the response. Meanwhile, the ANOVA test analysis shows that the car speed, in comparison with other factors such as distance and surface inclination, is regarded as the most significant factor that has influence on the distance-time. Diagnostics case statistics reports are then used to obtain the point of the optimum response which is the region around the current operating conditions. Deployment of the classical experimental design method to evaluate factors effects of the experiment is the unique feature of the current research as compared to the previously conducted studies. After analysing the results, the optimum point within the experimental range investigated, is obtained when the distance-time is 8.13 sec., which is obtainable when B<sup>-</sup>, C<sup>+</sup> and D<sup>+</sup>. This value is the maximum time between starting point after speed bump and the stop point. This implies that the location for setting up the speed bump is at 20 m prior to the stop point in order to achieve the minimum speed and the convenient stop at the stop point. The experimental results show that the proposed mathematical model explained the performance indicators within the ranges of the factors that are being examined effectively. As the current operating condition is normally far from the true optimum response, for the future studies, experimenters need to move from the current operating conditions to the optimum region in the most efficient way using the minimum number of experiments.

Table 8 - Treatment combinations used for confirmation experiments

Run	Factors				No. of replicates (Time (Sec.))			Total	Average
	A: Car weight (No. of Passengers)	B: Car Speed (km/hr)	C: Distance (m)	D: Surface Inclination (%)	R <sub>1</sub>	R <sub>2</sub>	R <sub>3</sub>		
1	5	10	20	7	5.71	8.68	9.98	24.38	8.13
2	1	10	20	7	8.42	8.54	8.15	25.11	8.37
3	5	10	15	0	4.73	4.71	4.78	14.23	4.74
4	1	10	15	0	5.00	4.76	5.14	14.90	4.97
5	5	20	10	0	1.76	2.27	2.14	6.17	2.06
6	1	20	10	0	1.95	2.00	2.19	6.14	2.05
7	1	20	20	0	4.65	3.83	4.14	12.62	4.21
8	1	30	15	0	2.13	2.29	2.20	6.62	2.21

Table 9 - Confirmation experiments

Run	Factors				Average (Actual Time (Sec.))	Prediction (Time (Sec.))	Residual	Error (%)	95% PI low	95% PI high
	A: Car weight (No. of Passengers)	B: Car Speed (km/hr)	C: Distance (m)	D: Surface Inclination (%)						
1	5	10	20	7	8.13	8.12	0.00	0.06%	6.26	10.96
2	1	10	20	7	8.37	8.12	0.25	2.98%	5.78	12.24
3	5	10	15	0	4.74	4.39	0.35	7.35%	3.68	5.34
4	1	10	15	0	4.97	4.39	0.57	11.53%	3.64	5.41
5	5	20	10	0	2.06	2.11	0.06	2.91%	1.85	2.44
6	1	20	10	0	2.05	2.11	0.07	3.28%	1.84	2.46
7	1	20	20	0	4.21	4.20	0.01	0.12%	3.56	5.04
8	1	30	15	0	2.21	2.05	0.16	7.05%	1.80	2.36

REFERENCES

[1] Ansari Ardeh, H., Shariatpanahi, M., Nikkhah Bahrami M.: *Multiojective Shape Optimization of Speed Humps*, Struct Multidisc Optim, Vol. 37, No. 2, 2008, pp. 203-214

[2] Salau, T.A.O., Adeyefa, A.O., Oke, S.A.: *Vehicle Speed Control Using Road Bumps*, Transport, Vol. 19, No. 3, 2004, pp. 130-136

[3] Vrubel, Y., Kapskij, D., Mazalevskij, D., Samoylovich, T., Korzhova, T., Kuzmenko, V.: *Some Questions of Speed Humps Application on the Roads*, The 8<sup>th</sup> International Conference - Reliability and Statistics in Transportation and Communication, 15-18 October 2008

[4] Huang, J., Zhang, X., Li, Z.-b., Wan, J.-j., Liu, P.: *Evaluating the Speed Reduction Effectiveness of Speed Bump on Local Streets*, ICCTP 2011 : Towards Sustainable Transportation Systems, American Society of Civil Engineers, 2011, pp. 2348-2357

[5] Khorshid, E., Alfares, M.: *A Numerical Study on the Optimal Geometric Design of Speed Control Humps*, Engineering Optimization, Vol. 36, No. 1, 2004, pp. 77-100

[6] Parkhill, M., Sooklall, R., Bahar, G.: *Updated Guidelines for the Design and Application of Speed Humps*, ITE 2007 Annual Meeting and Exhibit, Pittsburgh PA, Institute of Transportation Engineers, 2007

[7] Pedersen, N.L.: *Shape Optimization of a Vehicle Speed Control Bump*, Mechanics of Structures and Machines, Vol. 26, No. 3, 1998, pp. 319-342

[8] Chadda, H., Cross, S.: *Speed (Road) Bumps: Issues and Opinions*, Journal of Transportation Engineering, Vol. 111, No. 4, 1985, pp. 410-418

[9] Pau, M.: *Speed Bumps May Induce Improper Drivers' Behavior: Case Study in Italy*, Journal of Transportation Engineering, Vol. 128, No. 5, 2002, pp. 472-478

[10] Wang, C., Shi, Y., Chen, Y.-s.: *The Research of The Effect of The Speed Bump on The Road*, Shanxi Architecture, Vol. 35, No. 1, 2009, pp. 287-288

[11] Zhen, F.: *Research on Design and Application of Road Speed Control Facilities*, Master Dissertation, Jilin University, 2008

[12] Pau, M., Angius, S.: *Do Speed Bumps Really Decrease Traffic Speed? An Italian experience*, Accident Analysis & Prevention, Vol. 33, No. 5, 2001, pp. 585-597

[13] Shao, Y.-m., Xu, J., Peng, Q.-y.: *Effect of Changing Cross-Section Dimension of Speed Bumps on Impact Applied to Pavement and Vehicles*, International Conference on Transportation Engineering 2007, American Society of Civil Engineers, 2007, pp. 3761-3766

[14] Uy, M., Telford, J.K.: *Optimization by Design of Experiment techniques*, Aerospace conference, 2009 IEEE, Big Sky, MT, March 2009, pp. 1-10

- [15] **Hambli, R., Richir, S., Crubleau, P., Tavel, B.:** *Prediction of optimum clearance in sheet metal blanking processes*, The International Journal of Advanced Manufacturing Technology, Vol. 22, No. 1, 2003, pp. 20-25
- [16] **Antony, J., Capon, N.:** *Teaching Experimental Design Techniques to Industrial Engineers*, International Journal of Engineering Education, Vol. 14, No. 5, 1998, pp. 335-343
- [17] **Montgomery, D.C.:** *Design and Analysis of Experiments*, 7<sup>th</sup> edn., Wiley, Hoboken, N. J., 2008
- [18] **Montgomery, D.C., Runger, G.C.:** *Applied Statistics and Probability for Engineers*, Fifth edn., John Wiley & Sons, 2011
- [19] **Montgomery, D.C.:** *Introduction to Statistical Quality Control*, Sixth edn., John Wiley & Sons (Asia) Pte. Ltd., 2009
- [20] **Anderson, M.J., Whitcomb, P.J.:** *DOE Simplified: Practical Tools for Effective Experimentation*, 2<sup>nd</sup> edn., Productivity Press, 2007
- [21] **Anon:** *Design-Expert® Software*, Version 8.0.6, Help information, Stat-Ease, Inc., 2009