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PROPOSAL OF REDESIGN OF SPEED HUMP NEAR EDUCATIONAL ZONES: A CASE STUDY OF BILIMORA

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Abstract*— Speed hump is one of the most popular and economical traffic calming devices used globally. Speed humps are typically used in local streets of residential areas, school, college or university campuses, hospitals, etc. Speed humps are mostly designed to reduce speed of motorized vehicles. However the impacts of speed humps on non-motorized users have not been taken into consideration while designing and installing speed hump. The bicyclists suffer from discomfort, vibration, low back pain while daily passing over hump. This study aims to reduce the discomfort caused by different geometry speed hump on bicyclists. In this study, a questionnaire survey of bicyclists was conducted at four schools of Bilimora city. A questionnaire was prepared and only bicyclists were interviewed. Variables such as height of hump, age of participant, gender of participant and frequency of using hump were used to predict discomfort level. Multiple linear regression analyses were conducted to develop a statistical relationship between the variables. Discomfort model was successfully developed and validated with the help of SPSS (Statistical Package for the Social Science) software. Results of questionnaire survey have shown that 86% of bicyclists feel discomfort while passing over hump and hence it is necessary to enhance riding comfort of bicyclists. Hence this study proposed a redesign of speed hump to reduce discomfort to bicyclists.

Keywords*— Traffic calming, Speed hump, Discomfort, Bicyclists, SPSS Software.

I. INTRODUCTION

Traffic calming is the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behaviour and improve conditions for no-motorized street users. In order to make a region non-motorized friendly traffic calming devices are most popular. Among all, speed humps are the most commonly used traffic calming device mainly because it is economical and efficient.
A speed hump is a raised area in the roadway pavement surface extending transversely across the travel way. The travel length of hump is 3.7 metre and height is 0.10 metre for the crossing speed of 25 km/h for general traffic **(IRC, 1996).** Speed humps increase safety for pedestrians and non-motorized vehicle users. It is mainly used to reduce speed of motorize vehicles in speed sensitive areas such as schools, residential local streets, hospitals, etc.
The primary objective of installing speed hump is to introduce discomfort through shock and vibration to driver and occupant while passing over hump at a speed beyond speed limit. An ideally speed hump should be designed in such a way that, above the design speed, a driver suffer from increasing level of discomfort but without losing directional control and without any vehicle damage. Non-motorized road users are important elements of urban transportation across the world. But the users of the four-wheelers were target groups in most of the studies and were considered to be affected the most because they were in majority form. The non- motorized vehicles such as bicyclists suffer severe vibrations while crossing hump even at slow speeds. Daily impact of speed hump on bicyclists while crossing, may lead to health issues like lower back problems.
It is also important to note that in developing countries, due to economic factors, most of the bicycles which are used for daily commute do not have any kind of shock absorbers. Hence, due to its rigid structure, the bicycles transfer the vibration directly to the riders, causing greater discomfort. Hence discomfort caused to non-motorized users need special attention and suitable measures should be taken to reduce it.
The main objectives of this study are as follows:

- ✓ To study the discomfort experienced by non-motorized users while passing over different geometry hump.
- ✓ To obtain field data regarding level of discomfort and response of bicycle users while passing over speed hump.
- ✓ To develop a Multiple Linear Regression model.
- ✓ To propose a design for modification of speed hump to minimize impact to non-motorized users.

II. REVIEW OF LITERATURE

There have been several studies conducted to understand the relationship between geometry of speed hump and level of discomfort they induce on human. This section comprises some of the literatures who study effect of speed hump on vehicle riders.

Watts. [2] has studied about the effectiveness of different geometry hump. They compared long hump and short hump. It has been observed that more height of short hump lead to safety problems such as risk of loss of control or vehicle damage by grounding, impact on tyre, etc. The results have shown that long hump produced uncomfortable ride at speed around 30kmph, but at low speed (8kmph), driver can cross with reasonable comfort.
Pau and Angius. [10] developed a linear regression model which can predict 85th-percentile hump-crossing speed based on the total available lane width. They concluded that R-Sq. equaled to 0.50.
Kassem And Nassar. [6] investigated the effects of hump parameters on the dynamic behaviour of vehicle and driver. They developed a mathematical modeling of vehicle and driver. They conclude that vertical acceleration of the driver should not exceed 0.6 g for comfortable ride.
Ufuk and Mustafa. [14] evaluated speed control bumps (SCBs) and speed control humps (SCHs) in terms of their harmful effects on human health and the body. It has been observed that for the same height of both, the drivers were subjected to more vibrations from the SCBs than from the SCHs. Results have shown that SCBs produce more vibration than SCHs, thus SCBs are quite inconvenient designs for the human spine.
Khorshid et al.[4] conducted a study on health risk on human body's lower back due to different geometry humps. Seven types of humps used for experiment.. The results have shown that the newly designed hump, polynomial hump produced low level of shock to driver hence proved to have less health risk compared to other humps. They suggested that the circular speed hump should be modified to eliminate hazard.
Vilma et al.[15] conducted an experiment on 58 humps. The level of discomfort to the driver of car and the occupants were measured. It has been observed that at time when vehicle passing a flat surface and time when vehicle passing a hump, the vibration shocks increase up to seven times.
Bjarnason. [1] has analyzed the effect of different geometry speed hump on the comfort level experience by drivers. They concluded that driving comfort is related to vertical acceleration and crossing speed.
Bowrey et al. [3] have discussed two injury cases of passengers seated on buses. They concluded that few years after the injury they continues to suffer from low back pain, neck pain.
Patel and Vasudevan. [13] have discussed the impact of speed hump on bicyclists. An experiment is conducted using nine subjects. They were asked to ride bicycles over four different geometry hump and to report the level of discomfort they felt in Borg CR 10 scale. The vibration values were recorded by the accelerometer. It has been observed that bicyclists feel larger discomfort even at speed lower than speed limit. VDV values for bicyclists have shown that they feel larger discomfort than motorized two-wheeler.
Khorshid and Alfares. [7] presented a mathematical model of a vehicle–driver vibration system. They observed that if CC increased from 0.9g to 3g, then the new optimal solution also change. They concluded that speed hump design can also be improved by the hump profiles in the rise and return stages.
Sahoo. [12] developed two linear regression models. The hump-crossing speed was predicted based on the area- to-width ratio of 30 sites using different geometry hump, where R-Sq. equaled to 0.56 for two-wheeled vehicles and 0.60 for passenger cars.
Zainuddin et al. [17] developed two models for predicting 85^{th} percentile speed reduction and discomfort level. They concluded that these models can be used as a basis for the design of speed hump geometry for a selected 85th-percentile speed reduction and discomfort level.
The design for the modification of speed hump to reduce discomfort to bicyclists has been proposed by **Vasudevan et al. [16]** to make hump bicycle friendly. They introduced a couple of mini humps. The modification was named "K-pass". Data were collected before and after the modification of hump. Results have been shown that over a period of eight months, 70% of the bicyclists chose to use K-pass. It has been observed that a high proportion of motorized two-wheeler users also used the K-pass but at a low speeds.

III. DATA COLLECTION

This step involved two main steps: (i) Measurement of dimensions of speed humps and (ii) Questionnaire Survey. Each of these step are discussed as follows:

A. Measurement of Dimensions of Speed Hump

The first part of this study is to identify speed humps which will be used for data collection. Bilimora city was selected as a study area. There were so many speed humps installed in a city. But this study focuses on a educational zones of a city. Keeping in mind this requirement, four school sites were selected for study. The geometry of all four selected speed humps was different.
The geometries of the selected humps were measured using measuring tape. The travel length of hump is 3.7 meter and height is 0.10 meter for the crossing speed of 25 km/h for general traffic (IRC, 1996). However, these guidelines were not followed in most of the cases as speed humps were made on-site (not pre-cast) and hence their geometry varied significantly. The dimensions of speed humps used in study are shown in Table 1.

Table 1 Dimensions of speed humps used in study

Site	Height of hump (m)	Travel Length of hump (m)	Ratio
1	0.055	0.75	0.0733
2	0.09	2.25	0.0400
3	0.08	1.94	0.0412
4	0.07	1.76	0.397

B. Questionnaire Survey

Once the speed humps were finalized, the next step was to conduct Questionnaire survey. Questionnaire survey or Paper and pencil interviewing method is the most frequently used method for data collection. It represents a process of personal interviewing of a sample population. Interviewer holds a printed-out questionnaire and the respondent reads the question and fills the answers into the questionnaire form. This survey was conducted at four schools of the city. Sample size of 266 was selected and only bicyclists were interviewed. This survey was conducted during peak hour of area. Questionnaire of 26 questions have been prepared. Sample bicyclists have been interviewed and their opinions and responses have been collected.

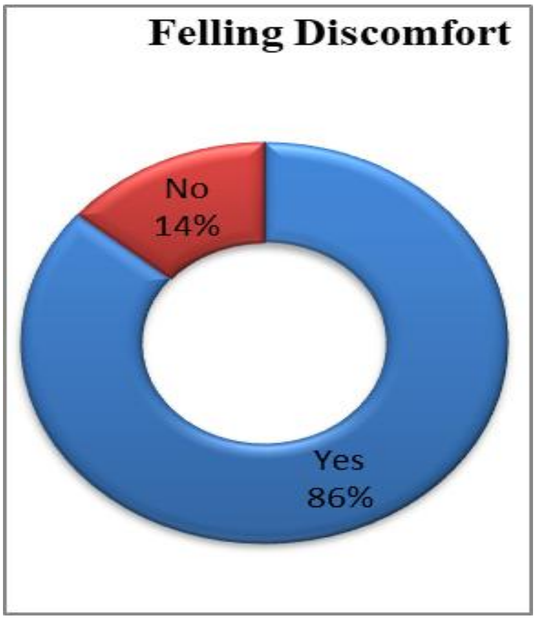

Figure 1 Users opinion on feeling discomfort

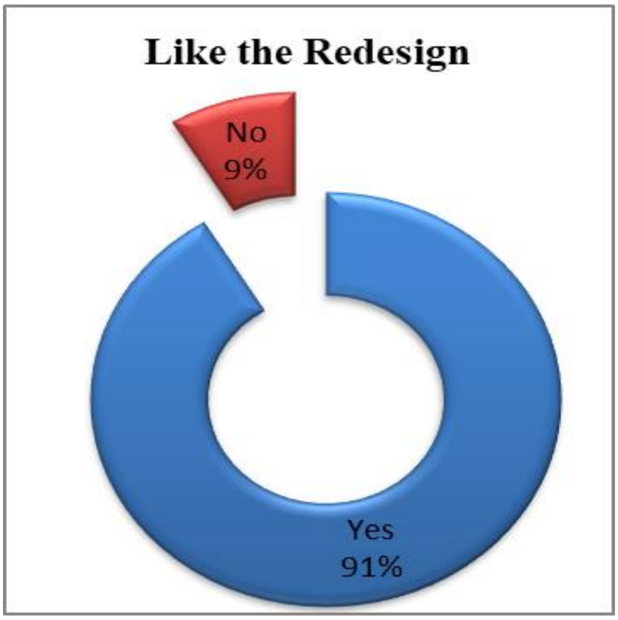

Figure 2 Users opinion on redesign of hump

IV. DATA ANALYSIS

Multiple regression analysis is an extension of simple linear regression to allow for more than one independent variable. This type of analysis applies when several predictor variables exist. By considering several predictor variables, X_1, X_2, X_3…..Xp; such analysis can provide better explanation of the dependent variables, and Y and the model are useful in prediction modeling. The general form of multiple regression analysis is as shown in Eq. (1):

$$\mathbf{Y} = \beta_0 + \beta_1 \mathbf{X_1} + \beta_2 \mathbf{X_2} + \ldots + \beta_P \mathbf{X_P} + \varepsilon \qquad (1)$$

where Y is the dependent variable, X_1,X_2,X_3…..Xp are independent predictor variables that should be free from error, β_0, β_1... β_P are unknown constants, and ε is the random error. Before the data can be analysed, it must be checked for any skewness and outliers that may affect its distribution. These errors may exist due to several factors such as during the data collection process, transferring data onto sheets. By using statistical software called **SPSS**, a box plot is used to detect the outliers. The process of data analysis is as shown in Fig. 3.

Figure 3 Model development process

V. PROPOSED REDESIGN OF SPEED HUMP

Couples of mini humps can be install; at the both sides of speed hump. The design parameters should be considered by kept in mind that bicyclist should be passed easily without causing discomfort and motorized two-wheeler not allowed to pass or to pass with very less speed. Mini humps can be provided of a same geometry as that of the original hump to maintain aesthetics view of road. The spacing between the mini humps and the main hump may affect the speed and comfortable ride for bicyclists. Hence, special attention is necessary for estimating design parameters.

The European manual for design of chicane [5], recommended the value of deflection angle as 45°. As shown in Fig. 4, when a bicycle passes through the cut portion of the original speed hump, half length of the bicycle will be behind the hump and half will be in front of the hump. Hence, the length of the path that a bicycle traces from mini bump to the cut portion can be assumed as 1.5 times the length of the bicycle. Now average length of bicycle is 1.75 m, hence the length of path traced by bicyclist can be 2.62 m (1.5 × 1.75). From the Fig. 4, the minimum value of X derived as 1.86 m (1.5 × 1.75 × Sin 45). As the length of typical bicycle is 1.75, for an X of 1.86 m it can be difficult to pass from modification without putting foot on ground. In this case, the value of Y selected as 60 cm.

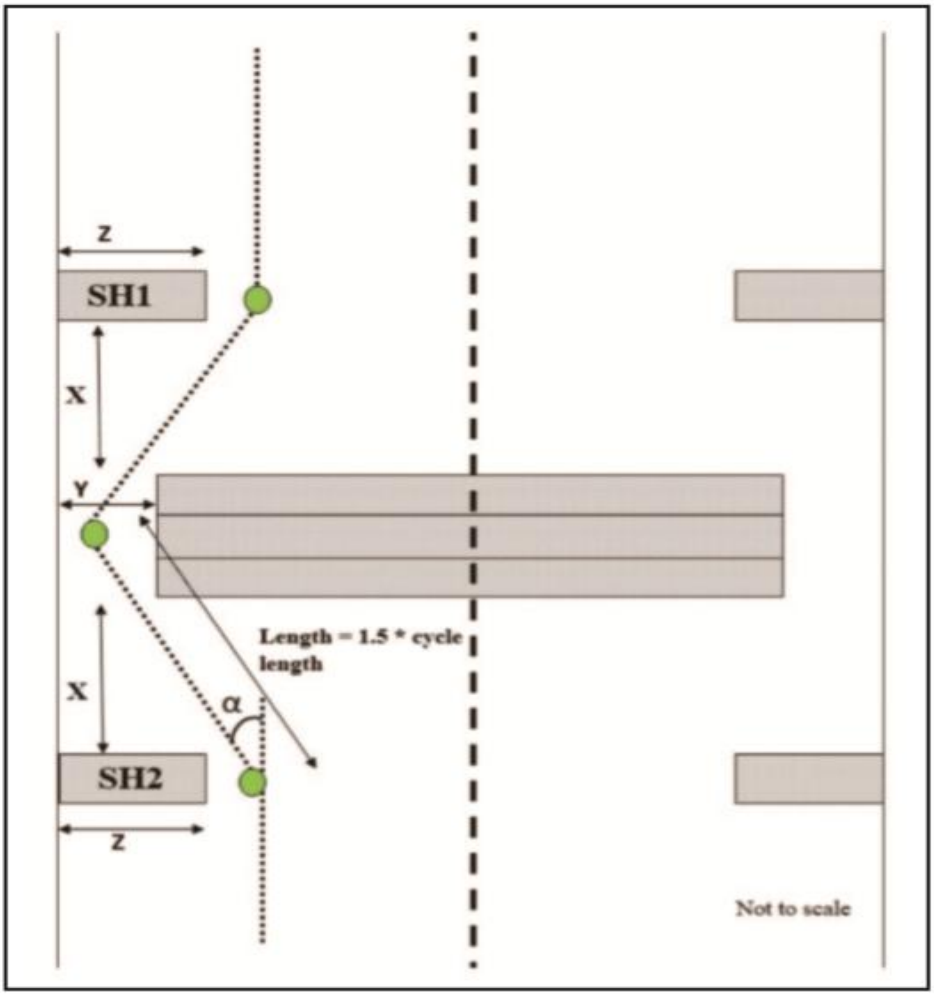

Figure 4 Design elements to modify hump

The value of the Z (width of mini hump) higher than 1.5 times the value of Y would increase the difficulty for the bicyclists riding in the edge strip of the carriageway because they have to merge with the traffic of motorized vehicles, resulting in chances of vehicle–bicycle conflicts.

The preferred dimensions of design parameters are as follows:

•X should be between 2.0 and 3.0 m;

•Y should be same as the width of the bicycle lane (if exists); if the bicycle lane does not exist, a minimum value of 60 cm is required for two-lane roads; a larger value can be chosen for wider roads; and

•Z should be not more than 1.5 times the value of Y.

The value of design parameters (X, Y, and Z) should be modified as per requirements. If wider bicycle paths are present, then the values of Y should be adjusted such that values of Z do not become very large.

VI. RESULTS

The descriptive statistics for model after the identification and removal of outliers are shown in Table 2. Referring to table, the values of the skewness and kurtosis for most of the variables except for frequency and width were near zero. According to **Park (2006)**, a normally distributed sample has a skewness and kurtosis value near zero. This showed that the data in general were normally distributed.

Table 3 displays the correlation matrix of variables. The results of the correlation analysis showed that the age was significantly correlated with the discomfort where age ($r = 0.716$, p-value <0.05) was positively correlated to discomfort compared to the other variables, which had a low r value and a p-value > 0.05. To a certain extent, discomfort, was significantly related to age and should be selected in the model development.

The discomfort model includes variables such as the Age, Gender, Height of Hump, and Frequency of Using Hump as the predictor. Table 4 shows the constant value and the transformed predictors. The hypotheses for the estimating the model can be stated as follows:

•Ho is the predictor that cannot be used for predicting in the model.

•H_1 is the predictor that can be used for predicting in the model.

Table 2 Summary of descriptive statistics for discomfort model

	N	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness	Kurtosis
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic
Age	266	14	17	15.55	.998	.996	.001	-1.056
Discomfort	266	0	7	4.49	1.355	1.836	-.516	.347
Period	266	1	3	2.49	.652	.424	-.921	-.258
Frequency	266	1.00	4.00	1.3496	.75357	.568	1.988	2.660
Gender	266	1.00	2.00	1.3158	.46571	.217	.797	-1.375
Height In m	266	.055	.090	.07167	.014508	.000	.000	-1.634
Width In m	266	6.80	7.40	7.2325	.19183	.037	-1.554	1.119
Valid N (List wise)	266							

Table 3 Correlation matrix among variables

		Discomfort	Age	Period	Frequency	Gender	Ht. in m	Width in m
Discomfort	Pearson Correlation	1	.716**	.100	-.550**	.082	-.018	.075
	Sig. (2-tailed)		.000	.102	.000	.185	.769	.221
	N	266	266	266	266	266	266	266
Age	Pearson Correlation	.716**	1	.160**	-.325**	.164**	-.045	-.150*
	Sig. (2-tailed)	.000		.009	.000	.007	.465	.014
	N	266	266	266	266	266	266	266
Period	Pearson Correlation	.100	.160**	1	-.114	-.104	.745**	-.121*
	Sig. (2-tailed)	.102	.009		.064	.090	.000	.049
	N	266	266	266	266	266	266	266
Frequency	Pearson Correlation	-.550**	-.325**	-.114	1	.093	-.007	-.404**
	Sig. (2-tailed)	.000	.000	.064		.131	.908	.000
	N	266	266	266	266	266	266	266
Gender	Pearson Correlation	.082	.164**	-.104	.093	1	-.246**	-.310**
	Sig. (2-tailed)	.185	.007	.090	.131		.000	.000
	N	266	266	266	266	266	266	266
Height In m	Pearson Correlation	-.018	-.045	.745**	-.007	-.246**	1	.336**
	Sig. (2-tailed)	.769	.465	.000	.908	.000		.000
	N	266	266	266	266	266	266	266
Width In m	Pearson Correlation	.075	-.150*	-.121*	-.404**	-.310**	.336**	1
	Sig. (2-tailed)	.221	.014	.049	.000	.000	.000	
	N	266	266	266	266	266	266	266

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 4 Regression analysis for estimating discomfort model

Model	Predictor	Coefficients		t	Sig. (p-value)	R-Square
		B	Std. Error			
1	(Constant)	1.391	.932	-7.929	.000	63 %
	Height In m	1.030	3.649	.282	.028	
	Age	.811	.056	14.597	.000	
	Frequency	-.643	.073	-8.827	.000	
	Gender	.057	.117	.486	.013	

Table 5 Analysis of Variance (ANOVA[a]) for final discomfort model

Model	Source	Sum of Squares	DF	Mean Square	F	Sig. (p-value)
1	Regression	304.435	4	76.109	109.115	.000[b]
	Residual	182.050	261	.698		
	Total	486.485	265			

a. Dependent Variable: discomfort
b. Predictors: (Constant), gender, frequency, height in m, age

From Table 4, Age, Gender, Height of Hump, and Frequency of Using Hump were significantly independent variables for predicting discomfort, where the p-value was less than 0.05, meaning that Ho was rejected and H_1 was accepted. Hence, these predictors can be included in the model for estimating model.
The analysis of variance (ANOVA) portion of the output is as shown in Table 5. The hypotheses for the ANOVA test can be stated as follows:
•Ho is the model that cannot be used for predicting.
•H_1 is the model that can be used for predicting.
From Table 5, the p-value for model was less than the α-level of 0.05; thus, Ho was rejected and H_1 was accepted. Hence, the regression model is significant and thus could be used to explain or predict the discomfort model. The equation for predicting the discomfort is developed as shown in Eq. (2):

$$\text{Discomfort} = 1.391 + 1.030\,(\text{Height}) + 0.811\,(\text{Age}) - 0.643\,(\text{Frequency of Using Hump}) + 0.057\,(\text{Gender}) \quad (2)$$

The probability plot and goodness-of-fit tests, such as the Anderson-Darling and Kolmogorov-Smirnov normality tests, Shapiro-Wilk test are used to assess whether the residuals are distributed normally. As can be seen in Fig. 5, the points were scattered closely around a straight line, which meant that the residuals were distributed normally. The hypothesis test for Shapiro-Wilk normality test can be stated as follows:
•Ho is the residual for the predicted model is normal.
•H_1 is the residual for the predicted model is not normal.

Table 6 Normality test result

Statistical Test	p-Value
Shapiro-Wilk Test	0.141

As shown in Table 6, since p-value of the Shapiro-Wilk test is more than 0.05, Ho was not rejected and the null hypothesis (H0) was accepted. Therefore, the residuals for the model followed a normal distribution curve. The validity can be checked by re-estimating the model using the independent data set. The number of independent data can be used for validation is about one-third of the overall data used in the development stage. The objective of using the independent data set is to perceive how well the model would perform on the new data set. If the results are consistent, then it can be concluded that the regression model provides strong support and are applicable under broader circumstances.

Table 7 Model Validation Results

Model	RMSE	MAE	MAPE (%)	p-value	R-square
Discomfort	0.793	0.593	14.704	0.655	0.716

The Model validation can be done by using the RMSE, MAE, and MAPE Values. The result is considered good when the value is small. Table 7 indicates that the model has a small value for RMSE, MAE and MAPE; hence models can predict good results. Therefore, model can be accepted.

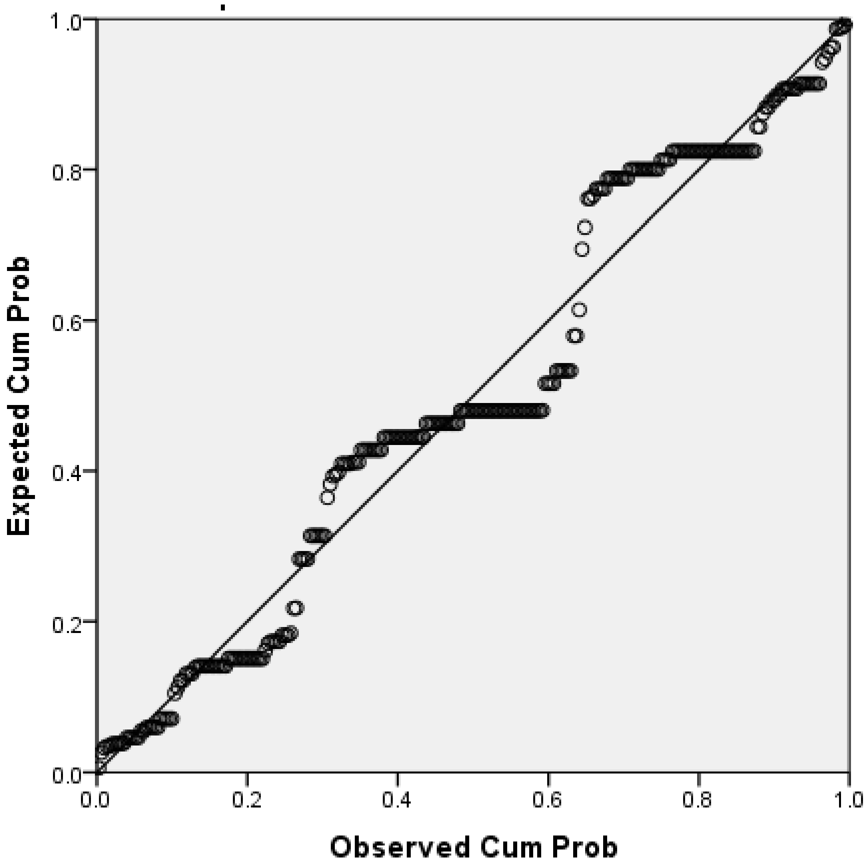

Figure 5 Normal Probability Plot of Residual for Discomfort Model

VII. CONCLUSION

Bicyclists face huge challenges on roads in urban areas, especially in developing countries where dedicated facilities to accommodate bicyclists are not exist in most of the places. There are so many literatures focuses on study the discomfort of motorized users, but not many studies addressed discomfort of bicyclists. One of the reported studies pointed out that daily passing over a hump can cause long term health issues.

In this study, a questionnaire was prepared and only bicyclists were interviewed to know their responses and level of discomfort they felt while passing over hump. Statistical relationship was established between independent variables (height of hump, age of participant, gender of participant and frequency of using hump) and dependent variable (discomfort). Multiple linear regression model was developed and validated by using SPSS software, where R-squared equalled 0.626. Results of questionnaire survey shows that 86% of bicyclists feel discomfort while passing over hump, and 91% of bicyclists think that it is necessary to modify the design of hump. Hence in this study redesign of speed hump is proposed to reduce discomfort to bicyclists.

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