Application of Fuzzy Logic for Evaluation of the Level of Social Acceptance of Traffic Noise Pollution Reduction Strategies in Western New York

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Abstract

Traffic noise pollution is a huge issue throughout the world, especially in urban areas. Traffic noise pollution can cause serious health issues including headaches, nausea, irritability, and insomnia. It can also cause a lower percentage of intellectual development in children's brains after long-term exposure when compared to a quiet environment. Solutions to this problem have been implemented in the past and many options have been proposed. However, the social aspect of the solutions is also important. These social indicators are often qualitative and thus difficult to measure. This paper presents the application of Fuzzy Logic, to evaluate the social acceptance of different noise reduction strategies in the region of Western New York (WNY). A questionnaire was utilized to collect data for the region. The created fuzzy model was verified using the questionnaire filled out by residents of WNY. The results gained from the developed fuzzy model showed that the highest level of social acceptance is for Planting Trees at 61.30% and the lowest level of social acceptance is for Traffic/Transportation Restrictions at 22.10%.

Keywords
Noise Pollution, Social Acceptance, Fuzzy Set Theory, and Fuzzy Logic

1. Introduction
Noise pollution is a growing issue year after year. Its intensity level can be very high and its influence can be very widespread. However, it is somewhat localized and does not cause regional or global pollution like some other sources such as water or air pollution. Although our cities and towns allow a great deal of convenience when everything is close and any store is a short drive away, it can also cause some inconvenience as well. As the development of cities and towns helps to boost the economy, it can also cause an increase in various noises, such as the sound of construction sites, the sound of car horns, the sound of the car engines, or the noise generated by social activities. All of these factors contribute to noise pollution. The rapid increase in the number of motor vehicles has caused the noise pollution of urban road traffic to become more and more serious. It has gradually become the main pollution source of urban environmental noise, and it has also become a difficult point in environmental noise control.

Noise level is a major concern for the population living in urban areas or along major roads. Noise can cause and aggravate cardiovascular disease. Also, it could cause some damage to children's brains. Children who have been exposed to noise for a long time have about 20% lower intellectual development than in a quiet environment (Den Boer & Schroten, 2007). Noise affects people's normal life and rest. Residents living on both sides of arterial roads can be troubled by traffic noise pollution at any time. The survey data in Den Boer, et al. (2007) shows that long-term exposure to a high vibration in a noisy environment can make people irritable, nauseous, causing headaches and insomnia. Den Boer, et al. (2007) reported that 70 decibels of noise or higher can affect 50% of people's sleep and any sudden noise of 60 decibels or higher can also wake people from sleep.

To find out the best methods and solutions to prevent noise pollution, it is necessary to collect the information of cost estimates of noise, valuation of damages imposed on health or property values, costs of preventing noise, and contingent valuation of willingness to pay to avoid noise. Studies have been done to learn about noise pollution. However, these studies have not considered annoyance levels due to traffic. Kim, et al. (2019) conducted a study about the effect of noise in Korea in 2018 with 1022 participants. The result showed that residents who were very annoyed by noise pollution were willing to pay between $7.55 and $8.83 annually to reduce their annoyance level to zero. The same study showed the benefit of noise reduction economically based on residents' willingness to pay to reduce noise pollution by 1 dB(A), totaling $2.91 million per year. Lera-López et al. (2013) studied how much people are willing to pay to reduce the noise from road transportation. The authors used Sound Level Meters (CVM) to measure the economic valuation of both noise and air pollution. The study showed that only high levels of noise had an impact on personal evaluation, whereas any level of air pollution had a significant influence on personal evaluations.

Social Acceptance is a huge part of any community solution. Milutinović, et al. (2016) studied the social acceptance of waste treatment solutions. The study found that any solution that did not have the social acceptance of the community was doomed for failure. Social indicators such as the cost and effectiveness of the noise reduction solution are very important to the solution's success. However, it is extremely difficult to measure social acceptance quantitatively. Social sustainability factors are heavily qualitative which makes them hard to measure and they can increase the level of uncertainty in any evaluation. However, Fuzzy Logic provides a way to measure qualitative data such as opinions or feelings. Boclin & De Mello (2006) demonstrated how to apply the Fuzzy logic approach to quantify qualitative data and also to quantify uncertainties. This study applied Fuzzy Set Theory and Fuzzy Logic for developing a model to quantify and evaluate the level of social acceptance for different measurements of traffic noise prevention. A questionnaire involving 11 questions that as contained in appendix 1 was applied for data collection. The questionnaire was used to obtain the knowledge and experience of participants. The result is compared to the result obtained from the fuzzy model.

Noise pollution is an ongoing, serious issue that has both mental and physical side effects for residents. One of the main contributors to noise pollution is traffic noise. This study analyzed the social acceptance of various traffic noise pollution reduction strategies. There is significantly more vehicle noise now than there was many years ago and there will be more in the future. Therefore, methods should be developed to measure social acceptance so that effective solutions can be provided. No strategy will be effective unless society participates and agrees with the solution. Any plan with which the majority of the community disagrees is doomed for failure. Almost every person contributes in some way to traffic noise. Mitigation strategies must include social acceptance for them to work. To evaluate the social acceptance of the solutions to prevent noise pollution, this research will use the Fuzzy logic methodology and build the Fuzzy model to compare to the results gained from a questionnaire provided to a variety of people. Through this process, the best traffic noise reduction strategy is determined based on the level of social acceptance of the community.

2. Methodology

This paper presents the approach of Fuzzy Logic and develops the Fuzzy Model to evaluate the level of Social Acceptance for different methods of traffic noise reduction. Two main social factors are focused on when evaluating different approaches to reducing traffic noise pollution, these are cost and effectiveness. The methodology of this research is to model the level of social acceptance related to the different ranges of cost and effectiveness. Through the model, the relationship and interaction among the three social factors can be determined. Afterward, the results of the Questionnaire are used to develop solutions and determine which method has the highest social acceptance. Data collection will be executed by the method of the questionnaire which is sent out to the people living in Western New York. The questionnaire is designed to learn about the people's basic knowledge and opinions about traffic noise pollution in Western New York and their attitudes to the different approaches to reducing traffic noise pollution**.**

As shown in Table 1, the fuzzy sets defined for the effectiveness of reduction strategy were: bad, not bad, good, pretty good, and excellent. The fuzzy sets defined for the reduction method cost were very low, low, moderate, high, and very high. And social acceptance was defined through inputs of effectiveness and cost. The fuzzy sets defined for social acceptance were totally unacceptable, unacceptable, little unacceptable, acceptable, and totally acceptable.

Additionally, to develop the fuzzy model, it is necessary to add some rules to make a relationship between the output (social acceptance) and inputs (effectiveness and cost). In this part, we used the "and" operator for the two inputs so that it could show how social acceptance would be affected by different effectiveness with different costs. The rules were added in the same manner as the information in Table 1, for example, if the Effectiveness of the reduction strategy was Bad and the reduction method Cost was Very Low then the Social Acceptance was Little Acceptable.

Table 1. Fuzzy Rules for Determining the Model

Social Acceptance					
Reduction	Effectiveness of Reduction Strategy				
Method Cost	Bad	Not Bad	Good	Pretty Good	Excellent
Very Low	Little Acceptable	Little Acceptable	Acceptable	Totally Acceptable	Totally Acceptable
Low	Unacceptable	Little Acceptable	Acceptable	Acceptable	Totally Acceptable
Moderate	Unacceptable	Unacceptable	Little Acceptable	Acceptable	Acceptable
High	Totally Unacceptable	Unacceptable	Unacceptable	Little Acceptable	Little Acceptable
Very High	Totally Unacceptable	Totally Unacceptable	Unacceptable	Unacceptable	Unacceptabe

Figures 1 & 2 showed the membership functions of the input variables while the membership function of the output variable is contained in figure 3. The range for input and output variables is set from 0 to 100. This is equally distributed for each level.

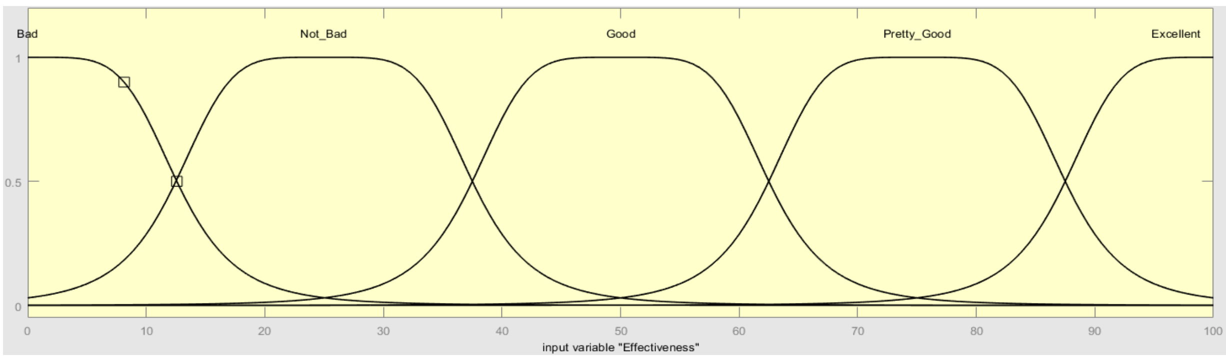

Figure 1: Membership Function for Input Variable "Effectiveness" (Bell Shaped)

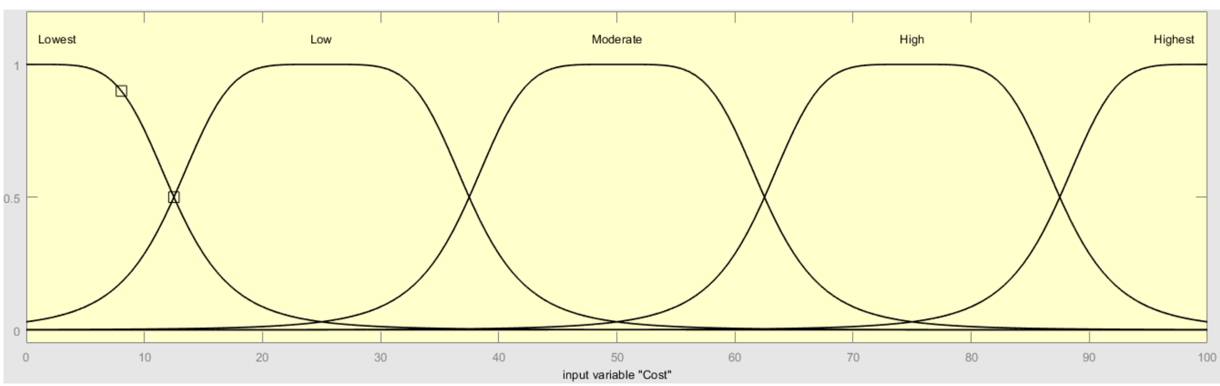

Figure 2: Membership Function for Input Variable "Cost" (Bell Shaped)

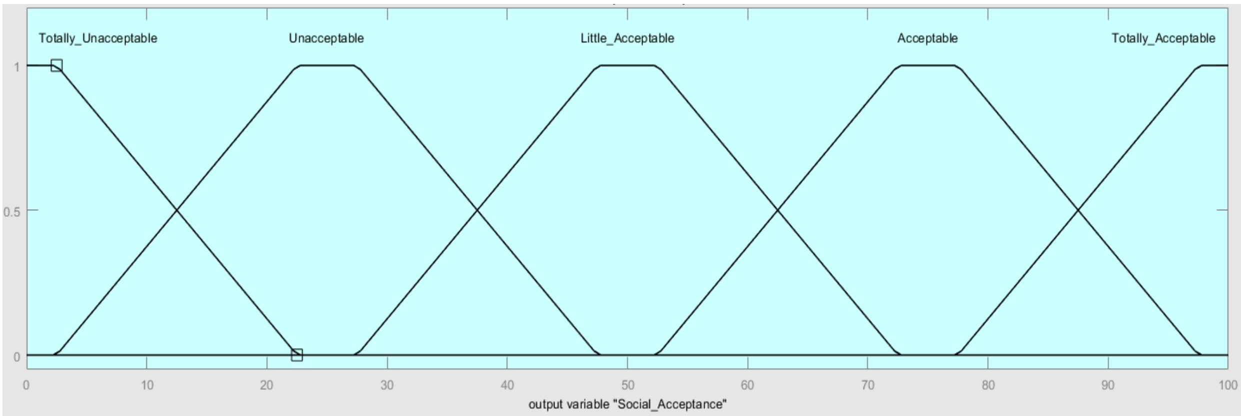

Figure 3: Membership Function for Output Variable "Social Acceptance" (Trapezoidal Shaped)

After setting the functions of variables and rules, the decision surface was shaped as shown in Figure 4. From this response surface, it can be observed that for any combination of cost and effectiveness, indicated on the X and Y axes, respectively, the level of social acceptance, indicated on the Z-axis, can be determined. The response surface shows that as the cost decreases and effectiveness increases, social acceptance increases.

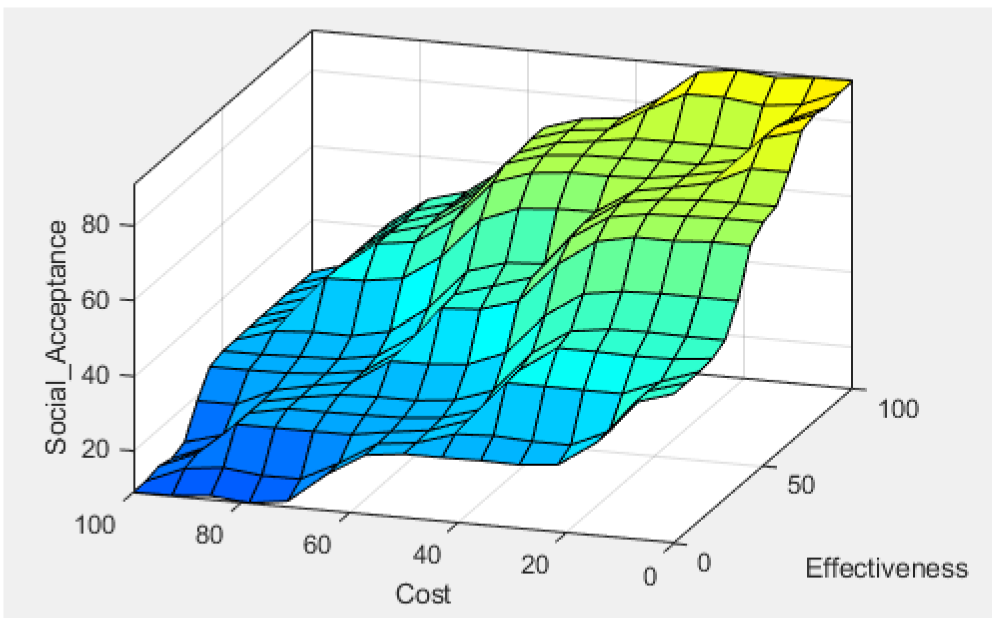

Figure 4: Decision Surface for Fuzzy Model

The questionnaire was made up of two parts. The first part is designed to obtain data about people's basic knowledge and opinions about traffic noise pollution reduction methods. The second part is designed to obtain data about the attitude towards each approach for preventing traffic noise pollution. This questionnaire was designed with responses ranging from 1 (totally disagree) to 5 (totally agree).

According to the fuzzy model presented, two questions from the questionnaire were chosen and answers to these questions are compared to the input variables in the fuzzy model. The question for input variable effectiveness (answer to question Q8) relates to the best way to reduce noise pollution is to build walls, quieter road surfaces, plant trees, traffic/transportation restrictions. The question for input variable cost (answer to question Q9) relates to the willingness to pay to help reduce noise pollution in Western New York for building walls, quieter road surfaces, planting trees, traffic/transportation restrictions. By comparing the questionnaire results to the Fuzzy Model, the noise reduction method that is more socially acceptable is determined.

3. Results and Discussion

After processing the questionnaire survey, a total of 26 responses were obtained. Figure 5 shows the ages and genders of the 26 respondents. The age range is from 21 to 37, with 24 and 25-year-old respondents holding the largest percentage. The number of male respondents is more than that of female respondents.

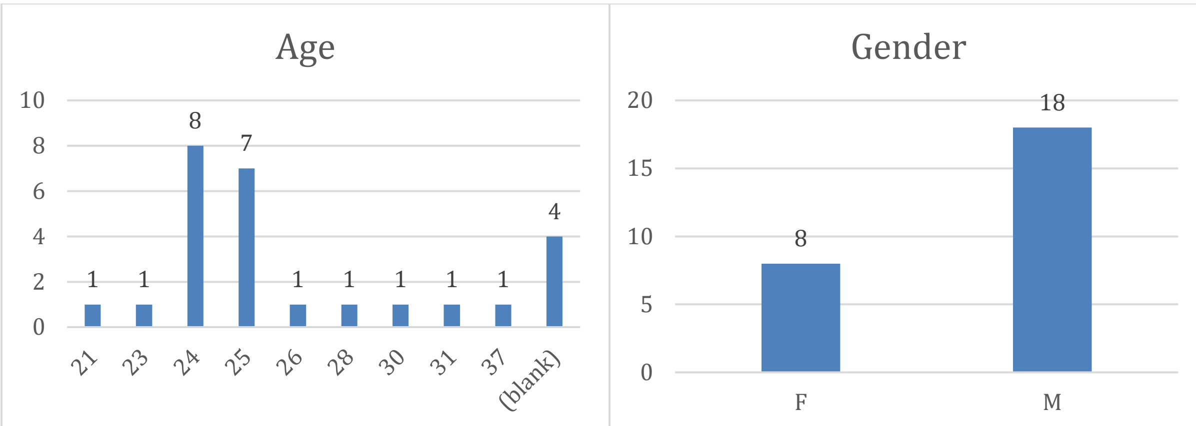

Figure 5: Ages and Genders of Respondents.

Figure 6 shows the survey taker's attitude toward the effectiveness and cost of the methods of traffic noise pollution reduction. Question 8, "The best way to reduce noise pollution is," and Question 9, "I would be willing to pay to help reduce Noise Pollution in Western New York," were used to evaluate effectiveness and cost. The percentages shown below represent responses that are answered with "agree" and "totally agree" for: build walls, quieter road surfaces, planting trees, and traffic/transportation restrictions, which are used as input data in the developed fuzzy model.

The results of the responses show the attitude of respondents about the effectiveness of noise reduction methods (question Q8): 62% of respondents think that planting trees is the most effective way of noise pollution reduction, while only 38% of respondents think that building walls and traffic/transportation restrictions are the best way of reducing traffic noise. The reason for this result may be the lack of knowledge related to the benefits of building walls and traffic/transportation restrictions.

The results obtained show that 62% of respondents are willing to pay for planting trees to reduce noise pollution, while only 8% of respondents are willing to pay for implementing traffic/transportation restrictions. Also, there are quite fewer respondents willing to pay for building walls and quieter road surfaces, which are only 15% and 12%. The reason for getting such results may be the consequence of lack of individual financial ability and the doubts about the actual effectiveness of the building walls, quieter road surface, and traffic/transportation restrictions.

The respondents believe that planting trees is not only definitely effective to reduce traffic noise pollution but also reducing air pollution and protecting the natural environment. In addition, 62% of respondents are willing to pay for planting trees, which indicates that compared with other methods, they may consider that planting trees would cost the least regardless of the effectiveness.

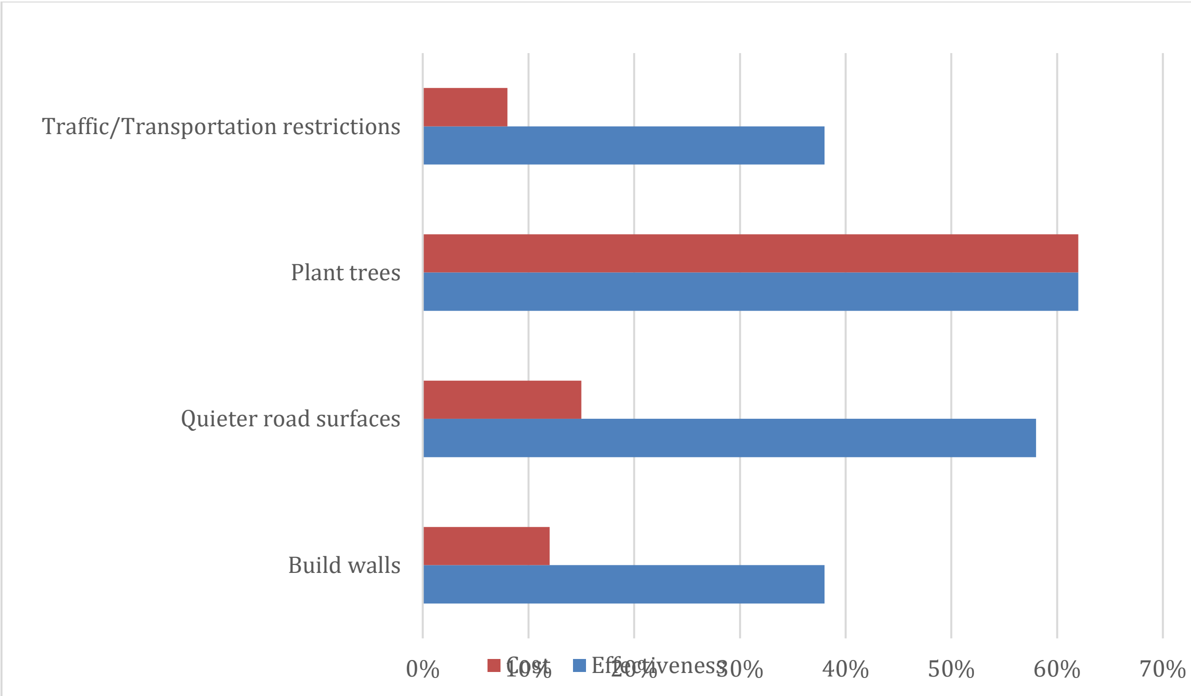

Figure 6: Attitude of respondents about noise reduction methods.

Table 2. Level of Social Acceptance of Traffic Noise Pollution Reduction Methods

	Build walls (%)	Quieter road surfaces (%)	Plant trees (%)	Traffic/Transportation restrictions (%)
Effectiveness (Q8)	38%	58%	62%	38%
Cost (Q9)	12%	15%	62%	8%
Level of social acceptance	22.20%	30.70%	61.30%	22.10%

The results mentioned above obtained by the survey in Western New York, as well as the application of the developed fuzzy model, the level of social acceptance of certain traffic noise pollution reduction methods (building walls, quieter road surface, planting trees, and traffic/transportation restrictions), were calculated and depicted on Table 2.

The results obtained show that the method in the highest level of social acceptance in Western New York is for planting trees (61.3%) and after that for quieter road surface (30.7%). The method in the lowest level of social acceptance is for traffic/transportation restrictions (22.1%).

4. Conclusion

This study uses the developed fuzzy model to evaluate the level of social acceptance of certain noise reduction methods by two input variables. The study showed that fuzzy set theory and fuzzy logic can provide an approach to deal with uncertainty in determining social indicators. The level of social acceptance obtained from the fuzzy model indicates that people have common knowledge and experience of the function of planting trees to reduce noise and they can easily accept this method depending on both effectiveness and cost. For the methods of quieter road surfaces, building walls, and traffic/transportation restrictions, some of the respondents are not clear with the actual effectiveness of these methods and the high cost. Uncertain effectiveness may make them consider that these methods are not worth investing in, which could cause low social acceptance.

Some of the limitations in this study include the small number of respondents and the small age ranges of respondents. 26 respondents are insufficient, and most respondents are 24 and 25 years old who may have less knowledge and experience of the noise reduction methods. To increase the accuracy and reliability of this study, it is important to have much more respondents who are in different age ranges.

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Biography

Johnson Adebayo Fadeyi is a lecturer in the Department of Industrial & Systems Engineering at the University at Buffalo, New York, USA. He holds a doctoral degree from Wayne State University, USA. His research interests include sustainable manufacturing, sustainable product development, and product lifecycle management. In these areas, he has published research papers and presented his work at conferences including IISE and INFORMS. He is a reviewer for several journals.

Appendix 1. Questionnaire Design

Gender	Male		Female		
Age					
Education Level	High School		Undergraduate	Graduate	
Please rate the level to which you agree with each statement. (1=Totally Disagree, 5=Totally Agree)					
Q_1: Noise Pollution is a big problem in Western New York (WNY).					
	1	2	3	4	5
Q_2: Noise Pollution problems in WNY could be solved in ways other than traffic / transportation restrictions.					
	1	2	3	4	5
Q_3: Certain types of Noise Pollution is unavoidable.					
	1	2	3	4	5
Q_4: I am bothered by Noise Pollution in Western New York.					
	1	2	3	4	5
Q_5: Most of my friends are Bothered by Noise Pollution in Western New York.					
	1	2	3	4	5
Q_6: There are many places throughout Western New York that can benefit from Noise Pollution reduction.					
	1	2	3	4	5
Q_7: Trees help to reduce noise pollution.					
	1	2	3	4	5
Q_8: The best way to reduce noise pollution is:					
a) Build Walls	1	2	3	4	5
b) Quieter Road Surfaces	1	2	3	4	5
c) Plant Trees	1	2	3	4	5
d) Traffic / Transportation Restrictions	1	2	3	4	5
Q_9: I would be willing to pay to help reduce Noise Pollution in Western New York.					
a) Build Walls	1	2	3	4	5
b) Quieter Road Surfaces	1	2	3	4	5
c) Plant Trees	1	2	3	4	5
d) Traffic / Transportation Restrictions	1	2	3	4	5
Q_{10}: Most of my friends would pay to help reduce Noise Pollution in Western New York.					
a) Build Walls	1	2	3	4	5
b) Quieter Road Surfaces	1	2	3	4	5
c) Plant Trees	1	2	3	4	5
d) Traffic / Transportation Restrictions	1	2	3	4	5
Q_{11}: Noise Pollution reduction should be charged according to the amount of noise to be reduced.					
	1	2	3	4	5