

Application of Neurofuzzy in the Development of Road Bump Designs

S.A. Oke, M.Sc.¹, A.O. Johnson, B.Sc.², T.A.O. Salau, Ph.D.³, and A.O. Adeyefa, M.Sc.⁴

^{1,2} Department of Mechanical Engineering, University of Lagos, Akoka-Lagos, Nigeria

^{3,4} Department of Mechanical Engineering, University of Ibadan, Ibadan, Nigeria

E-mail: sa_oke@yahoo.com

ABSTRACT

This contribution is on the development of a neurofuzzy model that aids in capturing imprecision and uncertainty in the various road bump parameters. Road bumps are structures built on roads to act as obstructions to vehicles plying these roads. The neurofuzzy methodology is used to check the vehicle speeds to acceptable standards. Particular use is made of neurofuzzy since it is an improvement on the traditional model proposed earlier in the literature. The work is motivated by the need for a more reliable and easily understandable methodology that guides decision makers in making correct decisions in a timely manner. The results obtained demonstrate that it is feasible to apply the model in practice. The paper is new in that it proposes a novel approach to quantifying the results of road bump design in order to achieve worthy and reliable result.

(Keywords: road bump, traffic control, neuro-fuzzy, uncertainties, imprecision, speed bump design, mathematical model)

INTRODUCTION

Road bumps are playing an increasing role in the enforcement of speed limits and pedestrian safety through the control of speeding vehicles (Baguley, 1981; Jarvis and Sweatman, 1982; Kassem and Al-Nassar, 1982; Stevens, 1986). In recent years, governments and safety agencies have been the driving force behind these structures on roadways (Sato et al., 1999). The motivation for this arises from steady advances made in curbing road accidents both on commercial and residential roads, particularly in developed countries (Clement, 1983).

Several professionals and researchers working in the areas of road bumps have proposed

different models and frameworks that would assist in specifying the parameters of interest in road bump design (Kassem and Al-Nassar, 1982; Laitakari and Alppivuori, 1981; Rylander and Bjorkman, 2002). In one of the studies, Salau et al., (2004) applied Fourier series to formulate holistic equations that combine stages of road bump development. Trigonometric functions are used to model the behaviour of the stage in the process. Vibration analysis was also carried out to determine the effects of road bumps on vehicular systems. Arising from this was a model component which referred to isolation factors which offer guidance on a safe frequency at which vehicles could travel over road bumps.

Another contribution to road bump design addresses the often ignored aspect of the velocity wavelength systematic analysis (Oke et al., 2005). The variation that was introduced in the study is the use of hollow rectangular shaped bumps versus the conical shaped bump previously studied in the literature. However, the emphasis was not to develop a new formula for the velocity of vehicles that pass over the road bumps. This is achieved by assuming that the vehicle passes through a medium of a particular refractive index, which is air in this case.

Today, road bump designs, construction, repair, resurfacing, and monitoring have gone through major changes due to advances in technology and strategies (Zaidel et al., 1989; 1992; Zaidel and Bar-Ziv, 1988). The use of soft computing techniques, such as data mining, fuzzy logic, artificial neural networks, genetic algorithms, and neurofuzzy techniques which have been recognized as improved tools for solving problems in the servicing industry, are gradually being recognized in the field of road management (Wu and Harris, 1997; Shahin et al., 2003; Olunloyo et al., 2004; Meesad and Yen, 2000).

Soft computing tools are sets of frameworks that are used for tracking uncertainty and imprecision, and optimizing existing models, among other functions. In tracking uncertainty, fuzziness and ambiguity are two prime considerations (Bingham, 2001; Bossley et al., 1999; Lee et al., 2001). The parameters of road bumps could lack definite or sharp distinctions, primarily due to vagueness, cloudiness, haziness, unclarity, indistinctness, and sharplessness (Watts, 1973).

If the parameters of road bumps are ambiguous (one to many relationship), it could be due to disagreements in the choice of several alternatives (dissonance, incongruity, discrepancy, and conflict) or if two or more alternatives are left unspecified (variety, generality, diversity, equivocation, and imprecision). For a detailed account of the basic types of uncertainty, readers are referred to Klir and Yuan (1995).

While fuzzy logic has been widely used for tracking uncertainty, its integration with artificial neural networks is a recent development in capturing the individual weaknesses in fuzzy logic and artificial neural networking (Harris, et al., 1995; Ivan et al., 1998).

The offspring of this marriage, neurofuzzy, has been applied for numerous tasks: in the reinforcement learning of traffic signal control (Bingham, 2001), for identification of autonomous underwater vehicles (Bossley et al., 1999; Lee et al., 2001), in real time modeling and control (Harris et al., 1995), for robust parameter estimation (Ivan et al., 1998), and in vibration monitoring (Meesad and Yen, 2000). Therefore, there is a need to use and develop a practical approach such as the neurofuzzy approach which can deal with uncertainty or vagueness in system parameters.

The remaining sections of this paper are organized as follows:

1) Discussion of the model formulation. Under this section, the authors outline and discuss the notations used in this model. Also some assumptions are made which reflect the conditions under which the framework developed here would best operate.

2) Methodology which captures uncertainty and imprecision that is typical of road bump design

measurements. The methodology incorporates the definition of the input parameters that are used to capture data processed into the output element. The output is then transformed into optimistic, pessimistic and normal level measurements. The structure of the neurofuzzy model shows the interrelationship among input, layers and output elements.

3) Conclusions on the study. This section will discuss future directions into which interesting research may be initiated.

METHODOLOGY

The following are some of the various road bump shapes (Figures 1 and 2):

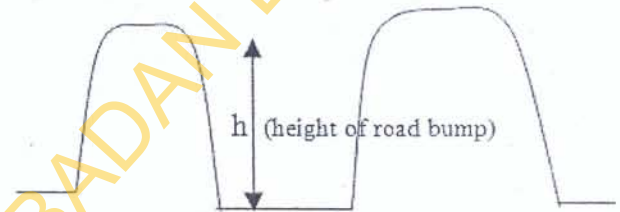


Figure 1: Conical-Shaped Road Bump.

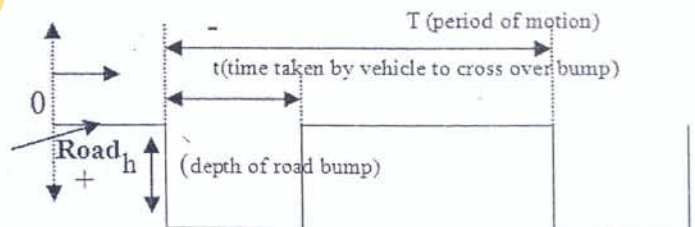


Figure 2: Road Bump with Hollow Rectangular Shapes.

Definitions and notations

- d_e : relates to the effective distance between two successive bumps
- Σ : indicates summation sign
- y_{max} : represents maximum speed of vehicle
- h : means high
- l : means low
- n : means normal
- h : indicates bump height

- λ : defines distance between two successive bumps
- m : means mass of the vehicle
- s : relates to the width of the bump
- k : represents spring constant
- c : means damping constant
- x : indicates input
- y : indicates output
- y_d : defines the desired output
- gh : means getting high
- gl : means getting low
- gn : means getting normal

Assumptions

The structural design of road bumps is diverse. The most common structure is the conical-shaped road bump. There also exists the hollow road bump, usually referred to as the road-hump. In between these two distinctions are various combinations of road bump designs.

Despite the variation in road bump designs, a list of common assumptions are applicable to them, such as presented here. The first assumption is the variability of vehicle speeds. Usually, the speed of the vehicle before approaching the road bump would be different from what it has in between two consecutive road bumps. When approaching road bumps, the vehicle needs to slow down and after crossing it, it then accelerates.

The second assumption relates to the angle of inclination which the road bump makes with the surface of the road. Unless for an inverted road hump with a low height, the road bump considered here is assumed to have an angle of inclination less than 90° . This is to prevent impact due to collision of the vehicle with the bump.

The third assumption states that road bump's angle of inclination with the road should not be close to zero. This is because there would be limited effect of the road bump on the vehicle if it were so.

Fourthly, the vehicle is assumed not to decelerate rapidly between road bumps. This would prevent accidents that may occur in view of sudden brake application.

The fifth assumption is that there is an indication for awareness of road bumps ahead. This is to

prevent sudden application of the vehicle's brakes due to late awareness of road bumps ahead.

The sixth assumption is that vehicles have a self-suspension system. This is to provide for a smooth ride and good handling characteristics.

Another assumption is that the vehicle tire/wheel is at contact with the road at all times. This is to prevent resonance of the vehicle.

The last assumption made relates to the weight of the vehicle. The weight of the vehicle is assumed to be supported in all its wheels. Thus, when vehicle hits a bump, the effects on the entire wheel will be the same.

The methodology describes the application of neurofuzzy to the design of road bumps by considering the effect of road bumps on the vehicle system. The basic structure that shows the mathematical relationship among the variables that act on the vehicle as it moves along consecutive road bump is show in Figure 3.

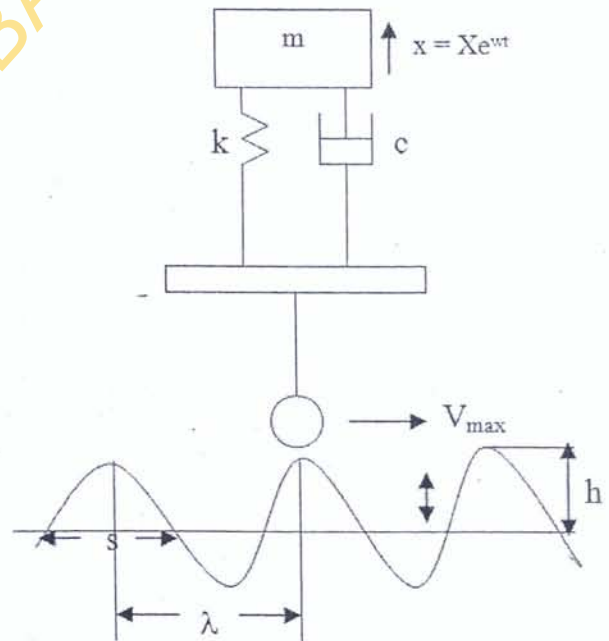


Figure 3: The Structure of the Vehicle-Road Bump Interaction.

The diagram shows that effective distance between two consecutive bumps denoted as d_e . The distance is equivalent to $(\lambda-s)$. This effective distance is for different speed limits, shapes, and aesthetic characteristics of bumps. Consideration is also given to other parameters of road bumps such as height and circular type. Other structures may require different parametric specification, however, the results obtained in the current work are applicable to the varieties of design (i.e., rectangular shaped or a combination of some circular and rectangular shapes). For a detailed description of the mathematical modeling of the problem, the reader is referred to Salau et al. (2004) and Oke et al. (2005).

The neurofuzzy methodology that is applied in the current work combines the inherent attributes of fuzzy logic and artificial neural networks. Fuzzy logic has the attribute of capturing uncertainty and imprecision. However, the advantage of artificial neural networks in specifying more precisely the nature of uncertainty in a network is utilized. The starting point of the procedure for applying a neurofuzzy methodology is to define the input parameters that are used in the process towards obtaining the output.

The basic input into the neurofuzzy model are mainly the bump height, the distance between two consecutive bumps, mass of the vehicle, width of the bump, the spring constant of the vehicle, the damping constant of the vehicle, and the maximum speed that the vehicle could attain.

The output that could be obtained from the modeling is basically three-fold: optimistic, pessimistic, and normal. The optimistic output refers to a situation that is desired, the normal output relates to results that come out on the average, while the pessimistic output is the undesired level of output. In mathematical terms, these outputs are stated as follows:

- $(\sum hde - V_{max}) = H$ (Optimistic)
- $(\sum hde - V_{max}) = L$ (Pessimistic)
- $(\sum hde - V_{max}) = N$ (Normal)

The next stage in the modeling is to evolve the structure of the neurofuzzy application (Figure 4). The structure is made of three distinct parts namely input, layers, and output. The inputs are denoted by 'X'. This could be X_1 , X_2 and X_3 for the framework shown in Figure 4.

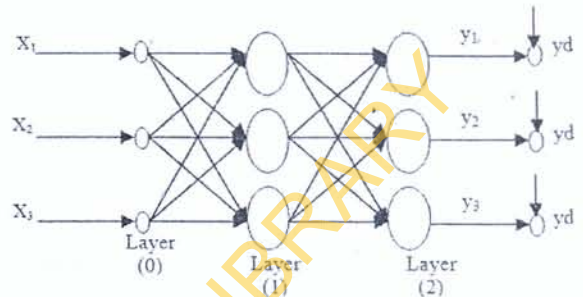


Figure 4: The Neurofuzzy Structure for the Road Bump Design Problem.

Each of these 'X' values may represent different inputs such as bump height, distance between two consecutive bumps, the spring constant of the vehicle, the damping constant of the vehicle, etc. As such, the number of 'X' values may be equivalent to the number of input parameters that we are considering. In this case, the structure of the diagram would be more complicated than what is illustrated above.

The second division of the neurofuzzy structure consists of layers. Layers are interconnections between the input and output neurons. In this particular defined instance, three layers are specified. These are layers 0, 1, and 2.

The next segmentation of the neurofuzzy structure is the output. This is represented by 'y'. Particularly, we have y_1 , y_2 , and y_3 . The output has to be refined in order to obtain the desired output. The refined output is referred to as the desired output, 'yd'. For a clearer view of the neurofuzzy model, the schematic layout diagram in Figure 5 may be helpful.

However, a number of rules guide the implementation of the neurofuzzy model for the case considered here. These are referred to as system operating rules. The definitions of these rules are as follows:

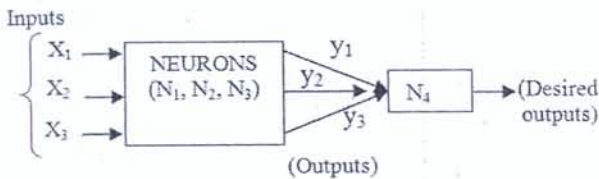


Figure 5: Layout of the Neurofuzzy Model.

System Operating Rules

- INPUT # 1: ("Input," High (H), Low (L), Normal (N))
- INPUT # 2: (Getting High (GH), Getting Low (GL), Getting Normal (GN))
- CONCLUSION: ("Output", Optimistic (H), Pessimistic (L), Normal (N))
- INPUT #1: System Status
- Input: $\{(\sum hde - V_{max})$
 H = High, L = Low, N = Normal
 GH = Getting High, GL = Getting Low, GN = Getting Normal
- OUTPUT: Conclusion & System Response
- OUTPUT: $H = O_p, L = Nil, N = Nil$

In applying the rules, the following 'IF-THEN' statement applies:

- IF $(\sum hde - V_{max}) = H$, AND $(\sum hde - V_{max})$ remains H, THEN output = Op
- IF $(\sum hde - V_{max}) = L$, AND $(\sum hde - V_{max})$ remains L, THEN output = Nil
- IF $(\sum hde - V_{max}) = N$, AND $(\sum hde - V_{max})$ remains N, THEN output = Nil

It should be noted that the optimistic situation (Op) is the state where the maximum speed of the vehicle (V_{max}) is lowest. This is the desired output that is of paramount concern to researchers and practitioners on road bump design.

CONCLUSION

The impact of vehicle speed control with the use of road bumps on preserving the lives of pedestrians is well documented in the recent literature on traffic safety. This study is an addition to the body of knowledge that investigates the control of vehicles through the reduction of speed by the use of road bumps:

In particular, the neurofuzzy model is used as an approach in capturing the imprecision and uncertainty involved in quantifying the parameters of road bump design. Several questions may be posed in order to address the utility of this article as a worthwhile contribution to the literature. In particular, five of these questions are addressed here: (i) what do we learn from the article that we do not know? (ii) why is it worth knowing? (iii) how will we know that the stated conclusions are valid? (iv) given the rate of development in the road bump literature, where do we expect the current study to have expanded to in the next few years? And (v) what are the additional tools that we expect in the area?

We have developed a neurofuzzy approach in the design of road bumps for the control of vehicle speeds. This is a new contribution to the body of knowledge on road bump design. The approach is adopted in order to improve on the use of fuzzy logic, which attempts to capture imprecision and uncertainties.

The fusion of artificial neural network and fuzzy logic has been scientifically proven to produce better results than the independent usage of fuzzy logic or artificial neural networks. This contribution may therefore be judged as beneficial to the safety community. The paper presents an approach that is worth knowing for several reasons. Of particular significance is the improvement in the quality of decision making that the model would aid, particularly for government projects where a large sums of money are invested in road bump design for pedestrian safety. In such projects, the ability to capture and define project imprecision and uncertainty would yield some cost savings. The study a practical case example is used to demonstrate the feasibility of applying the proposed methodology. The conclusion of the model being feasible is validated by the case study.

In recent times, significant extension of frontal knowledge seems to have been made on the development of road bumps design. It is expected that scholars in various associated fields would intensify efforts of extending scholarship in this fertile area. Scholars in mathematics, highway engineering, economics, and other areas are expected to be contributors.

With the contribution of mathematicians, additional applications are expected to be made to road bump design. For example, collaborative research may apply some or all of the following concepts in mathematics to road bump design: (i) theory of partitions of integers, (ii) enumeration of set partitions, (iii) combinatorics of finite sets, (iv) commutative Algebra and (v) basic hyper-geometric series (q-series).

Economists would study the economics of road bumps with the introduction of cost models under conditions of inflations. Highway engineers may be interested in relating road bump design to traffic flow on the road. Such a study could lead to the quantification of economic losses of time by road users during traffic jam. There are several additional tools in operations research vehicle dynamics, etc. that could be added to the study to enrich this body of knowledge.

REFERENCES

1. Baguley, C. 1981. "Speed Control Humps – Further Public Road Trials". TRRL Lab. Rep 10/7. Transport Road Research Laboratory: Crowthorne, UK.
2. Bingham, E. 2001. "Reinforcement Learning in Neurofuzzy Traffic Signal Control". *European Journal of Operational Research*. 131(2):232-241.
3. Bossley, K.M., Brown, M., and Harris, C.J. 1999. "Neurofuzzy Identification of an Autonomous Underwater Vehicle". *International Journal of Systems Science*. 30(9):901-913.
4. Clement, I.P. 1983. "Speed Humps and the Thousand Oaks Experience". *Institute of Traffic Engineers Journal*. 53:35-39.
5. Harris, C.J., Brown, M., Bossley, K.M., Mills, D.J., and Feng, M. 1995. "Advances in Neurofuzzy Algorithms for Real-Time Modeling and Control". *International Journal of Approximate Reasoning*. 13(4):269-285.
6. Ivan, N., Lucia, V.R., and Wagner, C. 1998. "A Novel Approach to Robust Parameter Estimation Using Neurofuzzy Systems". *Information Sciences*. 110(1-2):81-102.
7. Jarvis, J.R. and Sweatman, P.F. 1982. "The Loading of Pavements in the Vicinity of Road Humps". *Australian Road Research Board, Proceedings of the 11th Conference*. 11(2).
8. Kassem, E. and Al-Nassar, Y. 1982. "Dynamic Considerations of Speed Control Humps". *Transportation Research: Part B*. 16:291-301.
9. Klir, G.J. 1989. "Is there more to Uncertainty than Some Probability Theorists Might Have Us Believe?". *International Journal of General Systems*. 15:360.
10. Laitakari, P. and Alppivuori, K. 1981. "The Effect of a Hump and an elevated Pedestrian Crossing on Vehicle Comfort and Control". Report 69-Hs-032-620. Technical Research Center of Finland: Helsinki.
11. Lee, C.S.G., Wang, J.S., and Yuh, J. 2001. "Self-Adaptive Neurofuzzy Systems for Autonomous Underwater Vehicle Control". *Advanced Robotics*. 15(5):589-608.
12. Meesad, P. and Yen, G.G. 2000. "Pattern Classification by a Neurofuzzy Network: Application to Vibration Monitoring". *ISA Transaction*. 39(3):293-308.
13. Oke, S.A., Salau, T.A.O., and Adeyefa, A.O. 2005. "Vehicle Speed Control Using Road Bumps: Part 2". *Transport*. 20(3):99-105.
14. Olunloyo, V.O.S., Ajofoyinbo, A.M., and Badiru, A.B. 2004. "Neurofuzzy Mathematical Model for Monitoring Flow Parameters of Natural Gas". *Applied Mathematics and Computation*. 149:747-770.
15. Rylander, R. and Bjorkman, M. 2002. "Road Traffic Noise Influenced by Road Bumps". *Journal of Sound and Vibrations*. 1:157-159.
16. Salau, T.A.O., Adeyefa, O.A., and Oke, S.A. 2004. "Vehicle Speed Control Using Road Bumps". *Transport*. 19(3):130-136.
17. Sato, T., Yano, T., Bjorkman, M., and Rylander, R. 1999. "Road Traffic Noise Annoyance in Relation to Average Noise Level, Number of Events, and Maximum Noise Level". *Journal of Sound and Vibration*. 775 - 748.