International Journal of Computer Applications (0975 – 8887)
Volume 106 – No.17, November 2014

Urban Market Fire Disasters Management in Nigeria: A Damage Minimization based Fuzzy Logic Model Approach

V.O.Oladokun
Department of Industrial and Production Engineering, University of Ibadan, Ibadan, Nigeria

C.G Emmanuel
Department of Industrial and Production Engineering, University of Ibadan, Ibadan, Nigeria

ABSTRACT
Frequent fire disasters in crowded urban business and market structures have become a major concern to Nigerian urban planners. Urban renewal schemes are being initiated to minimize the occurrence of fire accidents and other associated problems by various levels of government in Nigeria. However there is need for a systematic approach and tools predict the performance of potential intervention schemes and policies and also to ensure that the resources deployed for these schemes achieve the highest possible impact. This study was therefore aimed at developing a soft computing based tool for analyzing fire accident occurrence and prevention systems for commercial complexes. The relevant quantities, key accident causative factors, and their relevant interactions in a fire accident occurrence system were identified through literature search and interview with fire experts. Appropriate linguistic variables and their equivalent term sets were developed for these factors. Using the Matlab fuzzy logic toolbox various possible membership functions were numerically tested to identify the most suitable function for each linguistic variable. A fuzzy inference system of the commercial building fire accidents model was then developed. Model validation was carried out based on data obtained for some randomly selected markets within Ibadan city using structured checklists and expect rating format. Fire risk indexing was used to carry out evaluation by ranking the factors. Four key input factors, namely Users' Safety Culture, Incipient fire Likelihood, Building resistant to fire spread and potential damage level, were identified. The Gaussian and Trapezoidal membership functions were the most suitable. The resulting model was a two stage Mamdani type Fuzzy Inference system using sixteen and twenty-five rule knowledge bases respectively. The checklist and rating format was found easy to use. The performance of the model compared well with results from the literature. It is concluded that Fuzzy logic inference system can serve as a decision support system for fire safety management commercial complexes.

General Terms
Safety, Soft computing, Fire, Classification, Decision support system

Keywords
Fire Accident, Fuzzy Logic, Fuzzy inference, Risk Analysis, Safety.

1. INTRODUCTION
1.1 Problem Background
The lack of adequate planning of many in many Nigerian cities and urban areas is creating safety challenges in managing the various centers of activities. The frequent occurrences of fire disasters across various cities in Nigeria have become a major cause for concern for all stakeholders [1]. One of the most vulnerable clusters is the market places and commercial complexes. These disasters commonly referred to 'market fires', which continue to destroy valuables worth billion of naira, have become a major burden on the Nigerian fragile economy.

Various urban renewal schemes have been initiated to minimize the occurrence of fire accidents and other associated problems by various levels of government in Nigeria. These efforts revolve around such programs like enlightenment campaigns, relocations of settlements areas and temporary closures of markets. Unfortunately many of these interventions only come after the disasters have occurred and in many cases with stiff resistance from the populace. There is therefore the need to have a proactive approach to fire safety management integrated into overall management of our built environment in Nigeria.

Some previous studies [2] highlighted the need for regulatory bodies and stakeholders to have access to easy to use quantitative tools for predicting of commercial complexes to fire disasters. In this study we are proposing that such prediction methods should be extended to include capability to incorporate potential losses and damages from accident. This is particularly necessary to have a systematic approach and tools can be used to demonstrate the impact of intervention schemes and policies of the various urban renewal schemes. Since resources for these intervention schemes are limited it important efforts are optimally deployed for these schemes to achieve the highest possible impact. This study was therefore aimed at developing a soft computing based tool for analyzing fire accident occurrence and prevention systems for commercial complexes.

1.2 Recent Fire disasters in Nigeria
The issues related to fire safety has become important issues in national discourse. A good number of fire incidents have been reported and documented by Nigeria news media, the fire service departments and the National Emergency Management Agency. The News Agency of Nigeria reported that over 50 market stalls were gutted by fire in the early hours of 5th of March 2008 in the Kuto Market of Abeokuta, the capital of Ogun State. In an earlier incident on 1st March

2008, goods worth over one hundred million (N100m) was lost to a fire that engulfed part of the Industrial Spare Parts Market along McDermott Road in Warri, Delta state while over 2,000 shops at the popular international Tejusho Market, Lagos were razed down by inferno on the 19th of December, 2007.

In the year 2011, according to the record of the Department of Fire Service of Oyo state, 349 fire incidents occurred in the city of Ibadan, the capital city of Oyo sate in South west Nigeria, destroying property worth millions of naira. The number of the casualties and the figure of the incidents showed an increase of such disasters compared with previous year (2010) with a recorded figure of 319 fire incidents. In the capital city of Abuja a fire accident on the second floor of the National Assembly annex building housing the Legal and Accounts Departments of the National Assembly Service Commission consumed huge amount of valuables on March 22, 2012.

1.3 Fire Accident and Safety Management

Fire deaths and property losses could be eliminated or at least be curbed if regulatory authority could identify potential fire zones in advance for effective management. This however will require enhancing the capacity of relevant regulatory institutions in evaluating the proneness of existing buildings to fire accidents using appropriate risk analysis tools. Measures to reduce the severities of damages of fire accidents can be appropriately deployed and effective prevention measures put in place if the potential of fire accident in any environment can be evaluated.

One of the tools of fire risk analysis is the checklist. The checklist involves the listing of attributes affecting risk analysis and the identification of the presence or absence of specific fire accidents attributes. Other tools used for analysis are Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Failure Modes and Effects Analysis (FMEA), Failure Modes and Effects Analysis (FMEA), Cause/ Effect Analysis, Functional Hazard Analysis (FHA), Human Error Analysis, and Software Hazard Analysis. The conventional approaches used for hazard or risk analysis are Energy Trace Barrier Analysis (ETBA), Hazard and Operability Study (HAZOP), Subsystem Hazard Analysis (SSHA), System Hazard Analysis (SHA), Operating and Support Hazard Analysis (O&SHA), Hazard Analysis Schedules, Multi-criteria Evaluation (MCE), Multi-criteria Decision Analysis (MCDS), System/ Integrated Hazard Analysis (SHA/IHA) and Failure Mode, Effects and Criticality Analysis (FMECA). A major requirement for effective fire prediction is the use of easy to use tool that can perform well the face of limited and imprecise data.

1.4 The Fuzzy Logic: A brief Overview

Fuzzy logic modeling approach mirrors the functioning of the human thought and reasoning in handling uncertainties, vagueness, imprecision and incomplete information associated with many real-life problem-solution processes. Fuzzy logic a key component of soft computing was first introduced in 1965 by Lot A. Zadeh with the concept of fuzzy sets as an extension of the classical set theory formed by crisp sets [3]. Fuzzy logic is a logical system that is an extension of multivalued logic. While classical logic is based on the theory of crisp set Fuzzy Logic adopts the theory and algebra of fuzzy sets. In a crisp set theory any given element is either totally included in a set or totally excluded from the set. On the other hand a fuzzy set is a set without a crisp, clearly defined boundary that can contain elements with only a partial degree of membership.

The computing system, based upon classical set theory and two-valued logic, is inadequate in handling complex real life problems efficiently the way human handles them. Fuzzy logic modeling reflects and accommodate the human experience that not all questions can have clear Yes or No answer or black and white categorization: there are situations that carry a Yes and No, where things fall into grey areas, that is when it is expedient to sit on the fence. Human capability to make sense out of fuzzy knowledge, involving vague, imprecise, uncertain, ambiguous, inexact, or probabilistic data is reflected in the use of human languages to handle such information.

The requirement to capture and represent the real world with its fuzzy data motivated the theory of fuzzy sets. Fuzzy set theory provides a mathematical tool for modeling uncertain, imprecise and vague data encountered in most real life situations.

Fuzzy Logic provides a remarkably effective way for computing model to draw definite conclusion from vague, ambiguous or imprecise information to a detail and precise information like human. Fuzzy Logic incorporates an alternative way of thinking which allows modeling complex system using higher level of abstraction originating from our knowledge and experience. It provides a very powerful tool for dealing quickly and efficiently with imprecision and nonlinearity. Fuzzy set theory is able to cope with the imprecision and uncertainty which is inherent in human judgments and decision making processes by the use of linguistic terms or variables and degrees of membership.

Human use linguistic variables often to describe, and maybe classify, physical objects and situations. A Linguistic Variable, the equivalent of mathematical variable, can take words or sentences as values. For instance, a linguistic variable X with label Speed, can assume values like ‘Very fast’, ‘Fast’, ‘Slow’, or ‘Very slow’. Fuzzy set can classify elements into a continuous set using the concept of membership functions (MF) and degree of membership (μ) to represent the gradual changes from 0 to 1. So in fuzzy logic, the truth of any statement becomes a matter of degree. For more in depth readings on Fuzzy logic, theories and applications see [4][5][6][7][8][9]

2. METHODOLOGY

The methodology essentially involves building a decision support system for managing the fire accident and consequent loss interaction system using a fuzzy inference system. The fuzzy inference system modified for the fire accident system is as shown in figure 1

2.1 Study Locations and Data Gathering

Eight commercial complexes located in one Nigeria’s largest city, the ancient of Ibadan Southwest Nigeria were used for the study. The data and relevant information were gathered from interview of occupants and observation of activities and interactions on these complexes. Fire service departments’ experts as well literature were consulted to gain insight into the various factors in the fire accident system. The following factors were tracked the people present in the complex, the type of activities or usage of the complex, the sources of ignition and the flammability of items in the complex, the structural features of the commercial complex. The levels or states and interactions of these factors in a building complex’s utilization system will determine the associated risk of fire.

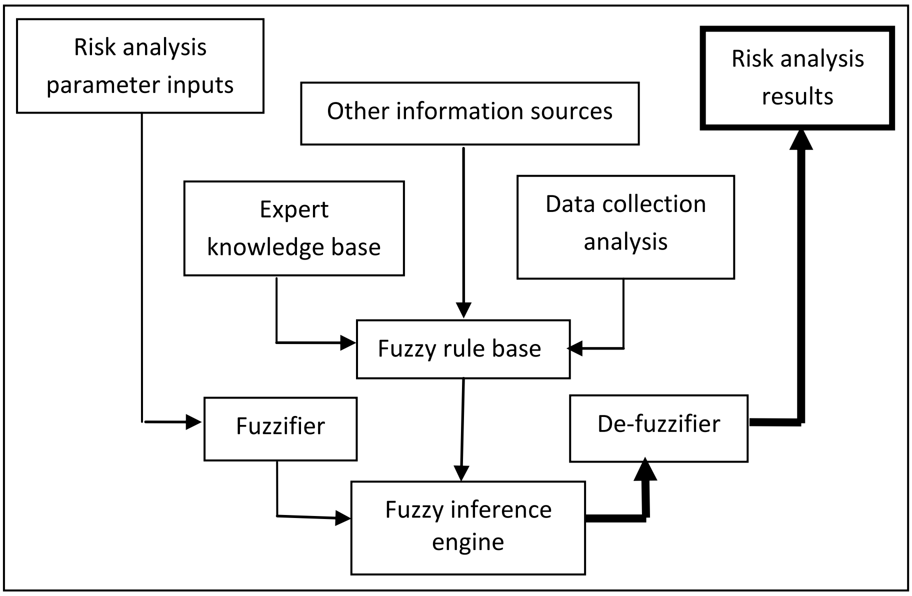

Figure 1. The Overview of fire risk analysis prediction model

2.2 Fuzzy Model description

The various input factors were aggregated into three major factors as proposed in [1]: 1) Safety Culture 2) Spread Tendency 3) Likelihood of Fire Accidents 4). The first factor, tagged Safety Culture, captures the behavioral patterns of the users that borders on their level of adherent to standard safety rules and regulations. This factor also implicitly captures whether the users are cutting corners on the suitability or appropriateness of the complex to support their trade activities and inventory types. The second factor, Spread Tendency, measures the ability of the complex to localize an incipient fire to the originating unit. This is essentially a function of the complex's architecture, material used for internal partitions and roofing. Masonry walls and concrete floors will restrict better than wooden or plastic walls. Some architectural design will allow for quick and effective intervention of firefighting systems and easy evacuation etc. This study however identify incorporated the Consequence Severity factor to account for potential losses in estimating inference output which is the Risk level. The Consequence Severity factor is determined by the measures of severities which are in terms of lives involved, injuries sustained destruction of storage or market products or properties and many others.

2.3 Linguistic Variables and Membership Functions

The factors identified were changed into fuzzy expressions using appropriate linguistic variable and the membership functions as summarized in table1 based on the Mamdani's fuzzy Inference approach. Some contextual descriptions of the input and output variables are given in Table 2. Fire safety experts and experienced users rate and describe any given complex by using the term sets to give their opinions along the 3 three input factors. It is possible for multiple experts to score each factor on scale of 1 to 10 depending on the context and the weighted mean adopted. The consequence severity can reflect the relative monetary value of assets that will be lost if a fire accident should occur. Injuries and loss of lives can be surrogated by potential insurance claims.

Table 1: Linguistic Variables Term set and Membership functions

Linguistic Variables (Attributes)	Term sets (Abbreviation)	Membership function
Input 1		
Safety Culture	Poor	Trapezoidal
	Fair	Pi-shaped
	Good	Pi-shaped
	Very Good	Trapezoidal
Input 2		
Spread Tendency	Restricted	Trapezoidal
	Slow Spread	Trapezoidal
	Fast spread	Trapezoidal
	Very Fast Spread	Trapezoidal
Stage 1 Output ↔Stage 2 Input		
	Input 1	
Likelihood	Very Low	Trapezoidal
	Low	Trapezoidal
	Average	Trapezoidal
	Frequent	Trapezoidal
	High Frequent	Trapezoidal
Input 2		
Consequent Severity	Negligible	Trapezoidal
	Minor	Trapezoidal
	Moderate	Trapezoidal
	Severe	Trapezoidal
	Catastrophic	Trapezoidal
Stage 2 Output		
Risk Level	Very Low	Trapezoidal
	Low	Trapezoidal
	High	Trapezoidal
	Very Low	Trapezoidal

Table 2a : Input Linguistic Variables description

Term set	**Input Linguistic Variables description**
1	**Safety Culture**
Poor	Users are nonchalant about, and or are ignorant of basic fire safety rules and practices. They cut corners in satisfying regulatory requirements.
Fair	Users are aware of safety requirements and make some efforts at meeting theme. There are no deliberate attempts at corners. Though efforts are below ideals.
Good	Users are educated about fire safety standards and practices. There is compliance with safety measures in terms of facilities provision and behavior.
Very Good	Users are educated about fire safety standards and practices. There is full compliance with safety measures in terms of facilities provision and behavior.
2	**Spread Tendency**
Restricted	When walls are made of concretes blocks, flooring made of ceramics, doors and roofing system made of noncombustible materials to minimize domino effects
Slow spread	This is a step below restricted. Fire can spread but slow pace.
Fast Spread	This occurs in complex made of woods, and shanty type of structure. When there are access paths. This is common in most of Nigeria market structures.
Very Fast Spread	This describe complex made of wood and shanty type of structure giving fire easy paths to adjacent units. This is common in most Nigeria market structures.
3	**Accident Likelihood**
Very Low	No fire accident, fire accidents are unlikely to occur since possibly people are in full compliance i.e. have very good safety culture and spread tendency restricted.
Low	Likely to happen since people are not in full compliance.
Average	Occasional fire accident,
Frequent	Fire accident is occurring more frequently
Highly Frequent	Expected to occur in most circumstance, repeated, multiples or recurring fire accidents
4	**Consequence Severity**
Negligible	1. No human occupants that can be hurt 2. Complex houses non combustible items or assets with low economic values. 3. No significant business loss in case of fire accident
Minor	1. Low population with few exposed to minor injuries/shocks incase of inferno. 2. Complex houses only non combustible items. 3. Very moderate business loss in case of fire accident
Moderate	1. Complex housing occupants prone to minor injuries but no death or complex housing assets of moderate economic loss if there is fire accident. 2. Significant though reversible business loss in case of fire accident.
Severe	1. Populated areas with possibility of death in case of fire accident 2. Complex houses only combustible assets with some economic value. 3. Significant reversible business loss in case of fire accident
Catastrophic	1. Highly populated complex or VIPs with potential for large number of simultaneous deaths and major injuries. 2. Complex housing highly valuable assets like data servers with serious business or security implications and possible irreversible damages of strategic importance possible

Table 2b: Output Linguistic Variable description

Term set	**Output Linguistic Variable description**
Very Low	This is a situation where the chances of fire accident are very remote and even if it occurs damages **and** possible losses are minimal. There is adequate capacity in place to curtail its spread and damages. It is safe
Low	This is a situation where fire accident will rarely occur, degenerate to serious inferno **or** possible damages are minimal damages. The situation is fairly safe.
High	This is a situation where fire accidents can occur and considerable damages occur. The situation is quite unsafe.
Very High	This is a situation where fire accident will most likely occur and cause losses or damages. The situation is highly unsafe and dangerous.

2.4 The Fuzzy Inference System Models

The overall combinations and interactions of the fuzzy elements are summarized in the proposed inference model shown in figure 2. The first stage output, Likelihood of fire accidents is generated by the two input variables, Safety culture of the users and fire Spread tendency in the complex. The output likelihood combined with Consequence Severity constitutes the input variables into the second stage to obtain the final output variable, Risk level. The conceptual model in figure 2 was implemented using the various linguistic variables and membership functions outlined of Tables 2a and 2b.

2.5 Fuzzy Rules

Appropriate Fuzzy Rule Base (see Table 3 for sample fuzzy rules) was defined to mimic a typical human expert's interpretations and decisions making process in the face various possible combinations of the input factors and corresponding output states.

Table 3 : Sample rules from Rule Base

	Stage 1				
			Stage 2		
Rule#	Safety Culture	Spread Tendency	Likelihood	Consequent Severity	Risk Level
1	Poor	*Restricted*	*Average*	*Moderate*	***High***
2	Poor	*Slow Spread*	*Frequent*	*Negligible*	***Low***
3	Poor	*Fast Spread*	High Frequent	*Catastrophic*	***Very High***
4	Poor	*Very fast Spread*	*High Frequent*	*Minor*	***High***
5	Fair	*Restricted*	*Low*	*Catastrophic*	***High***
6	Fair	*Slow Spread*	*Average*	*Negligible*	***Low***
7	Fair	*Fast Spread*	*Frequent*	*Minor*	***High***
8	Fair	*Very fast Spread*	*High Frequent*	*Negligible*	***High***
9	Good	*Restricted*	*Very Low*	*Catastrophic*	***Low***
10	Good	*Slow Spread*	Low	*Negligible*	***Very Low***
11	Good	*Fast Spread*	*Average*	*Minor*	***Low***
12	Good	*Very fast Spread*	*Frequent*	*Severe*	***High***
13	*Very Good*	*Restricted*	*Very Low*	*Negligible*	***Very Low***
14	*Very Good*	*Slow Spread*	*Very Low*	*Minor*	***Very Low***
15	*Very Good*	*Fast Spread*	*Average*	*Severe*	***High***
16	*Very Good*	*Very fast Spread*	Frequent	*Catastrophic*	***Very High***

3. APPLICATIONS, RESULTS AND DISCUSSION

3.1 Risk Assessment

One application of the fuzzy inference system is in the determination of fire accident risk associated with any existing structure. The proposed model was applied to eight different commercial units within Ibadan to demonstrate this area of application. The opinions of fire safety professionals on the performance of each complex with respect to the three input factors of Safety culture, Spread tendency and Consequence severity were captured using a carefully designed checklist form. The experts' scores on each factor on a scale of 0 to 10 were used to assign appropriate term sets to the linguistic variables as shown in tables 4 and 5.

Table 4 : Expert ratings of SAFETY CULTURE and SPREAD TENDENCY as input variables

	INPUT VARIABLES		OUTPUT VARIABLE
BULDING ID	SAFETY CULTURE	SPREAD TENDENCY	LIKELIHOOD
Site A	Very Good	Very Fast Spread	Average
Site B	Very Good	Very Fast Spread	Average
SITE C	Very Good	Fast Spread	Low
Site D	Good	Very Fast Spread	Frequent
Site E	Fair	Very Fast Spread	High Frequent
Site F	Good	Slow Spread	Low
Site G	Poor	Fast Spread	Frequent
Site H	Fair	Restricted	Average

Table 5 Expert ratings of CONSEQUENCE SEVERITY as input variable

	INPUT VARIABLES		**OUTPUT VARIABLE**
BULDING ID	LIKELIHOOD	CONSEQUENT SEVERITY	RISK LEVEL
Site A	Average	Catastrophic	High
Site B	Average	Catastrophic	High
SITE C	Low	Moderate	Low
Site D	Frequent	Catastrophic	Very High
Site E	High Frequent	Catastrophic	Very High
Site F	Low	Severe	High
Site G	Frequent	Moderate	High
Site H	Average	Negligible	Low

3.2 Intervention Strategies Planning

Another application is in the determination of possible intervention or remediation steps to pursue in order to reduce the observed risk to an acceptable level. Some 'What If Analysis' can be carried out to provide insights into the potential impact of interventions on the output variable(s). The surface maps of Figures 4 provide at a glance what improvements can be obtained by programme or policies altering any of the three factors. For instance if the occupants of a high risk location reduce the volume of their high valued assets within the complex (eg by using a warehousing in a more secured site) then the reduced Consequence Severity impact on the Risk level. For high valued assets the level of risk reduction may justify the additional cost of warehousing facilities. Another intervention can be an enlightenment campaign targeted at improving the safety culture of the people within a complex.

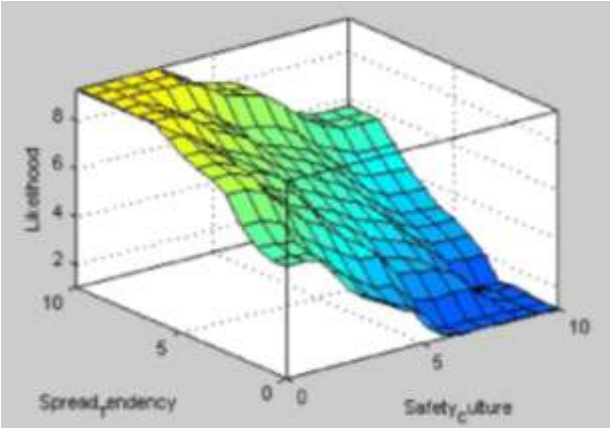

Figure 4a Input to output Surface Map of stage one

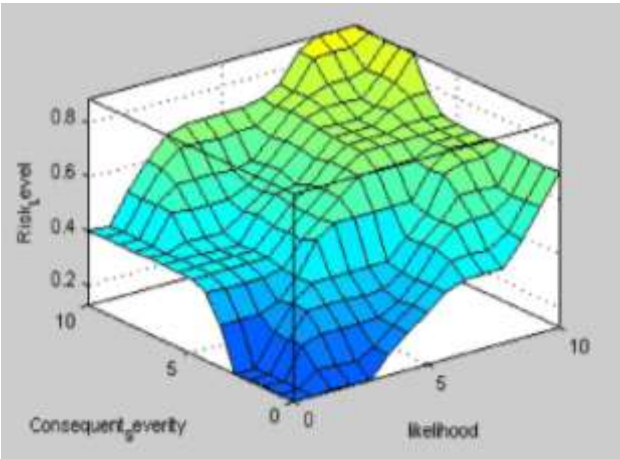

Figure 4b Input to output Surface Map of stage two

4. CONCLUSION

Three easy to use Linguistic input variables, Safety Culture of occupants, fire Spread Resistance, and the Economic Worth of assets at risk within a building, were used to define a fuzzy logic safety model for urban commercial complexes. Model applications indicate that fuzzy logic safety model provide as a good planning and management tool for urban renewal schemes aimed at reducing fire related disasters in cities. This model can provide a basis and quantitative framework for predicting the performance of safety programs and interventions. Also the idea of an integrated multi-modal community safety management system, based on the model, can be explored.

5. REFERENCES

[1] V. O. Oladokun, A. Kolawole and C. G. Emmanuel, "Risk Analysis Models of Fire Accidents In Nigeria Commercial Complexes: A Fuzzy Logic Approach," in *Proceedings of NIIE 2012 Conference*, Benin , 2012.

[2] V. O. Oladokun and F. A. Ishola, "A Risk Analysis Model for Fire Disasters in Commercial Complexes in Nigeria," *Pacific Journal of Science and Technology.,* vol. 11, no. 2, pp. 376-386, 2010.

[3] E. Volna, Introduction to Soft Computing, 1st ed., www.bookboo.com, 2013.

[4] S. K. a. K. Ali, "A Fuzzy Logic Approach for Reducing Handover Latency in Wireless Networks," *Network Protocols and Algorithms Vol. 2, No.4 ISSN 1943-3581,* pp. 61-87, 2010.

[5] Awasthi, S. S. Chauhan and S. K. Goyal, "A fuzzy multicriteria approach for evaluating environmental performance of suppliers.," *International Journal of Production Economics,* vol. 126, pp. 370-378, 2010.

[6] M. Chen, "A fuzzy-based decision-support model for rebuy procurement,. 2009.," *International Journal of Production Economics,* vol. 12, no. 2, pp. 714-724, 2009.

[7] E. H. Mamdani, "Applcation of Fuzzy Algorithms for Control of Simple Dynamic Plant," in *Proc, IEE 121*, 1974.

[8] A. K. Mandal, Introduction to Control Engineering : Modeling Analysis and Design, 1st ed., New Delhi: New Age International, Publishers , 2006.

[9] V. O. Oladokun and O. O. Okesiji, "Application of Fuzzy Logic to the Optimal Location of Public Utilities: A Case Study of Pedestrian Bridges," in *International Proceedings of Economics Development and Research* , Dubai, 2012.

[10] L. A. Zadeh, "Soft Compuiting and Fuzzy Logic," *IEEE Software,* vol. 11, no. 6, pp. 48-56, 1994.

[11] X. Li, D. Ruan and A. J. Van der Wal, "Discussion on Soft Computing at FLIN's 96," *International Journal of Inteligent systems,* vol. 13, no. 2-3, pp. 287-300, 1998.

[12] L. C. C. Lin, "Individualizing Learning Using Fuzzy Expert System and Variable Learning Route Model," in *12th WSEAS International Conference on COMPUTERS*, Heraklion, Greece., 2008.

[13] J. S. Jang and C. T. Sun, Neuro-Fuzzy and Soft Computing: A Computational Approach to Learning and Machine Intelligence, Prentice Hal, 1997.

[14] H. Mamdani and S. Assilian, "An experiment in linguistic synthesis with a fuzzy logic controller," *International Journal of Man-Machine Studies,* vol. 7, no. 1, pp. 1-13, 1975.

[15] L. Zadeh, "Fuzzy sets as a basis for a theory of possibility," *Fuzzy Sets and Systems,* p. 3–28, 1978.