Predicting workers’ unsafe workspace with fuzzy logic-based procedures; exploiting injury count in work hours

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Abstract. Loss due to accident in any workspace is either material or personal and is associated with costs of damages to machines and also injuries, disabilities and death to workers. In this study, a fuzzy logic based expert system called Workspace Injury Sensitive Expert System (WISES) was developed to predict the unsafe level of any workspace. Two input variables, hours-worked” and “Injury-Rate were fired into the system's Mamdani inference engine to generate the output as “Workspace-unsafe-ratings”. Data were collected from 20 workers in 20 workspaces and were run with WISES. The outcomes were compared with values obtainable using the existing Workplace Hazards Rating Mathematical Expression (WHRME). There existed a strong relationship (correlation coefficient of 0.710) between WISES and WHRME. The WISES had a statistically significantly lower level of rating \(0.50 \pm 0.02, \text{SEM}=0.007\), \(t(38) = 1.613, p = 0.115\) compared to WHRME \(0.60 \pm 0.30, \text{SEM}=0.004\) and the prediction capacity of both the systems were not significantly different. The developed expert system can find applications in any work environment that is prone to accident. It can also enhance the planning ability of managers and decision makers in industries when assessing workplaces and/or work methods disposed to accidents.

1. Introduction
The workspace is a designated place for an employee to conduct their work and is fitted with all the requisite equipment and facilities. Workspace design has many effects on the efficiency of the job and/or the level of comfort of workers using them. It is indicated that while workers in micro-sized workplaces are permitted to set up their own workspaces to accommodate the method of working, administrators in small-to-medium-sized businesses should assess all of their office workspaces in order to ensure thorough implementation of the injury reduction ergonomics program [1].

There are more than 260 million workplace incidents that result in 2 million deaths. The incidence of workplace accidents in the United States has been measured at more than $170 billion, and millions of working days have been lost annually. However, industrial related accident and fatality rates have been reported to be higher in developing countries than those in industrial countries [2,3].

Employees are an important component of any development in the industry and are vital to quality productivity. Therefore, it is expensive when an employee becomes injured. The creation and use of the ergonomics tool is a measure that can be used by managers in any sector to help avoid all types of accidents and to help workers work more safely for maximum effectiveness and productivity in their work spaces [4].

Worksite assessment and analysis is the startup step in the discovery of alternatives to possible occupational injury causes. Among which are analysis of: employees’ role on a regular basis, the physical components of workspace, environment and organizational structure such as work schedules) [1], which help to assess the context of risk[5]. However, there are several qualitative and quantitative approaches for assessing the likelihood of incidents. Fuzzy logic methods can provide a simple way to perform risk analyses [6].
In some developed expert systems and other areas where artificial intelligence is applied, Fuzzy Logic is in the form of logic used in which variables can have degrees of falsehood or truthfulness defined by a set of values which are between 1 and 0 [7].

Fuzzy technique is a combination of four distinct sub-processes: fuzzification (this determines the degree of truth for each rule premise), inference (the truth-value for the premise of each rule is computed and applied to the conclusion part of each rule), composition (all of the fuzzy subsets assigned to each output variable are combined together to form a single fuzzy subset for each output variable and defuzzification (converts fuzzy value to a single number-a crisp value) [8].

For risk management, fuzzy logic has been commonly used. In addition to the previous efforts, this study attempted to build a fuzzy logic-based expert system to predict hazardous workspace levels using the injury frequency calculation criterion.

This study compared the outcome of the developed expert system when used to assesses risk level in work spaces and that of using a Workplace Hazards Rating Mathematical Expression (WHRME).

2. Materials and methods

2.1 Fuzzy Logic Technique
This study utilized the theory of Fuzzy logic because it borrows the method of the legitimate reasoning of humans to construct its judgment. To transform the two input sets used into a fuzzy set, the trapezoidal membership function was used. In modeling linear uncertainty questions, the use of Trapezoidal are common. In fuzzy logic, membership features are of various kinds. Trapezoidal, Triangular, Gaussian, π-Shaped, Generalized bell and S-Shapedm are good examples. The simplest membership functions are formed using straight lines [9]. The trapezoidal curve is a function of a vector, x, as shown in (1). This however, depends on four scalar parameters, a, b, c, and d:

$$F(x: a, b, c, d) = \max(\min\left(\frac{x-a}{b-a}, \frac{d-x}{d-c}\right), 0)$$

(1)

2.2 Workspace Injury Sensitive Expert System (WISES)
Fuzzification of the input variables and output risk value, determination of the inference method and the generation of applicable rules and the defuzzification of the unsafe-rating values were three steps in the development of the fuzzy based WISES implemented on MATLAB.

2.2.1. Fuzzification of WISES input variables
As input variables for the method, two variables, namely "Injury Rate" and Whole work time" were selected. The two variables were stated to be sufficient for workplace risk rating measurement[10], as expressed in the Workplace Hazards Rating Mathematical Expression (WHRME) as:

$$\text{Frequency Rate (Unsafe Rating)} = \frac{\text{Total Number of Accidents / Injuries}}{\text{Whole Workhours}}$$

(2)

WISES was from the author’s knowledge who allocated four (4) linguistic values for each of the input and the output variables, as outlined in Tables 1 to 3.
Table 1. Output variable “Whole work hours”

| Interval | Linguistic value                  |
|----------|-----------------------------------|
| 0, 0.24, 32 | 1-day Whole-Work-Hour (WH₁)      |
| 24, 32, 56, 64 | 7-days Whole-Work-Hour (WH₇)     |
| 56, 64, 112, 120 | 14-days Whole-Work-Hour (WH₁₄) |
| 112, 120, 168, 176 | 21-days Whole-Work-Hour (WH₂₁)  |

Modified from Yusuf et al. (2016)

Table 2. Input variable “Rate of injury”

| Interval | Linguistic value         |
|----------|--------------------------|
| 0, 0, 1, 2 | Minimal Rate (MR)       |
| 1, 2, 4, 5 | Increased Rate (IR)    |
| 4, 5, 7, 8 | High Rate (HR)        |
| 7, 8, 10, 10 | Extremely High Rate (EHR) |

Modified from Yusuf et al. (2016)

Table 3. Output variable “Unsafe-Rating”

| Interval | Linguistic value       |
|----------|------------------------|
| 0, 0, 0.01, 0.02 | Very Low               |
| 0.01, 0.02, 0.03, 0.04 | Low                    |
| 0.03, 0.04, 0.05, 0.06 | High                   |
| 0.05, 0.06, 0.1, 0.1 | Very High              |

Modified from Yusuf et al. (2016)

2.2.2 Inference Method and Rules
The backbone of fuzzy inference systems is called the fuzzy reasoning and Fuzzy law. There are 16 for both inputs and each with four linguistic values. If-Then rules (all possible combinations of linguistic values of the premise) were fired into the WISES system's Mamdani inference engine.

2.2.3 Defuzzification of workspaces’ unsafe rating
With Mamdani’s inference as the most commonly employed and well suited to human input and centroid defuzzification, the ‘unsafe rating’ was calculated by the inference of the fuzzy rule set. There are more defuzzification methods available but the centroid is commonly used for its accuracy [11].

2.3 Validation process
2.3.1 Data collection
To validate the established expert method, twenty (20) samples including the 'whole-hour-worked' and 'injury-rate' obtained from the investigated accident/injury cases of some industries recorded by Yusuf et al. [12] were used.

The two sets of input variables were run in WISES. The WHRME as stated in (1) was also used to compute for accident frequency rating for each using the same variables and data from the 20 samples. The outcomes using the two media (WISES and WHRME) were interpreted based on the expert’s rating highlighted in Table 3. The results were thereafter compared.

2.3.2 Statistical Analysis
Using Spearman's rho correlation, the predictions of WISES and the computed values using WHRME were compared. The correlation strength was measured to determine if it is strong (|r| > 0.7), moderate (0.3 < |r| < 0.7) or weak (0 < |r| < 0.3). For further proof, independent t-test sample statistics were used. The distinction between the computed means of the two independent classes, WISES and WHRME, was tested by the t-test.
3. Results and discussion

The model used two inputs data to produce its output. Figures 1–3 are the Membership Function graphs which indicate all of the MFs related to the inputs (injury-rate and Whole-work-hours) and the output variables. The trapezoidal MF has four variables. The intervals and all linguistic interpretation are as mentioned in Table 2.

Considering a sequence of event in a workplace for an employee with a Whole-Worked-Hours of 63 hours and Frequency-of-Injury of 7.4. From Figure 2, the input membership function (IMF) for the variable “Total-Worked-Hours” is 0.7 (WH-14) (µWH-14(Total-Worked-Hour)=0.7) and 0.2 (WH-7) (µWH-7(Total-Worked-Hour)=0.2). From Figure 3, the IMF for the variable “Frequency-of-Injury” is 0.7 (HE) (µHE(Frequency-of-Injury)=0.7) and 0.4 (EHE) (µEHE(Frequency-of-Injury)=0.3).

Combining these, the following four logical inference reports are suitable:

By determining the connotation of the premises of the applicable laws, each of the relevant rules was decided. The inference mechanism distinguishes the rules are ON (i.e., whether its premises are MF) µ premise [Total-Worked-Hour, Frequency-of-Injury] > 0.0, to assess the suitability of each rule (matching).

To come up with a single conclusion, the inference engine combined the suggestions of all the rules. The final stage was defuzzification, which worked on the implied fuzzy set generated by the inference process (output fuzzy set) and linked the effects to generate the “sure” unsafe workplace scores.
A significant correlation was found as $r = 0.710$, p<0.01, after comparing the result of values produced by WHRME with that of the WISES for correlation using Spearman's rho. Because ($|r| > 0.7$) the correlation was considered strong.

The t-test applied to assess whether there was mean difference between WISES and WHRME showed that WISES (0.50 ± 0.02, SEM= 0.007) t(38) = 1.613, p = 0.115 had a statistically significantly lower rating level than WHRME (0.60 ± 0.30, SEM=0.004). Therefore the means of the two groups were not substantially different.

### Table 4: Variables measured, WHRME computation results, WISES predicted values and linguistic interpretations for 20 evaluated workers and workplace

| Subjects/Work Spaces | Total Hours Worked | Accident Rates | WHRME Rating | Meaning | WISES Rating | Meaning |
|----------------------|--------------------|---------------|--------------|---------|--------------|---------|
| 1                    | 23                 | 2             | 0.078        | V. High | 0.053        | V. High |
| 2                    | 131                | 5             | 0.038        | High    | 0.051        | High    |
| 3                    | 44                 | 2             | 0.042        | High    | 0.051        | High    |
| 4                    | 81                 | 7             | 0.088        | V. High | 0.053        | High    |
| 5                    | 1659               | 5             | 0.033        | Low     | 0.051        | High    |
| 6                    | 31                 | 3             | 0.089        | V. High | 0.053        | High    |
| 7                    | 53                 | 5             | 0.091        | V. High | 0.083        | V. High |
| 8                    | 129                | 5             | 0.041        | High    | 0.05         | High    |
| 9                    | 74                 | 2             | 0.031        | Low     | 0.03         | Low     |
| 10                   | 103                | 6             | 0.07         | V. High | 0.052        | High    |
| 11                   | 65                 | 2             | 0.032        | Low     | 0.03         | Low     |
| 12                   | 47                 | 5             | 0.121        | V. High | 0.083        | V. High |
| 13                   | 71                 | 7             | 0.123        | V. High | 0.053        | High    |
| 14                   | 95                 | 2             | 0.032        | Low     | 0.03         | Low     |
| 15                   | 113                | 1             | 0.012        | V. Low  | 0.014        | V. Low  |
| 16                   | 11                 | 1             | 0.131        | V. High | 0.084        | V. High |
| 17                   | 164                | 5             | 0.032        | Low     | 0.05         | High    |
| 18                   | 53                 | 4             | 0.081        | V. High | 0.053        | High    |
| 19                   | 66                 | 5             | 0.084        | V. High | 0.053        | High    |
| 20                   | 17                 | 1             | 0.071        | V. High | 0.013        | V. Low  |

Mean±Standard Deviation | 0.066±0.03 | 0.049±0.02

3.1 **Performance test for WISES**

Data on twenty selected work spaces involving twenty workers is presented in Table 4. Any of the workers had more than 2 years of experience working on their present job. As recorded by each employee, full working hours and the amount of injury incurred during the hours are specified. For each of the workplaces obtained using WHRME referred to in the equation, columns 4 and 5 are the accident ranking and definitions, respectively (1). The accident rating predictions of the established professional method and the performance interpretations were recorded in columns 6 and 7 using Table 3.

The values produced using WHRME ranged from 0.01 to 0.1, while the WISES system values were between 0.01 and 0.08. The WHRME forecasted High ‘or Very High ‘risk in 14 scenarios, and in the same pattern, the WISES platform equally forecasted either Very High ‘or’ High rating’ in all the 14 cases. This amount to 100% similarity for the two approaches.

In cases 17, 14, 11, 9 and 5 the WHRME suggested ‘Low’ these were repeated by WISES system in all except in 5 and 17 with ‘High’ rating. However, the predictions conformity was at 60%. On average, the WHRME value was 0.066±0.03 and that of WISES system was 0.049±0.02 both of which could be interpreted as ‘very high’.

3.1.1 **Correlation and Independent samples t-test tests**

A significant correlation was found as $r = 0.710$, p<0.01, after comparing the result of values produced by WHRME with that of the WISES for correlation using Spearman's rho. Because ($|r| > 0.7$) the correlation was considered strong.

The t-test applied to assess whether there was mean difference between WISES and WHRME showed that WISES (0.50 ± 0.02, SEM= 0.007) t(38) = 1.613, p = 0.115 had a statistically significantly lower rating level than WHRME (0.60 ± 0.30, SEM=0.004). Therefore the means of the two groups were not substantially different.
3.2 Discussion
Attempts to minimize workplace hazards have yet to satisfactorily improve on occupational health and safety in many industries among employees. Severe injury and death are also on the rise annually [13]. Roy[14] identified five among the commonest hazards in industrial workplaces. These include: ergonomic injuries; fire safety; slides, trips and falls; eye strain; and consistency of indoor air. WISES was suggested in this study to predict the hazardous level of work spaces using accident rates and whole-hours worked, in addition to attempts to improve workplace health and safety.

The WISES framework has been checked using scenarios from various workspaces. Comparisons between WISES and WHRME revealed that the mean values of the groups were not substantially different from the expected values of the two media and that the linguistic meanings were also identical. It is important to determine the level of safety to ascertain the degree of ignorance of many workplaces to the safety requirements and/or incompetence of ergonomics applications that occur in many workplaces. It also leads to the detection of unhealthy working environments [10].

In this study, WISES was presented to help assess the safety level of any workspace. If the system's outcome suggests that accident rates are increasing, it is possible to redesign the task method and/or workspaces by incorporating the required ergonomic design capable of minimizing workers' continuous exposure to the risk factors for the accidents.

The World Health Organization [15] stated that industrial ergonomists agree that the key means of minimizing employee exposure to workplace hazards are through engineering design, proper work practice among employees and administrative controls. Therefore in accordance with the implementation of ergonomics concepts, work methods and workspaces need to be constructed according to individual capacities and limitations. The costs of disregarding these basic concepts can include: injuries and occupational illnesses, higher medical costs, higher absenteeism, higher risk of accidents and mistakes, higher staff turnover, lower performance of manufacturing, litigation, low-quality jobs, lower emergency response spare capacity [15].

The results of the use of the WISES method and the contrast with WHRMEs have been satisfactory. The few weaknesses reported for WISES may be due to the limited variables of inputs and problems in the dataset that tend to decrease the perfection of the predictions, especially in cases where the outcome of WISES was higher in value than those predicted by WHRME.

Depending on the individual person, work environment and several other variables, there are risks in the incidence of workspace accidents. The proposed fuzzy-based expert system approach can deal with this uncertainty in the data and in the evaluation process, as reported by Zadeh.[7].

Considering the accidents' frequency rating of 4.0, this rate agrees with a membership degree of 1.0, in "Increased Rate (IR)" The fuzzy approach considers the inherent complexities of the classification system, the like of accident frequency of 4.1, which simultaneously can be regarded as "High Event" and "Increased Event" of 0.2 and 1.0 membership degrees, respectively.

In any workplace where hazards exist among all categories of workers, WISES may find applications. The ergonomics tool is recommended to help raise awareness of the need to put in place measures to minimize the rate of injuries in any job activity. However the addition of more variables such as accident severity and fatality may be considered for enhancement of the model in future efforts.

4 Conclusions
Workspace Injury Sensitive Expert System (WISES) was developed and proposed in this study to predict the insecure level of occupational workspace. Two inputs variables, “Whole work hours” and “injuries rate”, were used to develop the expert system. The system was a fuzzy logic based technique. When the output of WISES was compared with an existing Workplace Hazards Rating
Mathematical Expression (WHRME), the Spearman’s rho correlation coefficient test result was strong and there was no significant different in the t-test result of the predicted mean values of the two methods. WISES can be applied in any workspace where accident can occur. It can be engaged by workplace managers to measure work activities that may be prone to accidents.

References
[1]. Washington State Department of Labor and Industries Office Ergonomics Practical solutions for a safer workplace. [Internet] 2002 [cited 2002 October 16]. Available from http://www.lni.wa.gov/IPUB/417-133-000.pdf.
[2]. International Labor Organization. Work-related fatalities reach 2 million annually. Accessed March 20 2015. Available from: http://www.nieuwsbank.nl/en/2002/05/24/K016.htm.
[3]. Galal, A. Traffic Accidents and Road Safety Management: A Comparative Analysis And Evaluation in Industrial. Developing, And Rich -Developing Rateries. 29th Southafrican Transport Conference (SATC2010) ISBN: 978-1-920017-7-7, Pretoria, South Africa. 2010.
[4]. Christer, H. and Bodhi, P. Occupational Safety and Health in Developing Rateries. [Internet] 2000 [cited 2000 November 10]. Available from: http://nile.lub.lu.se/arbarch/arb/2000/arb2000_17.pdf, 2000.
[5]. Pokorádi, L. Application of Fuzzy Set Theory For Risk Assessment. Journal of KONBiN 2010; 3(14): 188-196,.
[6]. Kamil, B. and Juraj, V. Dagmar, V. Risk Analysis In Managerial Process And Fuzzy Approach. Transport and Telecommunication, 2013; 14(3): 214-222,.
[7]. Zadeh L.A. Toward Extended Fuzzy Logic —A First Step, Fuzzy Sets and Systems 2009; 160(21): 3175-3181,.
[8]. László, P O. Fuzzy logic-based risk assessment, AARMS Security. 2002; 1(1): 63–73.
[9]. Omar, A. M. A Aous, Y. A. Balasem, S. S. Comparison between the Effects of Different Types of Membership Functions on Fuzzy Logic Controller Performance International journal of Emerging Engineering Research and Technology 2015; 3(3): 76-83.
[10]. Yusuf, T. A., Sanusi, O. M Adeyemi, H. O. A Model for Determining the Safety Level of Occupational Work Using Accidents and Injuries Measurement Parameters: A Review Journal of Engineering Studies and Research, 2016; 22(1): 1-6,.
[11]. Pokorádi, L. Systems and Processes Modeling , (in Hungarian) Campus Kiadó, Debrecen, 2008.
[12]. Yusuf T.A., Ismaila S.O., Kuye, S.I., Samuel, O.D. Evaluation of the cost and effect of industrial accidents, European Journal of Scientific Research, 2015;132(2): 184-190,.
[13]. Azadeh-Fard, N. Schuh, A. Rashedi, E. Camelio, J.A. Risk assessment of occupational injuries using accident severity grade, Safety Science, 2015; 76: 160–167.
[14]. Roy, M. Five Common Office Hazards to Prevent. [Internet] 2017 [cited 2017 October 6] Available from https://www.shrm.org/resourcesandtools/hr-topics/2017.
[15]. World health organization (WHO), Global strategy on occupational health for all: The way to health at work. Recommendation of the second meeting of the WHO Collaborating Centres in Occupational Health, 11-14 October 1994, Beijing, China. Available from http://www.who.int/occupational_health/publications/globstrategy/en/index4.html.

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