FUZZY LOGIC ALGORITHM FOR AN IMPROVED ASSESSMENT INTO LIFTING-RELATED INJURY RISKS AMONG NIGERIA WOMEN

H.O. Adeyemi*[1], O.O. Akinyemi[2], Z.O..O. Jagun[3], S. I. Kuye[4], M.A. Sulaiman[5], N.S. Lawal[6], C.A. Adeyemi[7]

[*1,2,5,6]Department of Agricultural and Mechanical Engineering,
Olabisi Onabanjo University, Ago-iwoye, Nigeria.

[3]Department of Electrical and Computer Engineering,
Olabisi Onabanjo University, Ibogun Campus, Ogun State. Nigeria.

[4]Department of Mechanical Engineering,
Federal University of Agriculture, Abeokuta, Nigeria.

[7]Federal College of Education, Osiele Abeokuta, Ogun State, Nigeria.

ABSTRACT

In this study, a fuzzy logic model was adopted to assess the severity of risk involved in lowering and/or lifting by Nigeria women using three risk factors of weight (kg), height of the load (cm) and the handlers' arm's reach (cm). The leading objective was to provide an improved assessment tool to Risk Assessment Filter (RAF). The algorithm of the fuzzy inference engine applied sets of 64 linguistic rules to generate the output variable in lifting/lowering risk. The Spearman's rank correlation value of 0.85 at the confidence level of 0.01, indicated no significant difference between the initial assessors' suspicions' of risk with the use of the RAF and the developed model predictions. The risk values and interpretations generated by the model were confirmed not just similar to, but with better information than, using RAF. The study proposed a model for an improved injury risk assessment than RAF in the assessment of lifting risks, in manual material handling, among women. The ergonomic device, is simple, saves time and, can find its usefulness in, household chores, construction industry and offices where women are engaged in manual lifting operations.

***KEYWORDS**: Lifting; risk; assessment; filter; fuzzy; women; handler*

* Corresponding author: adeyemi.hezekiah@oouagoiwoye.edu.ng

1.0 INTRODUCTION

Lifting as defined by Occupational Safety and Health (OSH) (1999), is a forceful movement requiring energy and muscle effort which stresses muscles, tendons and ligaments and increases forces on the spine. Lifting operations typically entail some risk factors that cannot be totally eliminated. In fact, no manual handling activity is completely safe. The physically demanding nature helps explain why strains and sprains are the most common types of injury among the group of workers involving in lifting related jobs. Any lifting task may be considered hazardous if the imposed loads (forces) exceed the individual's strength and tolerance. Whereas the risk of injury is largely determined by the weight lifted. Hence, the amount of weight being lifted from the floor or above shoulder level should be reduced and in neutral posture (body not twisted). Keeping arms fully extended, for instance, when lifting heavy loads may strain the forearm muscles. In a similar manner, holding objects at arm's length can also increase the load on the lower spine by 15 times the original weight. It is therefore safer to hold the object as close to body as possible to reduce the strain on arms and back (Schneider, 2001; Goran and Eva 2005; OSHA, 2007; HWL, 2013; UNC, 2013; John, 2013).

Among the womenfolk, low back disorders are the most vital reported problem for those who work at construction sites and in industries where a series of lifting related tasks are carried out. This has the tendency to influence the quality of work and health of female workers (Manish, 2013). According to World Health Organization (WHO) (2004), women on the average, make up about 42% of the estimated global paid labor force population, making them indispensable contributors to national economies. In the developing countries, it is taken for granted that women will do most heavy lifting and carrying. In Nigeria, there are only few women in the formal labor force (Caroline and Chiedu, 2014). Most women are involved in daily paid work and some of which are into lifting related, most especially in the construction industry. Even at home where women tend to work more hours to make up the primary responsibility for family well-being, several casual lifting are engaged. Women's average lifting strength is only 50% of men's (Vingård and Kilbom, 2001). Meanwhile physical load may exert greater strain on the average. Women are therefore more often exposed to some physical risk factors such as; repetitive movements, material lifting and awkward postures among others (World Health Organization, 2006).

As part of its efforts at helping employers, managers, safety officers, safety representatives, employees and others reduce the risk of injury from manual lifting, Risk Assessment Filter (RAF), relevant to: lifting and lowering; carrying for short distances; pushing and pulling; and handling while seated, was developed by HSE (2004). Using the filter, the guideline in Figure 1 helps to assess the task. It was, however stretched that a more detailed assessment is necessary if: using the filter shows the activity exceeds the guideline figures; the activities do not come within the guidelines; there are other considerations to take into account; the assumptions made in the filter are not applicable; for each task the assessment cannot be done quickly. However for time or effort saving, it was stated that it may be better to opt immediately for the more detailed risk assessment. Whereas, a full assessment of every manual handling operation could be a major undertaking and might involve wasted effort (HSE, 2004). Hence the need for more automatic, less human involvement and more detailed risk assessments tools that will allow expertise input into design process of which this study was set out to achieve. The study developed and validated a model capable of assessing the severity of injury risks involved in lowering and/or lifting operations carried out by Nigerian women. The objectives are to: provide an improved and less human involvement, assessment tool to the RAF; provide more information on the severity of injury risk involved in lifting/ lowering operations than may be achieved using RAF and; minimize injuries among women in household chores and other lifting related jobs.

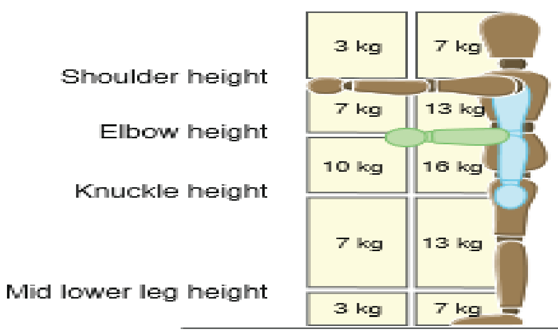

Figure 1. Areas around body within which loads may be lifted without risk for 95% of women population (MHOR, 1992).

2.0 MATERIALS AND METHODS

2.1 Selection of Lifting Tasks and Collection of Variables for the Model Development

In this study, three input variables were used. These variables are among the major factors mentioned in lifting and lowering RAF guidelines. These include "weight", "handler height" and "handler's arm reach". The applicable tasks considered were those based on; the load that is easy to grasp with both hands; the lifting operation that takes place in reasonable working conditions; and the handler in a stable body position (HSE, 2004). The output variable, lifting/ lowering injury risk, was determined by fuzzy logic.

2.2 Fuzzy Logic

The fuzzy logic algorithm was adopted in this study. The tool consists of heuristic rules that define the parameters of the focal problem. These include: data base, fuzzy rule base, fuzzy inference machine and defuzzification. Fuzzy Logic is applicable to artificial intelligence, control engineering, and expert systems (Padhy, 2005). The technique is functional in a wide range of applications designed to model the problem solving ability of human experts. It imitates the logic of human thought and how a person would make decisions, only much faster (Kozlowska, 2012). Fuzzy logic was widely used when human evaluations and the modelling of human knowledge in risk assessment are needed (Kahraman, 2006; Adeyemi et al., 2013). Among many recent attempts in risk assessments; Usanmaz and Gündoğdu (2014) presented an adaptive neuro-fuzzy inference system to estimate maximum forces and moments being generated at the hip joint during lifting tasks using the duration of the lift, the height and mass of the subject, and the load as input variables. A fuzzy logic was adopted by Jelena and Dagan (2014) for practical risk assessment of bridges under different hazards using the identified risks as input variables and bridge damage level as the output variable, Adeyemi et al., (2016) developed a fuzzy-based expert system called pain intensity prediction expert system to predict pain risk in shoveling-related tasks using scooping rate, scooping time, shovel load, and throw distance as input variables. An expert system called Musculoskeletal Disorders – Risk Evaluation Expert System (MSDs-REES) capable of assessing risks associated with manual lifting in construction tasks and proffer some first aid advices was earlier developed by the same author using load, posture and frequency of lift as inputs and the risk of low back pain as the output (Adeyemi et al., 2015).

The fuzzy rules used were that of linguistic and in the form of "IF-THEN". According to Yager et al. (1989), fuzzy IF-THEN rules allow to evaluate good approximations of the desired attribute values in a very efficient way. It allows available experts' knowledge to be included. A single if-then rule assumes the form 'if x is A, then y is B'. The if-part of the rule 'x is A' is the premise, while the then-part of the rule 'y is B' is the conclusion (Ajith, 2005).

2.3 Lifting/Lowering Risk Evaluation with Fuzzy Logic Model

The fuzzy logic approach in this study comprised three steps;

2.3.1 Fuzzification of Input Variables and Output Risk Values.

There are three general types of fuzzifiers to associate a grade to linguistic term, singleton fuzzifier, gaussian fuzzifier and trapezoidal or triangular fuzzifier (IIUC, 2012). The data used are vague, hence they were converted into fuzzy numbers. The crisp variables are transformed into grades of membership in linguistic terms of fuzzy sets. Intervals of 'handlers height' and 'arm reach' linguistic variables were carefully set using lifting and lowering RAF guidelines. The female anthropometrical parameters of the variables were drawn from other authors and were modified to form the intervals. Sources of which include the reported; average female arm length of 67.725 (11.38) cm (Adetifa and Samuel, 2012), forearm-hand length and upper arm of 45,00 (3.08) cm and 31 (3.45) cm respectively (Ismaila et al., 2013), popliteal height of 47.7 (3.5) cm (Ajayeoba and Adekoya, 2012), Knee height of 56.9(3.1) cm (Ismaila et al., 2010), average standing shoulder height of 129.1(4.92) cm (Onuoha et al., 2012). The weight classification linguistic variable was a modified version of the study results relating guideline weight for lifting and lowering (HSE, 2004). The output variable, lifting related risk level, was developed from the expert knowledge reported by Adeyemi et al., (2015). The numbers of MFs were determined by the author as well as the baselines. The expert knowledge developed the system linguistic's terms and intervals by detailing four linguistic terms of all the three inputs and the output variables as shown in Tables 1 to 4. Figure 2 to 5 are all the MFs for the input and output variables.

Table 1. Fuzzy set of input variable 'Handlers' height'

Linguistic Terms	Interval
Shoulder height (SH)	99.6,128.2,130.2,133
Elbow height (EH)	61.5, 98.1, 99.6, 128.2
Knuckle height (KH)	30.75,54.4,61.5, 98.1
Mid lower leg height (MLH)	0,27.2, 30.75, 54.4

Modified version of the study results relating Anthropometry of South Eastern and South Western Females in Nigeria (Ismaila et al., 2010; Onuoha et al., 2012)

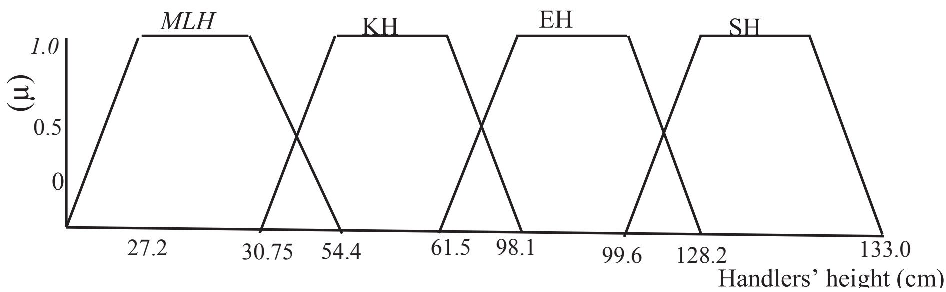

Figure 2. All membership functions for the input variable 'Handler's heigth'.

Table 2. Fuzzy set of input variable 'Weight'

Linguistic Terms	Interval
No load (NL)	0,0,0,0
Light load (LL)	0,3,5,7
Midium load (ML)	5,7,10,13
Heavy load (HL)	10,13,16,25

Modified version of the study results relating guideline weigth for lifting and lowering (HSE,2004)

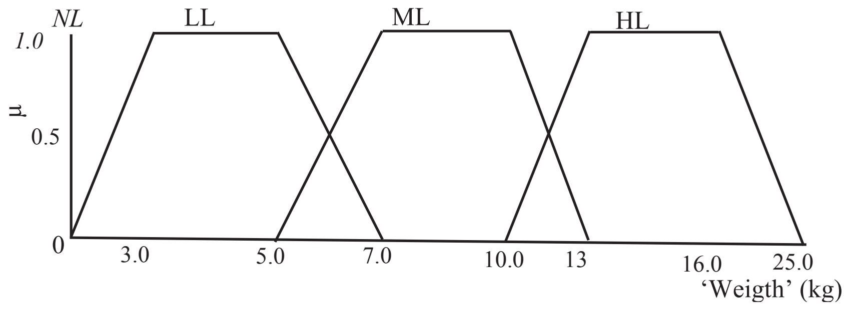

Figure 3. All membership functions for the input variable 'Weight'.

Table 3. Fuzzy set of input variable 'Handlers' reach'

Linguistic Terms	Interval
No movement (NM)	0,0,0,0
Low arm movement (LAM)	0,20,30,36
Normal arm movement (NAM)	30, 36, 45, 60
Extended arm movement (EAM)	45, 60,76, 85

Modified version of the study results relating anthropometric parameters of South and South West, Nigeria (Oladipo et al., 2013; Ismaila et al., 2013)

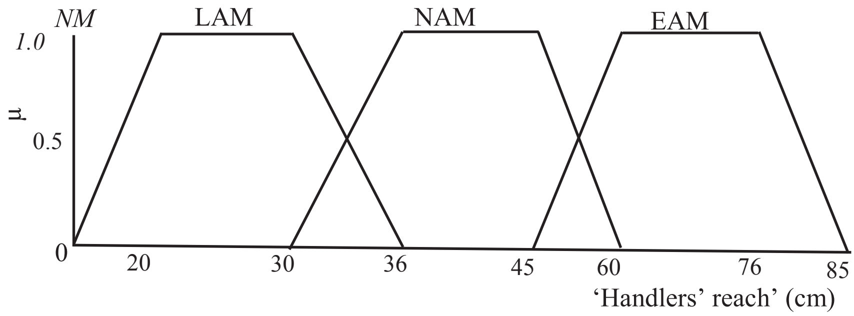

Figure 4. All membership functions for the input variable 'Handler's reach'.

Table 4. Fuzzy set of output variable 'Lifting/Lowering Risk' Adeyemi et al., 2015

Linguistic Terms	Interval
No risk (NR)	0,0,0,0
Low risk (LR)	0,0,1,1.1
Medium risk (MR)	1,1.1,2,2.1
High risk (HR)	2,2.1,3,3.1

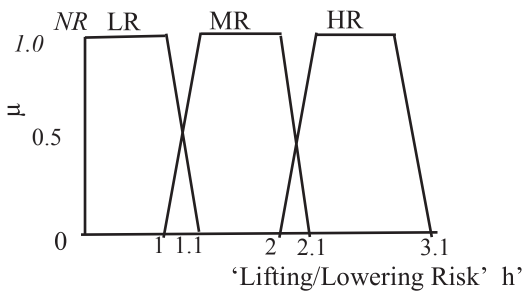

Figure 5. Showing all membership functions for the input variable 'Handlers' reach' (Adeyemi et al., 2015)

2.3.2. Determination of Application Rules and Inference Method

A fuzzy rule is a simple IF-THEN rule with a condition and a conclusion. The relationship between heuristic, input and output parameters enabled the formation of 'If Then Rules' (Bilkent University, 2014). With the three inputs used in this study and each having four (4) variables, a rule base matrix size of 4^3 resulting in total sets of 64 matrices were achievable. The rules were "fired" by Mamdani's fuzzy inference method-the most commonly seen fuzzy methodology. The technique is intuitive, has widespread acceptance and is well-suited to human inputs (Mamdani and Assilian, 1975). The following rules show only a portion of the 64 possible linguistic rules designed and fired into the inference engine of the model:

- 1. If (HandlerHeigth is MLH) and (Weigth is NL) and (HandlerReach is NM) then (LiftingRelatedRisk is NR)
- 3. If (HandlerHeigth is MLH) and (Weigth is ML) and (HandlerReach is NM) then (LiftingRelatedRisk is LR)
- 19. If (HandlerHeigth is MLH) and (Weigth is ML) and (HandlerReach is LAM) then (LiftingRelatedRisk is MR)
- 48. If (HandlerHeigth is SH) and (Weigth is HL) and (HandlerReach is NAM) then (LiftingRelatedRisk is HR)
- 64. If (HandlerHeigth is SH) and (Weigth is HL) and (HandlerReach is EAM) then (LiftingRelatedRisk is HR)

2.3.3. Defuzzification of Risk Value

Defuzzificcation converts the fuzzy value obtained from composition into a "crisp" value. This process is often complex since the fuzzy set might not translate directly into a crisp value. Two of the more common defuzzification techniques are the centroid and maximum methods (Gao, 2015). In the centroid method used in this model, the crisp value of the output variable is computed by finding the variable value of the center of gravity of the membership function (μ) for the fuzzy value.

2.4 Model Implimentation

The model was implemented in MATLAB®. MATLAB provides a symbolic solution and a visual plot of the result (Waleed, 2013) and creation of user interface (Kristian, 2009). For each case, all the three variables were fuzzified by the application. Active MFs were calculated according to rule table. The output, lifting/lowering risk, was defuzzified by calculating the center (centroid) of the resulting geometrical shape. This sequence was repeated for each scenario of lifting and/or lowering operations.

2.5 Model Validation

For statistical confirmation, Spearman’s Rank Correlation (SRC) coefficient was used. The RAF predictions which were presented either “injury not likely” or “injury likely” were ranked “0” and “1” respectively. The model predictions were also categorized into two; those with “no risk” and those with “one level of risk or another”. These two categories were equally ranked “0” and “1” respectively. The SRC used to establish the strength of relationship between the two sets of data at the confidence level of 0.01. The SRC significance table denoted the significance of their relationship. Spearman's rank correlation coefficient (r_s) is a reliable and fairly simple method of testing both the strength and direction (positive or negative) of any correlation between two variables (University of Regina, 2015).

3.0 RESULTS AND DISCUSSION

All Sixteen scenarios and possible cases formulated by ergonomics professional are shown in Table 5 on each of the cases the height, arm reach and mass of load lifted by the handlers were considered using RAF (Figure 1). The linguistic predictions are as indicated. The same data were run with the developed model to generate risk values where the interpreted results were shown in Table 4. The interpretations of the assessors and that of the model when compared show that in 10 out of the 16 samples (63%) where assessor predicted “injury most likely” using RAF, the model also predicted one level of injury or another in all the 10 cases. This represented 100% agreement using the two assessment tools. In the remaining 6 cases (37.5%) where the assessors predicted “injury not likely" the model however predicted "low risk" in three of such cases (50%), "No risk" in one (25%) and "medium risk" in two (33.3%).

Table 5. Predictions of human professionals using RAF method, and the developed model, on possible lifting variables

Cases	Measurement						HSE Advise	Model	
	MLH (cm)	KH (cm)	EH (cm)	SH (cm)	Weigth (Kg)	Reach (cm)		Risk Value	Prediction
1	25	-	-	-	6	40	INL	0.2	NR
2	25	-	-	-	9	40	IML	0.6	LR
3	24	-	-	-	5	80	IML	0.6	LR
4	5	-	-	-	3	110	INL	0.9	MR
5	-	57	-	-	14	76	IML	2.8	HR
6	-	54	-	-	12	38	INL	0.54	LR
7	-	62	-	-	15	71	IML	2.5	HR
8		43			6	115	INL	0.4	LR
9	-	-	98	-	14	35	IML	1.4	MR
10	-	-	92	-	13	72	IML	2.5	HR
11	-	-	97	-	20	37	IML	1.6	MR
12	-	-	102	-	7	68	INL	0.4	LR
13	-	-		125	15	42	IML	2.4	HR
14	-	-		129	6	38	INL	1.5	MR
15	-	-		132	4	82	IML	2.2	HR
16	-	-		137	10	75	IML	1.5	MR

INL= Injury Not likely,IML = Injury most likely, MLH = Mid lower leg height, KH = Knuckle height, EH = Elbow height , SH = Shoulder height

3.1 Statistics Analysis Tests

Spearman's rank correlation coefficient of 0.99 was the result when the RAF predictions were compared with that of the model. This shows a strong strength of relationship between the outputs of the two assessment tools. With the SRC value of 0.85 obtained using SRC table at the confidence level of 0.01, there is greater than 99% chance that the relationship is significant. Hence, there is no significant difference between the RAF injury suggestions and the model predictions.

In developing countries, women are exposed to different physical and psychological stressors such as repetitive work, heavy lifting and monotony. Women tend to work more hours at home and fewer outside of the home, compared to men. Within the household, women usually perform the daily tasks of cooking, cleaning the house, doing the laundry and caring for family members. All these works involve exposures to risks and hazards related to both physical (such as heavy lifting and carrying, repetitive working movements, sustained static postures, awkward postures e.t.c.) and psychosocial exposures (e.g. stress related to high mental demand, speed e.t.c) and can impair health (Östlin 2002; Messing, 2004). According to McDiarmid and Gucer (2001), the underestimation of women's work-related injuries and diseases could be more serious than that of men hence among the reasons while WHO (2006) suggested the necessity at increasing research efforts on women's health at work, particularly in developing countries like Nigeria.

In an attempt in this direction, this study adopted fuzzy algorithm to evaluate the risks connected with lifting and lowering objects based on three input variables; handler height (cm), weight of object (kg) and the handler's arm reach (cm). Parts of the advantages derive with the use of this approach are that, fuzzy logic provides the means to identifying intermediate values unlike other types of logic like Boolean. It handles the expression of vague concepts. For the fuzzy systems, truth values (fuzzy logic) or membership values (fuzzy sets) are in the range (0.0, 1.0), with 0.0 representing absolute falseness and 1.0 representing absolute truth (Gao, 2015). The fuzzy rules of this format contain linguistic variables which are easier for users' understanding and comprehension of the risk severity connected with any lifting attempt. For example, stating ordinarily by the assessors that 'injury is most likely' in scenario 5 where a woman handler lifted a 14kg object from her 57 cm knuckle height and her hands extended to 76 cm, may not be an enough information needed for her necessary decision to avoid possible injuries. However, with the use of the developed model, additional information are provided. The system clearly suggested that the handler may be injured and that the injury risk may be very high. The magnitude of the risk involved in the available information as provided by the model prediction is quite easy to understand and will help the handler at taken necessary action to avert occurrence of any vital accident.

The model provided good results comparable with the human assessors' opinions when the selected scenarios were run in the model. In all the cases (100%) where assessor used RAF to predict either "No injury" or "Likely injury", the model also predicted one level of injury or another only with additional and helpful information. The fuzzy approach in this study considered inherent uncertainties of the membership classification process, such as in the classification of a handler reach with 45.5 cm and another one with 46.1 cm, which could be relegated both as normal arm movement (NAM) and extended arm movement (EAM) at the same time. These arm movement (45.5 cm and 46.1 cm) simultaneously fit into the two membership functions but with different degree of memberships and interpretations.

A risk assessment model can be considered successful when it has the capacity at following human experts' predictions and fulfilled the objectives for which it was developed. Hence, success can be assigned to the development of this model because it mimics the predictions of the human assessors and with improved information helpful for right decision taking. This will prevent injuries among women in domestic manual material handling and enhance their safety and health. The model can find its applications among women in, household chores, construction industry and, offices where women are engaged in manual lifting or lowering operations.

There are however a number of limitations that should be aware of for future efforts. One of which is the posture of the individuals that was not included within the analysis but forms a significant lifting risk assessment variable that could be covered. Future efforts may consider inclusion of such variable and the development of similar model for the menfolk.

4.0 CONCLUSION

In this study a fuzzy logic based model was adopted to evaluate the severity of injury risks involved in lowering and lifting objects based on three risk factors of weight, height of load and the handler's arm reach. The model provided a structure that requires women at household chores, and/or other workplaces where women are engaged in lifting related tasks. The validation result indicated that the injury risk values and the linguistic interpretations provided by the developed model were confirmed not just similar but with improved information than that obtainable from the human assessors when using risk assessment filter. It is hopeful that adopting this technique will reduce, manual material handling related injuries occurrences and, medical bills and also enhance safety and health, among the womenfolk.

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