PREDICTING UNSAFE BEHAVIOUR OF CONSTRUCTION WORKERS

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ABSTRACT

The construction industry is known to be one of the most accident-prone of work sectors around the globe. Although the construction output is less in Sri Lanka, compared to developed countries in general, the magnitude of the accident rate in the construction industry is still significantly high. Most of the occupational accidents are due to the unsafe behaviour of the workers. Thus, studying the people-related factor in safety is an effective way to manage safety at work sites. This is a concept gaining more interest across industry sectors globally, and has the great advantage of needing the involvement of the individual employees. The paper therefore focused to investigate the factors influencing construction workers' unsafe behaviours and develop a model to predict unsafe behaviours based on those factors. The factors affecting construction workers' unsafe behaviour were identified through literature survey. Expert interviews were carried out to validate and generalize the factors found in literature, to the Sri Lankan context. Survey approach was used to collect data and the processed data were used to develop and train an Artificial Neural Network (ANN) model to predict unsafe behaviour of a construction worker. Then training and validation of the developed model under 7 design parameters was carried out using the data on influential factors of unsafe behaviour of 284 construction workers of C1 Building Construction sector. The data were applied to the backpropagation algorithm to attain the optimal ANN Architectures. The findings depict that the success of an ANN is very sensitive to parameters selected in the training process gaining good generalization capabilities in validation session. The model can be used to determine the unsafe behaviour level of construction workers and their safety training needs.

Keywords: *Artificial Neural Networks; Construction Industry; Unsafe Behaviour.*

1. INTRODUCTION

1.1. OCCUPATIONAL SAFETY IN CONSTRUCTION INDUSTRY

Occupational safety is among the most important performance indicators at worker level. The human, social and economic costs of occupational accidents, injuries and diseases and major industrial disasters have long been cause for concern at all levels from the individual workplace to the national and international (Alli, 2008). An International Labour Organization (ILO) report estimated that 2 million occupational fatalities occur across the world every year (ILO, 2003). The overall annual rate of occupational accidents, fatal and non-fatal, is estimated at 270 million (Hämäläinen *et al.*, 2006). Measures and strategies designed to prevent, control, reduce or eliminate occupational hazards and risks have been developed and applied continuously over the years to keep pace with technological and economic changes. Yet, despite continuous if slow improvements, occupational accidents are still too frequent and their cost in terms of human suffering and economic burden continues to be significant (Alli, 2008). Especially the construction industry is struggling to improve the in this area (Gatti & Migliaccio, 2013). Compared with other industries; Construction is always risky because of outdoor operations, work-at heights, complicated on-site plants and equipment operation coupled with workers attitudes and behaviours towards safety (Choudhry and Fang, 2008). The nature of the construction industry's rapidly changing conditions, associated work hazards, and the characteristics of construction organizations further aggravate the situation (Wilson, 1989, Jannadi & Bu-Khamsin, 2002). Furthermore, Jannadi and Bu-Khamsin, (2002) asserted that the construction industry, being highly fragmented, marginalizes the efforts to

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maintain safety standards. At site levels, construction site activities are physically dispersed across various locations. Thus, supervising and monitoring safety issues in the workplace is much more challenging.

A large number of construction accidents are reported and thousands of workers are killed or injured on construction sites each year (Liu, 2013). According to Abudayyeh *et al*. (2006), the rates of fatal and nonfatal injuries and illnesses in the construction industry are relatively high and have not dropped significantly during the past 10 years, despite the adoption of safety procedures and programs such as those developed and required by the Occupational Safety and Health Administration (OSHA). According to Bureau of Labour Statistics estimates, there were 5,703 fatal and 3.9 million nonfatal workplace injuries in the United States in 2006 (Bureau of Labor Statistics, 2007). Further, in United Kingdom, 22% of employee fatalities and 10% of reported major injuries are in the construction industry despite only accounting for 5% of British employment (Health and Safety Executive [HSE], 2013). Sri Lanka is considered to be one of the most vulnerable countries, and is ranked at a low level for safety performance due to lack of improvement measures (De Silva & Wimalaratne, 2012). Further, compared to developed countries in general, the magnitude of the accident rate in the Sri Lankan construction industry is significantly high as reported in other countries such as USA (Chau *et al*., 2004), UK (Sacks *et al*., 2009), Hong Kong (Siu *et al*., 2003) and Singapore (Chau & Goh, 2004).

1.2. CAUSES OF CONSTRUCTION ACCIDENTS

Occupational accidents are defined as unplanned occurrences which result in injuries, fatalities, loss of production or damage to property and assets (Raouf, 2011). These accidents are caused. They are the result of unsafe behaviours (human error) and unsafe conditions, or a combination of both (Heinrich, 1931, Magyar, 2006, Al-Hemoud & Al-Asfoor, 2006). Unsafe behaviour is an element immediately prior to an accident event which is significant in initiating the event, while unsafe condition is unsatisfactory physical condition existing in the workplace environment immediately prior to an accident event which is significant in initiating the event (SafetyPortal, 2013).

Construction industry has managed safety mainly through focusing on improving the 'hard' issues such as managerial systems, policies and better safety technology, in other words, unsafe conditions. However, in recent times, many organizations have realized that their accident rates have 'leveled off'. This has ignited a search for improvements in other areas to reduce accident numbers; and has led to the research into behavioural safety issues of the workforce (Oswald *et al*., 2013). Thus, more recently researchers are debating that a majority of workplace accidents and injuries are attributed to the unsafe behaviours of employees rather than unsafe working conditions (Mullen, 2004). In a study examining contributory factors associated with 100 construction accidents (Haslam *et al*., 2005), 70% of accidents were estimated to have involved failure associated with human error (e.g., behaviour and capability). These failures included workers' disregard for safety over other project priorities; inadequate hazard awareness and appraisal; and workers' propensity toward least efforts to accomplish defined project goals.

Research has analysed unsafe behaviours in detail during the past. Accident causation was pioneered by Heinrich (1931) with his development of the domino theory. The domino theory asserts that 88% of all accidents are caused by unsafe acts of people, 10% by unsafe actions, and 2% by acts of God. There have been further considerable efforts towards investigating how accidents occur. Another accident ratio that is often referred to is the 80:20 ratio (80% unsafe behaviours, 20% unsafe conditions) (Al-Hemoud & Al-Asfoor, 2006); however if human factor aspects such as equipment/process design and work procedures to have an influence on the unsafe conditions, then the accident ratio would be changed to 96:4 (i.e., 80% of the 20% of the unsafe conditions is added to the original 80% of the unsafe behaviours and resulting in 80%+ 16%= 96%). This ratio considers that the human unsafe behaviour element is even more contributing to accidents.

2. UNSAFE BEHAVIOUR OF CONSTRUCTION WORKERS

Aunger and Curtis (2008) defined behaviour as self-propelled movement producing a functional interaction between a being and its environment. Another study conducted by Furr (2009) classified behaviour in to two categories as ‘contextual’ and ‘general’. The researcher defined globally retrospective behaviour as general and contextually retrospective behaviour as contextual. The research focuses on behaviour intended to represent how a person acts rather than how a person thinks, feels or otherwise responds. Further, the research been limited to a particular context and area of performance (construction an occupational safety respectively) the contextual behaviour was taken into consideration.

There is no general agreement on definition of an unsafe behaviour. However, it has been defined in similar focus on unaccepted practices which have the potential for producing future accidents and injuries. Further, an unsafe act is defined as a behaviour that is committed without considering safety rules, regulation, standards and specified criteria in system, which can affect the system safety level (Fuller, 2005). Number of acts of unsafe behaviour has been identified by many researchers such as Petersen (1984), Anton (1989), Stranks (1994), Simachokdee (1994), Michuad (1995), Abdelhamid and Everett (2000), and Holt (2001). These researchers identified various acts of unsafe behaviour those could lead to serious accidents or fatality, under interchangeably used terms and phrases. By reviewing that literature, the researcher was able to isolate fifteen distinctive unsafe acts of construction workers as listed below;

- Working without authority on the job
- Annoyance and horseplay in the workplace
- Smoking, creating naked flame or sparks in areas where flammable materials are stored
- Leaving nails or other sharp objects protruding from surfaces
- Throwing or dropping objects from high levels
- Working under the effects of alcohol
- Working with lack of concentration
- Working in poor physical conditions
- Working at improper speeds
- Improper posture for tasks
- Incorrect use of tools and equipment
- Using defective equipment and tools
- Ignoring to wear PPE
- Removing safety guards from the workplace or equipment
- Servicing equipment which is in operation

3. FACTORS INFLUENCING UNSAFE BEHAVIOUR OF CONSTRUCTION WORKERS

The literature review included studies that investigated unsafe behaviours and accidents in the construction industry. Empirical Studies with a substantive focus on identifying factors that influence the unsafe behaviours and accidents, studies in which the participants were construction employees and unsafe behaviours and accidents were work-related were reviewed. Literature provided a number of factors that have influence on unsafe behaviour of construction workers. When studying these factors closely they can be categorized in to three main constitutes as Person (Individual Dynamics), Process (Work Environment) and Place (Organisational Safety Culture) as shown in Table 1.

Table 1: Factors in Influencing on Unsafe Behaviour of Construction Workers

Factor	Reference
Person (Individual Dynamics)	
Age	Hinze, 1997; Sawacha *et al*, 1999; Carpenter *et al.*, 2002; Parker *et al.*, 2007; Seixas *et al.*, 2008; Choudhry *et al*, 2009
Educational Level	Hinze, 1997; Carpenter *et al.*, 2002; Parker *et al.*, 2007; Seixas *et al.*, 2008; Masood & Choudhry, 2012
Experience	Siu *et al*, 2003; Choudhry & Fang, 2008; Masood & Choudhry, 2012
Gender	Hinze, 1997; Carpenter *et al.*, 2002; Parker *et al.*, 2007; Seixas *et al.*, 2008; Masood & Choudhry, 2012
Alcohol/drug abuse	Fang *et al*, 2006; Masood & Choudhry, 2012
Psychological distress	Abbe *et al.*, 2011; Borys, 2012; Lai *et al.*, 2011; López *et al.*, 2008
Income	Choudhry & Fang, 2008; Fang *et al.*, 2004; Hinze & Teizer, 2011; Suraji *et al.*, 2001; Zheng *et al.*, 2010
Attitudes towards OSH	Zohar, 1980; Cox, 1990; Cox & Cox, 1991; Dester & Blockley, 1995
Process (Work Environment)	
Hazardous Operation	Almen *et al.*, 2012; Pungvongsanuraks *et al.*, 2010; Vitharana *et al.*, 2015; Abdul *et al.*, 2003

Unsafe Conditions	Nouri *et al.*, 2008; Choudhry & Fang, 2008; Mitropoulos, 2005
Hazardous Equipment	Wachter & Yorio, 2014; Almen *et al.*, 2012; Abdul *et al.*, 2003
Place (Organisational Safety Culture)	
Management commitment to safety	Choudhry *et al.*, 2007; Pidgeon & O'Leary, 2000
Employee involvement	Kaskutas *et al.*, 2010; Meliá *et al.*, 2008
Proper safety procedures and rules	Aksorn & Hadikusumo, 2008; Choudhry & Fang, 2008
Efficient safety communication strategies	Borys, 2012; Meliá & Becerril, 2009

Artificial Neural networking was selected as the predictive modelling technique considering the context and scope of the study and data collected. Hecht-Nielson (as quoted by Caudill, 1987) defined the ANN as a computing system made up of a number of simple, highly interconnected processing elements, which process information by their dynamic state response to external inputs. Provided sample information, ANNs learn to generalize complex and nonlinear relationships and synthesize data for scenarios they have not experienced (Basheer, 1998).

In this research, the identified factors were validated to the local context through a pilot study. This is discussed under next section.

4. RESEARCH METHODS

In order to get the literature findings validated and further to identify specific variables that could be relevant under local practices, a pilot study was undertaken. Interviews were held with five managerial level experts having more than ten years of experience in the industry, of five reputed construction companies in Sri Lanka. Interviews were semi-structured as it allows in-depth and free flow of information from interviewees whilst at the same time providing a framework/guide for conducting the interview. The pilot study was followed by the main survey to collect the numeric data necessary for model development and training via a questionnaire survey. A target sample of 400 C1 Building Construction workers was selected within Colombo Metropolis considering the scale of operations and the time constraint.284 complete questionnaires were returned, resulting a response rate of 71%.The achieved sample consisted of Masons (28%), Carpenters (13%), Electricians (11%), Plumbers (7%), Welders (9%), Riggers (14%), Concrete workers (9%), Bar-benders (7%) and Aluminium workers (2%). Cronbach's alpha was employed to evaluate items scored in multiple answer categories. It is the most common measure of internal consistency, commonly used when the study has multiple Likert questions in a survey/questionnaire that form a scale and scale reliability is to be assured (Bonett & Wright, 2014). The model developed was a neural network with 3 layers. Input layer included 14 neurons which were the influential factors and the output layer had one neuron representing the unsafe behaviour score (USBS). Hidden layer(s) of neurons were introduced to the network in the structure design (refer Figure 1). Neuroph Studio was the software used in model development and training.

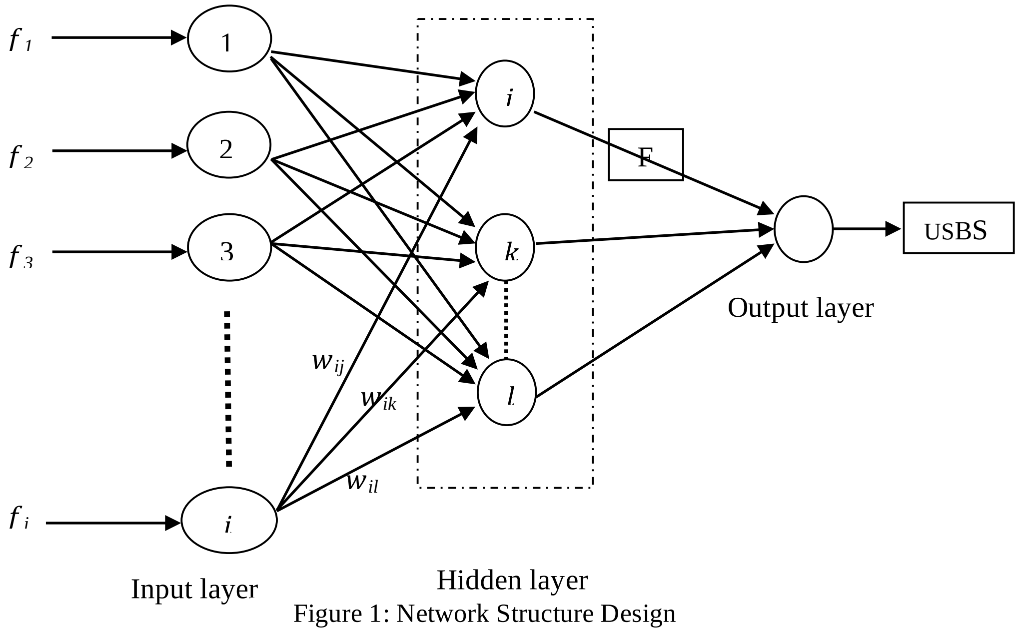

Figure 1: Network Structure Design

5. RESEARCH FINDINGS AND DISCUSSION

Pilot study findings confirmed the list of unsafe acts when experts agreed that it covers the unsafe behaviour of workers at construction sites profoundly. However, the influential factor list was moderated by the experts by removing 'gender' as a factor from the list. They pointed out that Sri Lankan construction industry is male dominated. All the other factors under the three constitute were approved by the experts. Based on the pilot study findings the questionnaire was developed and distributed. The completed questionnaires produced two datasets for data analysis as the data for calculation of the expected USBS and the data on influential factors. Dataset 1 included 15 items (variables) featuring unsafe acts committed by construction workers. Dataset 2 consisted of 14 items (variables) which were the influential factors of unsafe behaviour. The two datasets were analysed using Cronbach’s Alpha for reliability of the scale score in SPSS. The reliability of the scale scores of Dataset 1 (Unsafe Acts) was 0.82 which is regarded as ‘good reliability’; while the reliability of the scale scores of Dataset 2 (Influential Factors) was 0.795 which is interpreted as ‘acceptable reliability’. Thus, the reliability analysis results proved that the two datasets were sufficient to proceed with the data analysis. Next subsection discusses calculation of the

5.1. CALCULATION OF EXPECTED USBS

The data collected through the questionnaire were used to develop the database using MS Excel. The data must be scaled into the range used by the input neurons in the neural network, which typically is the range of 0 to 1 (Mitchell, 1997). Thus, to normalize the data set, each data point was divided from the maximum attainable value of the variable which placed both the input dataset and the target output dataset within the range 0 to 1. Out of the 284 training cases available from data collection, 277 cases were included in to the training set. 7 cases were reserved for testing the network once it’s trained. Based on the finding of ERI (2008), unsafe acts always have the potential to cause injury or death no matter the nature of the act or the excuse or justification used to commit them. Thus, each unsafe act found in literature is equally potential of causing an accident. Thus, the operationalisation of unsafe behaviour is the set of formative indicators (Unsafe Acts) supposing that the unsafe behaviour is the combined calculation of the different unsafe acts (Eq.1).

$$USBS = \sum_{\boldsymbol{i=1}}^{\boldsymbol{n}} (\boldsymbol{S_{ai}}) \qquad \textit{(Eq. 1)}$$

where:

ai is ith unsafe act, Sai is the Score of ith unsafe act, where ∀ Sai: 1≤Sai≤5 and n is the Number of unsafe acts.

On completion of the calculation of target output, a software package was to be decided upon which facilitates the design and training of the network in a comprehensive and user-friendly manner. Since the neural network model is hard to understand, the package to be selected must have the ability to simplify the NN model, reducing it to several parameters that users can alter. There are only few software products that offer full range of neural network customizable models, and they require expertise in understanding the neural network paradigm (Stojanovic, n.d). In open-source community, there are currently several stable neural network frameworks that offer to experts the tool for full customization of NN, models among those Neuroph is the most user-friendly and ample. Neuroph is lightweight Java neural network framework to develop neural network architectures. It contains well designed, open source Java library with small number of basic classes which correspond to basic NN concepts. It also has a good Graphical User Interface (GUI) neural network editor to quickly create Java neural network components. Thus, Neuroph Studio 2.8 was employed to design and train the Network. Next Section discusses the design and training of the ANN.

5.2. NETWORK STRUCTURE DESIGN

The multilayer feedforward neural networks are the most widely studied and used neural network model in practice (Vrajitoru, 2016). Feedforward neural networks are ideally suitable for modelling relationships between a set of predictor or input variables and one or more response or output variables. In other words, they are appropriate for any functional mapping problem where one wants to know how a number of input variables affect the output variable. Considering the research problem, it is clear that the feedforward neural network is the most suitable network type for the purpose. Three parameters determine the designing of the network:

number of neurons in the input, hidden and output layers. Generally, the input layer is considered a distributor of the signals from the external world. Hidden layer(s) are considered to be categorizers or feature detectors of such signals. The output layer is considered a collector of the features detected and producer of the response. However, the number of neurons in the input and output layers are pre-determined by the size of the input and output vectors respectively (Chew *et al*., 2004). For the created network, 14 input neurones and 1 output neurone were set as they represent the input and output data of the model. Additionally, bias nodes were added to increase the flexibility of the model to fit the data. Hidden layers were added in each training attempt and the number of nodes was changed until the optimum network obtained.

To train a neural network to perform a task, the weights of each unit must be adjusted in such a way that the error between the desired output and the actual output is reduced. This process requires that the neural network compute the error derivative of the weights. In other words, it must calculate how the error changes as each weight is increased or decreased slightly. The back-propagation algorithm is the most widely used method for determining error derivative of the weights (Zhang *et al*., 1998). Thus, a back-propagation algorithm with a 'log sigmoid' transfer functions in the hidden layer neurons will be used in the network training process.In this training, the total network error (E) is calculated as (Eq. 2);

$$E = \frac{\mathbf{1}}{\mathbf{2n}}\sum_{\boldsymbol{j=1}}^{\boldsymbol{n}}(\boldsymbol{T_j} - \boldsymbol{C_j})2 \qquad \textit{(Eq. 2)}$$

where:

n is the number of training samples, T_j is the target output of the jth training sample and $C_j$isthe corresponding computed output.

During the network training using Neuroph Studio, three learning parameters including max error, learning rate, and momentum were required to set. Learning rate was the constant in the algorithm of the ANN that affected the speed of training. Though the network would learn faster if the learning rate is high, if there is significant variability in the input, the network will not learn efficiently at a higher learning rate (Domingos, 2012). Thus, it was set at a low range to obtain smooth iterations in the training cycles.

A backpropagation network might settle to local minima by sliding down the error surface into a set of weights that does not solve the problem it is trained on. The Momentum allows the network to potentially skip through local minima (Rich *et al*, 2009). The training parameters were altered during the training until the optimum network is achieved. The stopping criterion (max error) for the optimum network was 0.01 while the learning rate was 0.2 and momentum was 0.7. It featured 20 neurons in the hidden layer. Shown in Figure 2 is the total network error graph of the optimum network. Figure 3 illustrates structure of the optimum network.

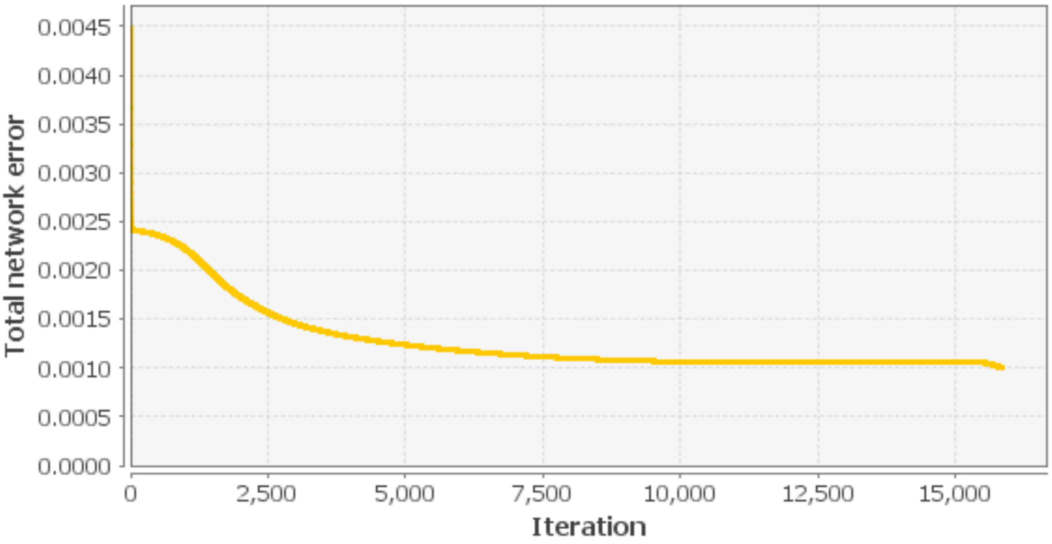

Figure 2: Total Network Error Graph of the Optimum Network

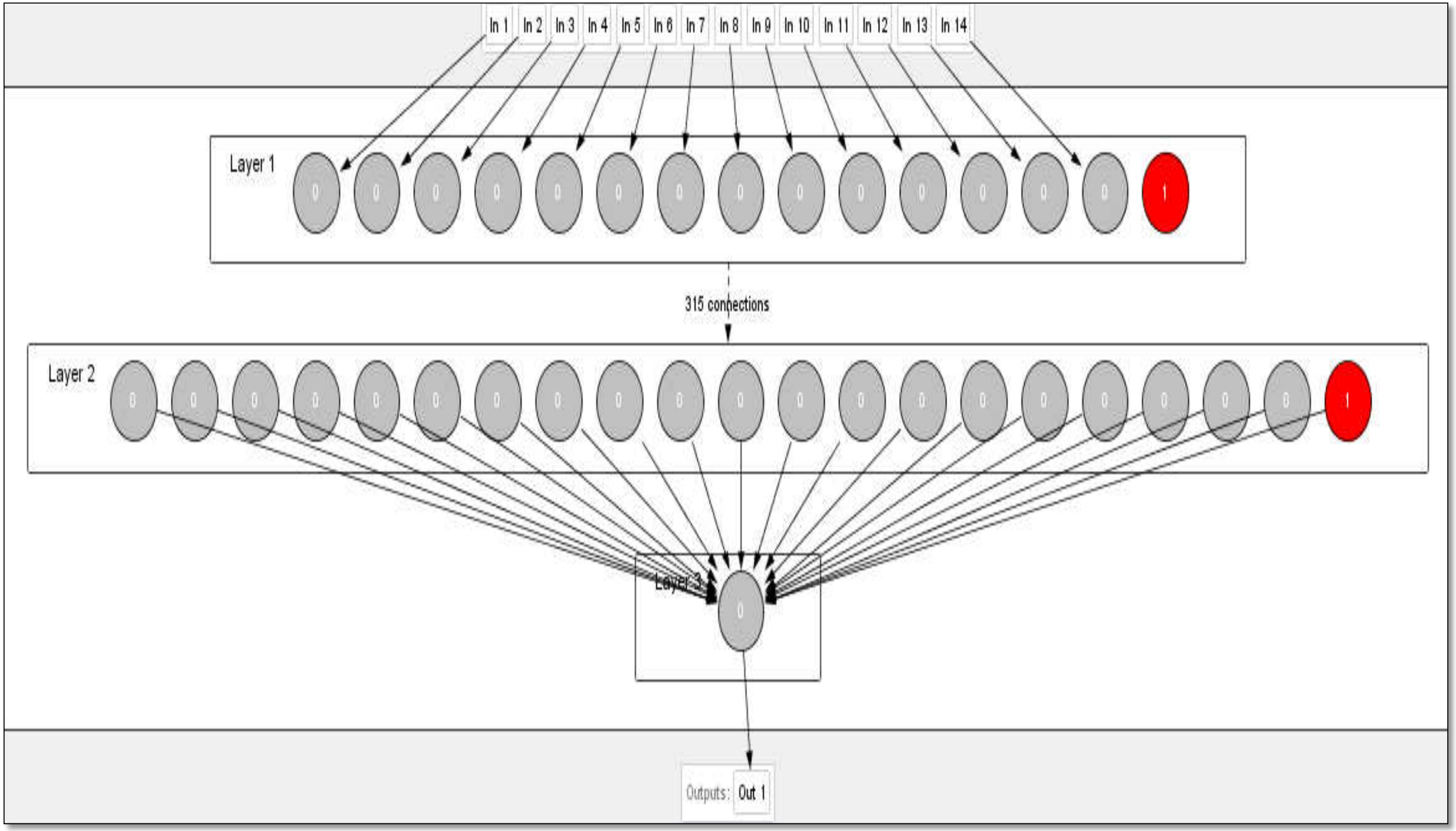

Figure 3: Structure of the Optimum Network

After training the network, 7 new data points were used to validate the network. Table 2 presents the validation results.

Table 2: Testing Results

Input	Network USBS	Expected USBS	Error
Case 1	0.286	0.293	0.007
Case 2	0.341	0.333	-0.008
Case 3	0.296	0.293	-0.003
Case 4	0.273	0.280	0.007
Case 5	0.288	0.293	0.005
Case 6	0.549	0.547	-0.002
Case 7	0.342	0.347	0.005

When considering the errors of the validation set, the error of each case was in the range of ± 0.01 which was the maximum error (1%), initially established for the predictive model. Hence, it can be concluded that ANN model has reached the expected performance level of the study.

6. CONCLUSIONS

The paper presents the findings on construction workers' unsafe behaviour and its influential factors. These factors were compiled from an in-depth literature review and further validated by a group of experts from the industry. In this paper, the identified factors are presented under three categories; namely, person, process and place. These acts of unsafe behaviour and influential factors were validated and moderated by the industry experts in the pilot study undertaken. While the experts confirmed the list of unsafe acts that characterise the unsafe behaviour, an influential factor, namely, 'gender' was omitted from the list considering the Sri Lankan context and significance to the subject matter, respectively. This moderated information was utilised in developing the questionnaire of the main survey, which targeted the workers in C1 Building contraction sites in Colombo metropolis, considering the scale of operation and the time constraint. Survey yielded a response rate of 71% and the generated data were utilised in developing a predictive model for construction workers' USBS. The internal consistency of the scales used in the questionnaire was tested using Cronbach's Alpha test and the model (neural network) was developed using Neuroph Studio software package. The optimum network was reached through trial and error method during training. The stopping criterion for the optimum network was 0.01 while the learning rate was 0.2 and momentum was 0.7. The network was then validated for generalisability using 7 new cases and the results confirmed that ANN model has reached the expected performance of the study. The developed model can be used in determining the safety training needs of workers who operate in the construction industry, based on the USBS.

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