Dewi Candraningrum
(Editor)

Narratives of Sustainable Development: Industry in the Global World Meeting Social Ecological Responsibility

Introduced by
Prof Bernard Adeney-Risakotta

Courtesy of painting by Vincent van Gogh, *Lady Arles*

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The Use of Artificial Neural Networks for Determining The Relative Importance of Affecting Variables on Outputs of Developed Technologies

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I. Introduction

It is acknowledged that industrialization results in not only benefits but also hazards for human being or environments. In the past times, the developed technologies mainly gave priority on gaining profits as much as possible while paying a little attention on possible negative impacts behind the developed process. People now realize the hidden high cost of it, and try to solve such problems in several ways. One of potential ways is to eliminate insignificant affecting variables on process that may even give undesired products or wastes. It is then needed a quantitative tool to identify these variables. This short paper highlights a brief analysis on determining of relative importance of affecting input variables on an output variable/product of developed technology or process using artificial neural networks (ANNs). To give an idea about ANNs, the discussion starts with description of ANNs. A demonstration to obtain weights factors parameters required in the determination of relative importance of affecting variables will be shown in this study.

II. Artificial Neural Networks

Referring to its name, the concept of ANNs imitates biological neural systems. In human being, any input of information caught by human senses is passed and processed by neural systems to result in an action output. Similar input data will be treated in the same way and result in similar output. At this point, the neural systems actually identify certain input with certain pattern of treatment to give certain output. Similarly, ANNs model comprises large connections between elements so-called neurons. These neurons consist of such functions to relate the

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output or target values with the given input. The correlation between output and input is trained by ANNs until the required minimum error (difference between ANNs predictions and real data) of target values is met by adjusting the values of connection parameters so-called weights (w), such kind of proportional coefficients.

An ANNs architecture is composed of at least three layers of neurons, as follows: one layer of input neurons (i), one layer of hidden neurons (h), and one layer of output neurons (o). An example of ANNs architectures is described in Fig. 1.

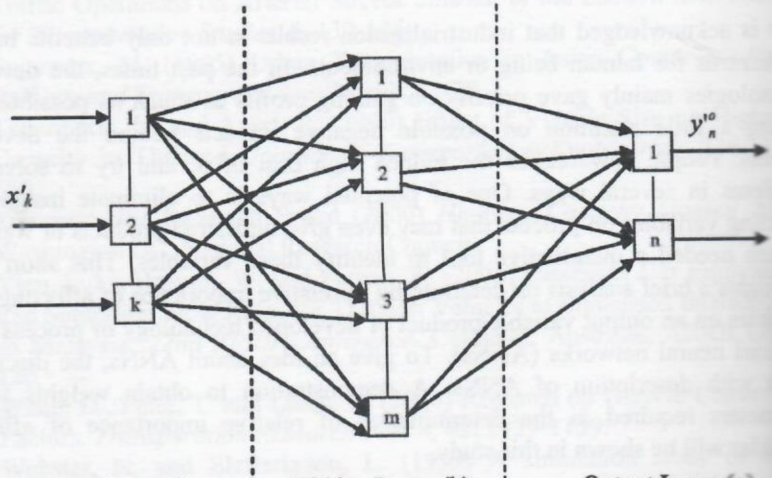

Fig. 1. An architecture of ANNs with a single hidden layer

The input neurons act as distribution channels that transmit the initial input into hidden neurons. No transfer functions take place in the input layer, and thus the output of input layer is exactly the same as its input,

$$y'^{i}_{k} = x'_{k}$$

x' and y' represent the normalized values of initial (raw) input and calculated output which are defined as follows,

$$x' = \frac{x - x_{\min}}{x_{\max} - x_{\min}}$$

where x, x_{min}, and x_{max} are the actual value of raw input, the minimum value of raw input, and the maximum value of raw input, respectively. The values of variables are normalized in order that they have the same range of values with the boundaries of transfer function used in the hidden layer. Before being transferred, the output from the input layer is processed by hidden neurons using weighted summation, as follows

$$x_m^h = \sum_{k=0}^{k} y_k^i w_{km}^{ih} + b_m \tag{3}$$

w_{km}^{ih} represents the weight factor emanating from neuron k in input layer i and terminating at neuron m in hidden layer h. b_m is the value of "bias" factor associated to neuron m. Bias neurons are added in the hidden and output layers to provide universal approximation of ANNs. Subsequently, x_m^h becomes new input for hidden layer and then is transferred by hidden neurons into certain output. The most widely used transfer function is the 'S'-shaped logistic sigmoid (logsig) of which formula is

$$f(x) = \frac{1}{1+\exp(-x)} \tag{4}$$

This transfer function is selected due to its unique features such as continuously differentiable, monotonic, symmetric, and bounded between 0 and 1. Inputting x_m^h into Eqn. (4) results in output of hidden layer $\left(y_m^h\right)$,

$$y_m^h = \frac{1}{1+\exp\left(-x_m^h\right)} \tag{5}$$

Since there is no transfer function in the output layer, the output of output layer is the same as its input. However, similar to the input of hidden layer, the input of output layer comes from the output of previous layer (i.e., hidden layer) that has been treated with weighted summation, as follows

$$x_n^o = \sum_{m=0}^{m} y_m^h w_{mn}^{ho} + b_n \tag{6}$$

Then, the output of output layer will be,

$$y_n^o = x_n^o \tag{7}$$

ANNs trains the model until the required minimum error (E_j) is achieved. E_j is defined as,

$$E_j = \sum_{j=1}^{n} \left(y'_{nj} - y^o_{nj} \right)^2 \quad (8)$$

It can be stated that model training in ANNs is essentially an optimization process to minimize error function as given in Eqn. (8) by adjusting the weights w at hidden layer.

ANNs is suitable to correlate input-output of complex processes where mechanistic model may be difficult to describe. ANNs usually works well as long as reliable and wide range of corresponding data is available for model training. Therefore, in practice ANNs has been applied commercially in such processes including business applications (voice signal stabilization in communication system, risk analysis system, etc.), aerospace (aircraft autopilot, simulation of flight path, detection of aircraft component fault, etc.), automotive (automatic guidance system, analysis of warranty activity), banking/financial/insurance (evaluation of credit application, mortgage screening, etc.), medical (cancer cell analysis, optimization of transplant times, etc.), and even chemical industries (process control, predicting output gasses of furnaces or other industrial processes, and oil-gas exploration).

III. Determination of Relative Importance of Affecting Variables

Using the values of weights obtained from model training of ANNs, the extent of dependency of output variable on each input variable can be determined based on partitioning of the connection weights of each hidden neuron into components associated with each input neuron. Garson has provided a correlation for this purpose, as follows,

$$IM(X_p) = \frac{\sum_{j=1}^{N_p} \left[\left(\frac{|I|_{pj}}{\sum_{k=1}^{N_p} |I|_{pj,k}} \right) |O|_j \right]}{\sum_{i=1}^{N_p} \left\{ \sum_{j=1}^{N_p} \left[\left(\frac{|I|_{pi,j}}{\sum_{k=1}^{N_p} |I|_{pi,j,k}} \right) |O|_j \right] \right\}} \quad (9)$$

where $IM(X_p)$ is the importance measure for pth input variable X_p. $|I|_{pj}$ is the absolute value of the weight corresponding to the pth input variable and the jth hidden layer. $|O|_j$ is the absolute value of the weight in the output layer corresponding to the jth hidden layer. N_p is the number of input variables. The higher value of IM is, the more important the corresponding variable is. The combination of ANNs and Garson equation is very potential tool to identify variables which may or not be eliminated from the process in order that undesired outputs can be avoided.

IV. Case Example

Due to insufficient time to collect the data of relevant case, a case example to be demonstrated was adopted from the author's current work. The output is the permeation flux of pervaporation, a membrane-based separation technique; whereas the input variables include the physicochemical properties of permeant-membrane material (i.e., solubility parameter difference of permeant-membrane, solubility parameter difference of permeant-permeant, molar volume of permeant, molar volume of polymeric membrane, diffusivity of permeant through membrane, membrane thickness, glass transition temperature of polymeric membrane, vapor pressure of permeant, bubble point of permeant, and heat of vaporization of permeant) and process conditions (feed concentration, operating temperature, and permeate pressure). In this case, an output variable is influenced by 13 affecting input variables with 141 data points of various pervaporation systems; 87% of it (122 points) is used for model training, and the remaining is for model testing. A demonstration of model training using ANNs will be shown in the slides executed using software Matlab. The determination of relative importance of input variables on output as given in Garson equation can be executed by software Excel; however, it is not shown in this paper.

V. Concluding Remarks

Any case of correlation between an output variable of process (product) and its affecting input variables can be built accurately using ANNs. To achieve this accuracy, reliable and wide range of data is required in the model training. The combination of ANNs and Garson equation is believed to be a valid tool in determining the level of relative importance of affecting input variables on an output of process. In conjunction with the issues highlighted in this proceeding, we can place different outputs based on different points of view (economics, humanity, hygiene, environment, etc.) with similar input variables. Each output may give different relative importance of input variables. Nevertheless, knowing the level of important variables can guide us how to treat a process so that a maximum benefit or minimum risk of an output can be achieved.

In addition, it must be pointed out that Islamic teachings given by Allah the Almighty has actually guided us how to treat natural sources in order that maximum benefits and or minimum hazards can be achieved. For instance, it is mentioned in the holy Qur'an that Allah has created everything with certain proportions and prohibited human being to do excessive spending or exploitation. The arisen problems in these days are mainly due to excessive exploitation on natural sources by hands of human being. So, except conducting efforts as proposed in this paper, implementing Islamic teachings by spending natural sources proportionally (as necessary to fulfill the need) is the most effective way to solve the problems.