Optimization Approach for Rehabilitation of Sever Damages in Concrete Members

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Abstract

Structural concrete members subjected to sever conditions may suffer from sever damages leading to extreme reduction in their strength and structural Behavior. Such reduction has risky effects on safety of structure. Diagnosing and rehabilitation of these damages is an essential objective to control the problems and to reduce the probability of building collapse especially in early stages. Selection of the optimum rehabilitation technique leads to structural and economic benefits. This selection is affected by several factors and requires high skills and experience. Therefore, development of an optimization system is very useful for selection of the best solution in the domain of this study. This study aims to develop a neural network system to select the optimum solution in this domain. The proposed system is verified and validated to ensure its efficiency and flexibility.

Keywords: Optimum Rehabilitation Technique, Neural Network, Concrete Members, Safety of Structure.

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1. Introduction

Severe conditions such as bad environmental effects, chemical attack, and overloading can cause serious deteriorations in concrete members. Rehabilitation of deteriorated members is essential to ensure safe, convenient, and comfort usage of the facilities. Selection of the best rehabilitation technique and best materials and methods is affected by several factors. Manipulating and analyzing of these factors lead to efficient problem diagnosing, correct causes specifying, and best selection of solutions in this domain. This process requires great skills, experience, and efforts which may not be available when or where required. In addition, providing skills and experience to pay efforts is, mostly, costly. Moreover, processing of all factors in this domain is very difficult even for professionals. Therefore, development of a computerized model capable to manipulate, process, and analyze all factors in the domain of the study is very useful to ensure correct diagnosing of the problem and optimization of solutions. This study proposed development of such model. The proposed model uses artificial neural network technique to deal with domain problems. The model considers all available data including technical, economic, environmental, and other factors to overcome the domain problem. Early overcome of domain problems can prevent disastrous effects. The user-interface of the computerized model was designed to be flexible and user-friendly to ensure simple communication between the users and the model to simplify the diagnosing-solving process. The proposed model can be used practicing engineer to overcome domain problems easily and efficiently. In addition, it can be used by the experienced engineers to overcome domain problems in short time and low efforts as well as manipulating all factors related to targeted problem. Moreover, the model can be utilized as an educational facility for training novices and students in this domain. It can, also, be adopted as an archive to document the knowledge in the study domain.

Recently, miscellaneous civil engineering problems are treated using neural network technique (Abdeljaber et al., 2016, Carli et al., 2014, Dewan et al., 2016, Farfani et al., 2015, Gholizadeh, 2015, Guzelbey et al., 2006a, Guzelbey et al., 2006b, Hakim et al., 2015, Mallela and Upadhyay, 2016, Mazrooei-Sebdani and Farjami, 2015, Wang and Adeli, 2015). Neural Networks are mathematical models motivated by the functioning of the human brain and nervous system (Shahin and Elchalakani, 2008). The neural network modeling phenomena is similar to that adopted in building of more classical statistical models (Zhang and Goh, 2016). The objective of these models is capturing the relationship among a historical set of model inputs and corresponding outputs (Zavrtanik et al., 2016). Nevertheless and dissimilar to most of statistical ways, neural networks do not need predefined mathematical equations of the relationship between the model inputs and corresponding outputs (Wang and Adeli, 2015). However, they use the data alone to determine the structure of the model and unknown model parameters (Shafabakhsh et al., 2015). This allows neural network to control the restrictions of existing modeling approaches (Azadi and Karimi-Jashni, 2016). Throughout the literature review, it was found that using of neural network system is suitable for the domain of the study. However, and to the best knowledge of the author, no neural network model was developed in the study domain. Therefore, the proposed model is important to fill the gap and to cover this domain.

2. Severe Conditions

Conditions that can cause damages in concrete members differ in type, severity and effects. Some concrete structures and infrastructure experience severe environment with substantial snowfalls during winter and extremely low temperatures that could be well below -20°C at night. On the other hand, the hot arid climate may cause degradation of concrete by alkali-silica reaction or other expansive reactions. Concrete members, also, suffer under severe environments involving penetration of chloride ions, sulfate attack, and freezing-and-thawing action. Severe environments, extensive experience demonstrates that it is not the disintegration of the concrete itself but rather chloride-induced corrosion of embedded steel which poses the most critical and greatest threat to the structures. The increasing amount of de-icing salt has created a special challenge, but de-icing salts are not the only source of problems. Chloride-induced corrosion is also an extensive and costly problem for concrete structures in marine environments. Common exposure of members for severe conditions can be abstracted in the following points:

1. Structurally reinforced concrete members exposed to chlorides with or without freezing and thawing conditions such as bridge decks, parking decks and ramps, portions of marine structures located within the tidal and splash zones, concrete exposed to seawater spray, and salt water pools.
2. Non-structurally concrete members exposed to chlorides and freezing and thawing such as porches, steps, pavements, sidewalks, curbs, and gutters (i.e. plain) concrete.
3. Continuously submerged concrete members exposed to chlorides but not to freezing and thawing such as underwater portions of marine structures.
4. Non-structurally reinforced concrete members such as underground parking slabs on grade exposed to chlorides but not to freezing and thawing.
5. Concrete members exposed to freezing and thawing in a saturated condition but not to chlorides such as pool decks, patios, tennis courts, freshwater pools, and freshwater control structures.
6. Concrete in an unsaturated condition exposed to freezing and thawing but not to chlorides such as exterior walls and columns.

7. Concrete not exposed to chlorides or to freezing and thawing such as footings and interior slabs, walls and columns.
8. Structurally reinforced concrete exposed to severe manure and/or silage gases, with or without freeze-thaw exposure. Concrete exposed to the vapor above municipal sewage or industrial effluent, where hydrogen sulphide gas may be generated such as reinforced beams, slabs and columns over manure pits and silos, canals, pig slats, access holes, enclosed chambers, and pipes that are partially filled with effluents.
9. Structurally reinforced concrete exposed to moderate to severe manure and/or silage gases and liquids, with or without freeze-thaw exposure such as reinforced walls in exterior manure tanks, silos and feed bunkers, exterior slabs.
10. Structurally reinforced concrete exposed to moderate to severe manure and/or silage gases and liquids, with or without freeze-thaw exposure in a continuously submerged condition. Concrete continuously submerged in municipal or industrial effluents such as interior gutter walls, beams, slabs and columns, sewage pipes that are continuously full (e.g., force mains), and submerged portions of sewage treatment structures.
11. Non-structurally-reinforced concrete exposed to moderate manure and/or silage gases and liquids, without freeze-thaw exposure such as interior slabs on grade.

3. Artificial Neural Networks

An artificial neuron is a very approximately simulated mathematical model of a biological neuron. A biological neuron is the basic functional unit of a human brain. Human brain is capable of parallel processing of many activities at a time due to a massively parallel huge network of neurons. A human brain functions with hundreds of thousands of such neurons which are interconnected by a highly complex network. One such neuron is illustrated in Figure 1. As can be seen from the figure, every neuron consists of a cell body, an axon and dendrites.

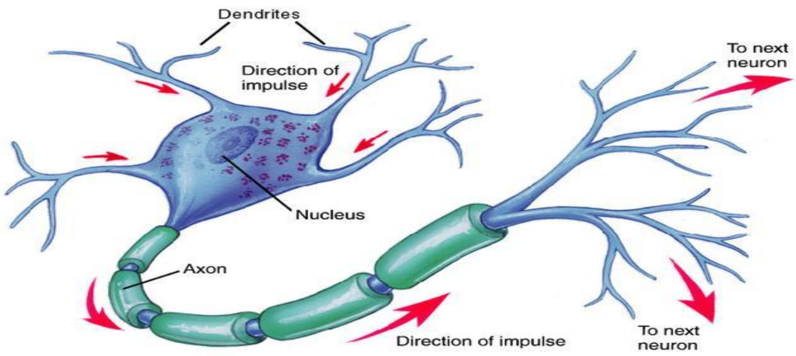

Figure 1 A Biological Neuron

A typical biological neuron receives an input through dendrites. Different dendrites meet at a particular point called a synapse. All the input from the different neurons is essentially summed up in the cell body. If the sum at a given time is greater than a particular threshold value, then the neuron fires, i.e. a signal is sent down the axon. In a similar fashion, an artificial neuron also receives signals from other neurons through the connections between them (Figure2).

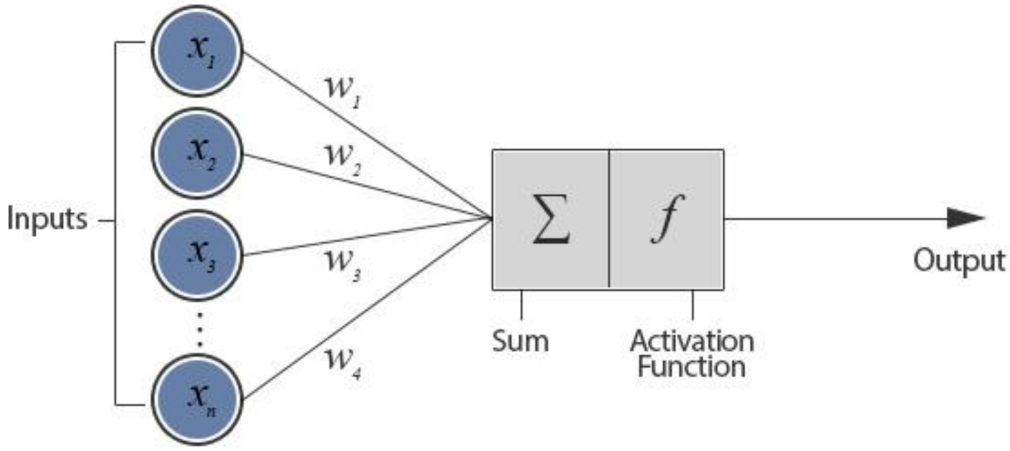

Figure 2 An Artificial Neuron

Each connection has a ‘synaptic’ connection strength which is represented by a weight of that connection. The incoming signal is multiplied by this connection strength. Thus an artificial neuron receives a weighted sum of outputs of all the neurons to which it is connected. This weighted sum is then compared with the threshold for the artificial neuron and if it exceeds this threshold, the artificial neuron also fires. When an artificial neuron is fired, it goes to a higher excitation state and a signal is sent down to other connected neurons. The output of a typical neuron is obtained as a result of a non-linear function of weighted sum as follows:

$$y_i = F(\sum x_i w_{ij}) - \theta \quad \ldots (1)$$

where F is a non-linear function, x_i and w_{ij} are the inputs and the weights from the i^{th} input node to j^{th} node and θ is the threshold value for the artificial neuron.

The node characteristics of an artificial neuron are thus determined by (1).

4. Optimization Models

The proposed system uses neural network technique to diagnose the domain problems and for optimization of solutions to recommends rehabilitation method and materials. To attain this objective, the system based on mathematical models involving a number of factors multiplied by coefficients. Since the selection of the optimum solution depends on correct diagnosing of the problem, the system based on same technique (neural network) in diagnosing. Diagnosing involves identification and analysis of member type and function, features and severity of defect(s), conditions (environmental, loading, and production), causes of deficiencies, usage and importance of facility, and environment considerations. Table 1 presents a number of parameters involved in this step.

The weight for each parameter based on its contribution in problem occurrence and severity. Same parameters may cause different effects in same members based on contribution of other factors. Table 2 presents an example for this aspect. The user of the system selects the factors that will affect the decision based on the existing conditions. The system explains each factor to help the user to select correctly (Table 3 presents an example).

The coefficients for every factor were imbedded in the inference engine of the system. The models process the inputs to diagnose the severity of the problem. Based on the result of the processing, the proposed system selects the optimum solution in terms of structural, practical, economical, and environmental conditions. This phase involves three sub-phases: selection of action, selection of method, and selection of materials.

For example, four solutions are probable to overcome deterioration in a concrete beam. The probable solutions are as follows:

(1) Neglecting
(2) Strengthening
(3) Replacing
(4) Demolition

The present system optimizes the solution using Equation (2) depending on existing conditions. Table 2 presents the factors that affect solutions, the value of each factor in each of the four cases (1, 2, 3, and 4), and the average weight of their related coefficients. The present system asks the user to select each factor based on site conditions and substitutes the value related to the selected factor (1, 2, 3, or 4) in the mathematical model to calculate the S-value.

The rules in the system inference engine are as follows:

If S = 0.000- 0.250	Then apply solution (1): Neglecting
If S = 0.251- 0.500	Then apply solution (2): Strengthening
If S = 0.501- 0.750	Then apply solution (3): Replacing
If S = 0.751- 1.000	Then apply solution (4): Demolition

$$S = \frac{Tc_f}{Nt_f} \times a \qquad \dots (2)$$

$$Tc_f = c_d \times C_D + r_c \times R_C + f_c \times F_C + l_s \times L_S + t_s \times T_S + f_y \times F_Y + l_d \times L_D + e_t \times E_T + s_f \times S_F + o_h \times O_H + o_w \times O_W + o_s \times O_S + a_c \times A_C + c_c \times C_C + m_d \times M_D \quad \dots (3)$$

$$Nt_f = s_i \times S_I + b_a \times B_A + p_a \times P_A \qquad \dots (4)$$

$$a = constant$$

Where *S* specifies the optimum solution, Tc_f represents technical factors value, Nt_f represents non-technical factors and the other symbols are defined in Table 2. However, several logical rules control the mathematical models to avoid incorrect solutions. For example, in case of historical, archaeological, Heritage, and other similar facilities, demolition is not included as a solution. IF-Then statements were involved in the source code of the computerized model to cover this point.

Table 1 A number of parameters involves in problem diagnosing

Member	Foundation (Separate, Strip, Raft, Pile cap) Column (Long/Short, Vertical/Inclined, External/ Internal) Beam (Simply supported/ Continuous/ Cantilever, Structural/ Cosmetic, Straight/ Curve, External/ Internal) Slab (One-way /Two-way / Flat, Floor/ Roof) Pier (Solid/ hollow, Vertical/ Inclined) Pavements (Plain/ Simply reinforced/ Continuously Reinforced/ Prestressed, Laterally supported/ Laterally unsupported) Shear wall Retaining wall Joints
Defect	Cracking (Hair cracks / Moderate cracks / Severe Cracks, Longitudinal/ Transverse / Diagonal/ Corner/ Crazing) Scaling (Minor/ Severe/ Very severe) Spalling (Minor/ Severe/ Very severe) Reinforcement Corrosion (Minor/ Severe/ Very severe) Member Collapse
Exposure	Thermal, Fire, Cold Weather, Nuclear, Alkali, Acids, Salts

	Carbonation attack, Petroleum Solutions, Water, Soil, Traffic Overload and Impact, Loss of Support
Causes	Inadequate design Inadequate construction Inadequate protection Incorrect usage Thermal cycling Accidental overloading Exposure to harmful conditions
Usage	Industrial/ Commercial / Residential/ Service Not Important/ Important / Very Important
Environment considerations	Prevention of airborne vapor or particles Control of noise and hazardous waste

Table 2 Factors considered in optimization of solution (an example)

Fc values				
Fc = 1	Fc = 2	Fc = 3	Fc = 4	Cf values
Minor	Moderate	Severe	Very Severe	0.95
Minor	Moderate	Severe	Very Severe	0.95
High	Moderate	Low	Very Low	0.89
High	Moderate	Low	Very Low	0.78
High	Moderate	Low	Very Low	0.69
High	Moderate	Low	Very Low	0.11
Low	Moderate	High	Very High	0.33
Short	Moderate	Long	Very Long	0.78
Short	Moderate	Long	Very Long	0.78
Non	Minor	Major	Essential	0.78

1Cf: coefficient represents average weight (by percentage) for each factor
Fc: factor represents existing condition

Table 2 Factors considered in optimization of solution (an example) (Continue)

			Fc values			
¹Cf	¹Fc	Parameter	Fc = 2	Fc = 3	Fc = 4	Cf values
c_d	C_D	Concrete Defect	Moderate	Large	Very Large	0.89
r_c	R_C	Reinforcement Corrosion	Moderate	Large	Very Large	0.69
f_c	F_C	Fc: Actual/Design	Rectangular	Other Regular	Irregular	0.51
l_s	L_S	Longitudinal As: Actual/Design	Sufficient	Insufficient	Extremely Insufficient	0.69
t_s	T_S	Ties As: Actual/Design	Sufficient	Insufficient	Extremely Insufficient	0.89
f_y	F_Y	Fy: Actual/Design	Effective	Moderate	Not Effective	0.51
l_d	L_D	Load: Applied/Design	Important	Minor	Very Minor	0.60
e_t	E_T	Exposure Time	High	Low	Very Low	0.78
e_t	E_S	Exposure Time	High	Low	Very Low	0.24
s_f	S_F	Structural Function				

[1]Cf	[1]Fc	Parameter	Fc = 1
o_h	O_H	Opening Height	Small
o_w	O_W	Opening Width	Small
o_s	O_S	Opening Shape	Circular
a_c	A_C	Air Content	Very Sufficient
c_c	C_C	Concrete Cover	Very Sufficient
m_d	M_D	Modifiers	Very Effective
s_i	S_I	Structure Importance	*Very Important
b_a	B_A	Budget Availability	Very High
p_a	P_A	Proficiency Availability	Very High

Table 3 Identification of severity level of exposure to sulphate

Degree of Exposure	Water soluble sulphate (SO_4) in soil sample, %	Sulphate (SO_4) in groundwater sample, mg/L	Water soluble sulphate (SO_4) in recycled aggregate sample, %
Very Severe	> 2%	> 10000	> 2%
Severe	0.2 - 2	1500 - 10000	0.6 - 2
Moderate	0.1 – 0.2	150 - 1500	0.2 – 0.6
Minor	< 0.1	< 150	< 0.2

5. System computerization and operating

In this study, the neural network system was computerized to ensure simple and flexible operating for different types of users. In computerization of this system, the researcher selected Visual Basic, one of the most widely used computer programming languages. It not only creates Windows programs, but also takes full advantage of the graphical way that Windows works by letting programmers develop their systems by using a computer mouse. Visual Basic is truly revolutionary and gives programmers a much more capable, efficient, and flexible way to write computer software programs (Olugu and Wong, 2012). This programming language offers ease of use, which is a requirement of the user interface (Mosa et al., 2013) and writes codes in a simple syntax in a natural mathematic language.

The present software encountered a few errors after coding and has undergone numerous modifications until all functional requirements worked properly. Errors may occur during program coding under Visual Basic or any other programming language. These errors must be captured and corrected to ensure that the product is error-free. To capture and correct errors in the present software, the developer performed several single tests during the coding process. Unit testing and integrated testing were performed. Unit testing involves testing the units one by one in separate testing activities; whereas, integration testing is performed to verify that all units operate together as expected (Aguilar et al., 2008). Testing was continually performed during all stages of the present software development to verify that each unit in the system performs its intended function. Three types of errors were captured and corrected in the present software testing, namely, syntax errors, runtime errors, and logic errors.

To run the system, the user shall provide the required inputs. Input data are processed in the software to provide the user with outputs (Rehabilitation methods and materials). The developer tested the interaction between the user and the present software. User interface is the interface between user and software. The user communicates with the software via this interface. Generally, user interfaces obtain information needed to obtain the objective by asking the user to answer questions or prompting the user to provide relevant information in a preformatted manner. User interfaces should be designed in such a way that they effectively collect information and structurally present the whole software without restricting the overall performance. A good graphic user interface also reduces the required learning time and the number of mistakes made by first-time users. Figure 3 illustrates an example interface window. The developer designed the interface windows to be clear, attractive, user-friendly, and interactive. Several cases were applied using the proposed system to ensure its validity in problem solving.

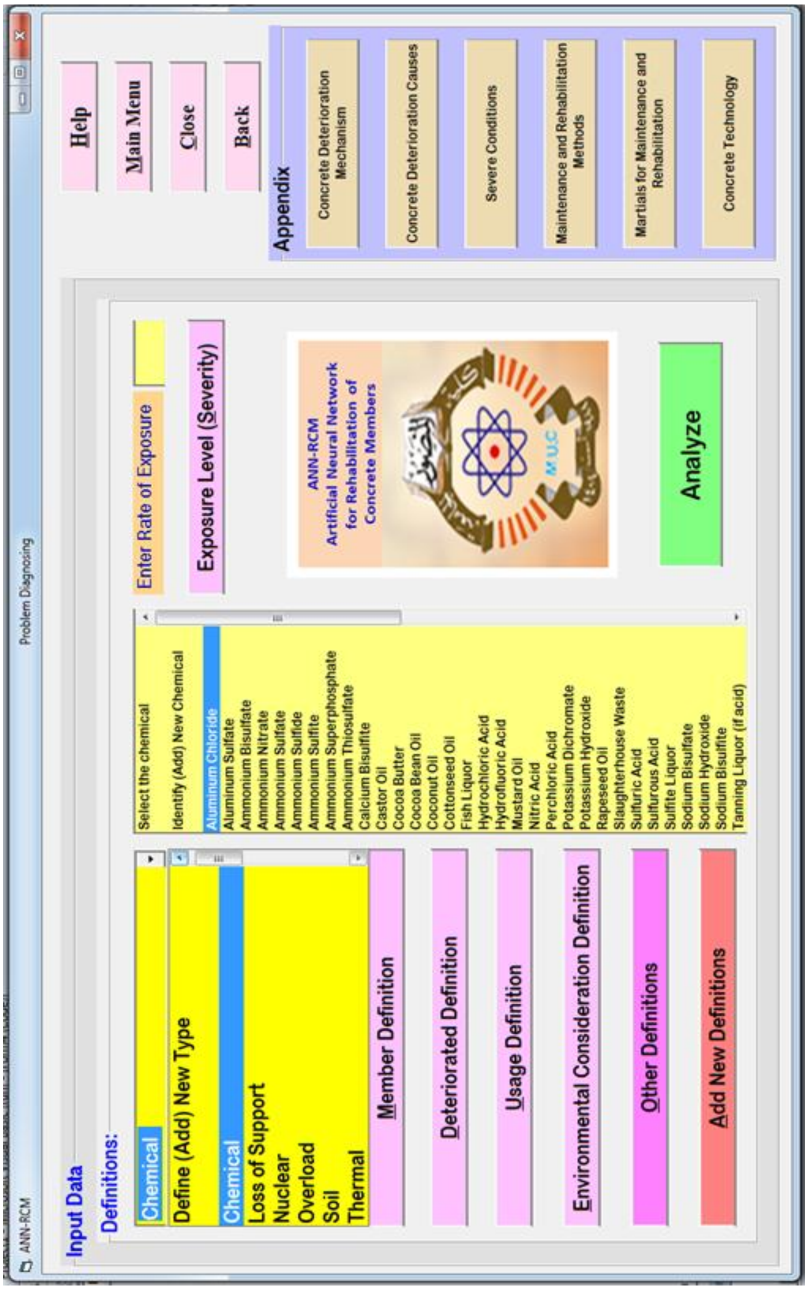

Figure 3 User interface window (an example)

6. Conclusions

Selection of optimum rehabilitation method and materials for concrete members exposed to severe conditions is a complex process that need for a high skills and experience to cover all related factors. Therefore, development of a computerized model to overcome the problems of this domain is an essential objective. The proposed model based on neural network technique to attain this objective. The model was computerized using Visual Basic programming language due its simplicity and flexibility as well as its popularity and capability to communicate with different users in an effective manner. The developed system involves attractive and interactive user-interface and tight inference engine. The system was tested to insure its correctness and effectiveness in solving the domain problems. It can provide the domain engineers with optimum solution considering technical, economical, and environmental factors. Moreover, it can be adopted as a media to archive the domain knowledge and as an educational tool to train novice engineers and engineering students.

The proposed system will be updated when new technologies are applied in the domain of the study. Problems may occur if the proposed system is operated for several days. In this case, the system can be restarted to solve the problem. Updating the system is a simple operation because the system includes help facilities within its source code. A knowledge engineer or any skilled Visual Basic programmer is qualified to update the system with the guidance of a domain engineer.

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الطريقة المثلى لتأهيل الاضرار البالغة في الاعضاء الخرسانية

م.د. احمد منسي موسى

المستخلص

تعاني الاعضاء الانشائية الخرسانية المعرضة لظروف قاسية من اضرار بالغة تقود الى انخفاض شديد في متانتها و دورها الانشائي؛ مما يؤدي الى مخاطر على سلامة المنشأ و يعد تشخيص و تأهيل تلك الاضرار هدفا جوهريا للسيطرة على المشاكل و تقليل احتمال انهيار المنشأ سيما في المراحل المبكرة. يقود اختيار طريقة التأهيل المثلى الى مكاسب انشائية و اقتصادية. و يتأثر هذا الاختيار بعوامل عديدة و يتطلب مهارات و خبرة عالية. لذلك فان تطوير نظام تمثيل في هذا المجال يعد مفيدا لاختيار الحل الافضل. تهدف هذه الدراسة الى تطوير نظام شبكة عصبونية لاختيار الحل الامثل في مجال الدراسة و كذلك اختبار هذا النظام لضمان فعاليته و مرونته.

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