HBRC Journal (2012) 8, 132–143

Housing and Building National Research Center

HBRC Journal

http://ees.elsevier.com/hbrcj

Assessment of the expected cost of quality (COQ) in construction projects in Egypt using artificial neural network model

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Received 22 March 2011; accepted 9 January 2012

KEYWORDS

Quality;
Cost of quality;
Construction;
Egypt

Abstract Many definitions for quality were provided by experts. Among these definitions are: quality is the fitness for use [14], conformance to requirements [4], quality is a predictable degree of uniformity and dependability, at low cost and suited to the market [6].

Cost of quality is an essential element of the total cost of any construction project. Consequently, the accurate assessment of such cost of quality can materially affect the reliability of the estimated cost of any construction project. Stated differently, the accurate and reliable cost estimating for any construction projects is not really possible without the deep investigation for the expected cost of quality of this project. Cost of quality is generally affected by many factors. Any attempt to assess the cost of quality of any project should take the different cost of quality factors into consideration.

The main objective of this paper is to establish a neural network model that will enable the construction firms to assess cost of quality for any future building project. This will improve the company's performance and its ability to compete with other companies through the improvement of bids accuracy. The "Neural Connection 2.0 Professional" was chosen to generate the proposed model. The main factors affecting the expected cost of quality were clearly identified. The different sequences of the model development will be deeply investigated. Moreover, the validity of the proposed model will be evaluated using a number of case study applications.

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Introduction

COQ is usually understood as the sum of conformance plus non-conformance costs, where cost of conformance is the price paid for prevention of poor quality, and cost of non-conformance is the cost of poor quality caused by product

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http://dx.doi.org/10.1016/j.hbrcj.2012.09.009

and service failure. These COQ can be also broken down into the three categories:

- *Prevention cost:* the cost of any action taken to investigate, prevent or reduce the risk of nonconformity.
- *Appraisal cost:* the cost of evaluating the achievement of quality requirements.
- *Internal failure cost:* the costs arising within an organization due to nonconformities or defects at any stage of the quality loop.
- *External failure cost:* the cost arising after delivery to a customer/user due to nonconformities or defects which may include the cost of claims against warranty, replacement and consequential losses and evaluation of penalties incurred.

Cost of quality is an essential element of the total cost of any construction project. Cost of quality is generally affected by many factors, such as planned COQ for the project, awareness of quality for project team, supervision team experience, labor skills, suppliers, design errors, defected material, plan of improving quality, external factors, accident, equipment down time and project duration.

The objective of this study is to identify the most important factors affecting cost of quality and to develop an Artificial Neural Network model that can help cost estimator to arrive at a more reliable assessment for the expected cost of quality of any building construction project.

Literature review

COQ models were classified into five groups of generic models. These are: P-A-F model, Crosby's model, opportunity cost models, process cost models and ABC (Activity Based Costing) models. Porter and Rayner [19] make a more comprehensive survey of the published literature and present a detailed review of quality cost models, focusing again mainly on the P-A-F category and its limitations. The following is a summary for the main literature concerning the cost of quality topic:

1. Vernon et al. (1985) [23]
   Increases in construction planning during design and coordination across the design-construction interface are shown to have very strong effects on reducing construction time and increases in the former variable, which also included aspects of value analysis, reduce the cost of the building [21].
2. Tesfai (1987) [22]
   Developed a good quality culture. Owners, designers and contractors will take quality seriously, preventive disciplines will be widely used and camaraderie's will be observed throughout the industry [20].
3. Davis et al. (1989) [5]
   A quality performance tracking system (QPTS) has been developed to provide for the quantitative analysis of certain quality-related aspects of projects, by systematically collecting and classifying costs of quality. By defining quality as "conformance to requirements," the cost of quality becomes measurable. It consists of two main parts, the cost of quality management efforts and the cost of correcting deviations [6].
4. Abdul-Rahman (1995)
   Stated that poor quality resulting from non-conformance during construction leads to extra cost and time to all members of the project team. The costs of rectifying non-conformance can be high and they can affect a firm's profit margin and its competitiveness. Construction-related firms can identify non-conformance information by employing a quality cost matrix as illustrated in a case study as a basis for improvement [1].
5. Abdul-Rahman (1996)
   Described the use of the quality cost matrix to capture the cost of non-conformance during a construction project and limited the Quality Performance Tracking System (QPTS) and developed a Quality Cost Matrix (QCM), which took into account the effect of a failure on time, particularly, the costing of accelerating work and specific causes of a non-conformance [2].
6. Abdul-Rahman (1997)
   Investigated the importance of client role in determining the quality of the end product; the usefulness of information on non-conformances in preventing failures and improving a process; problems with ground conditions; how most failure costs can be eliminated; how the contractor's role should include anticipating of problems; and how information on the cost of failures can be an indicator of weaknesses and assist in preventing the same failure in the future [3].
7. Low et al (1998) [16]
   Stated that there are three components that make up quality costs: prevention, appraisal and failure costs. Proper design and implementation of these work procedures would lead to reduced wastage as more work would be done right the first time [13].
8. Love (1999) [15]
   Determining the causal structure of rework influences in construction, contributes to study of quality in construction by capturing the complexity and dynamism of those factors that influence rework and project performance in a holistic manner. Rework is caused by errors made during the design process. These errors appear downstream in the procurement process and therefore have a negative impact on a project's performance [12].
9. Mwamila et al. (1999) [17]
   Stated that construction speed is impacted by the number and productivity of workers and can be increased by reliable equipment and early planning and design that maximize use of limited available resources. Building quality is dependent on standardization, product suitability evaluation, defect identification, and thorough planning. Labor costs are generally a small portion of total construction costs; however, labor is a key cost factor because it affects both quality and speed [14].
10. Heng Li et al. (2000) [12]
    Analyzed the causes and costs of rework projects and discussed. The findings reveal that the cost of rework for the case study projects was 3.15–2.40% of their project contract value. Changes initiated by the client and end-user together with errors and omissions in contract documentation were found to be the primary causes of rework [10].
11. Ofori et al. (2000) [18]
    Assessed the perceptions and expectations of contractors concerning ISO 9000 certification and the costs and ben-

efits in practice. Contractors' expectations of ISO 14000 certification were also ascertained, together with their environmental awareness, policies and current practices, and their views on measures which could promote its widespread adoption [15].

12. Firuzan (2002) [10]
Proposed a radical change in industry practice that will improve the quality of the construction process and the levels of customer satisfaction derived from it by evaluating the quality performance of the contractor. An alternative theory is developed of what constitutes quality, client satisfaction, performance, and their interrelationships in the context of the construction industry [7].
13. Irani et al. (2003) [13]
Developed the prototype Project Management Quality Cost System (PROMQACS) to determine quality costs in construction projects. The system was used to determine the cost and causes of rework that occurred in the projects. It is suggested that project participants can use the information in PROMQACS to identify shortcomings in their project-related activities and therefore take the appropriate action to improve their management practices in future projects [11].
14. Dikmen et al. (2005) [8]
Examined the applicability of QFD (Quality Function Deployment) as a strategic decision-making tool after the construction stage of a housing project to determine the best marketing strategy, to make a comparison between the performances of different competitors and to transfer the experience gained from the current project to the forthcoming projects (5).
15. Samadony et al. (2006) [21]
Revealed that the mean expenditure on quality in the Egyptian construction firms is about 26% of total cost, and the internal failure cost is about 10% from total project cost. The key to continuing success in quality management is the ability to collect poor quality information to improve the performance of the construction process. This information should then be incorporated into the design and management of the new projects. This information can also be used to measure the performance of construction firms so that continuous improvement is based on measurement of performance can be effectively implemented [18].
16. Rosenfeld (2009) [20]
Compare cost of quality versus cost of non-quality in construction. The methodology is based on quantifying the four types of quality-related costs in residential construction, and relates them to each other by expressing them all as percentages of the relevant total construction revenues [17].

Table 1 Categorized selection factors based on literature review [2].

S.No.	Factors from literature review
1	Planned COQ for the project
2	Awareness of quality for the project team
3	Supervision team experience
4	Labor skills
5	Project location
6	Suppliers
7	Design errors
8	Defected material
9	Plan of improving quality
10	External factor
11	Accident
12	Equipment down time
13	Project duration

Table 2 Categorized selection factors based on experts recommendations in questionnaire.

S.N	Factors
1	Class of contractor
2	Project size
3	Project type
4	Client type
5	Working time (8–12) hours
6	Working shifts (12–24) hours
7	Sub-contractor(s) nature
8	Firm(s) need for Work
9	Auditing process period
10	Labor turnover
11	Percentage of rejected submittals
12	Special construction engineering requirements
13	Wages of labors
14	Type of Contract
15	Execution Errors
16	Contractor(s) – joint venture
17	New construction techniques
18	Project cash-flow strategy
19	Special site preparation requirements
20	Weather condition

Data collection

The objective of this research paper is the development of an Artificial Neural Network model for Cost of Quality in construction projects in Egypt. The necessary information and required projects data were collected on two successive yet dependent stages: Combination between the factors affecting COQ collected from previous studies as shown in Table 1 and the applied Egyptian list of factors that is adaptable to the Egyptian construction market (experts opinions) as shown in Table 2 and collection of the required in-depth COQ data for a sample of building projects constructed in Egypt to be used during the model developing stage.

Data collection is divided into two stages, first stage is to perform a combination between the COQ factors from the comprehensive literature study and the Egyptian construction industry identifies COQ factors. A questionnaire is used to identify the final list of COQ factors adaptable to the Egyptian building construction market. The second stage was to collect data for 52 projects from several construction companies that represent the first and second category of construction companies in Egypt.

Based on comprehensive literature survey a list of 33 cost of quality factors were prepared. Tables 1 and 2 summarized these factors. A questionnaire survey was conducted among construction experts to identify the most important factors among theses list to be used as the input parameters of the proposed cost of quality model.

The questionnaire

The characteristics of the participating experts, the contractors and the academicians are setting the basis for the findings of the study. Experts for this extensive research were identified to obtain comprehensive and precise results. The experts were selected among the practicing, experienced contractor and professionals in Egypt and the academicians from the Egyptian universities. The survey has been successfully implemented with 60 experts with different scope of expertise in the Egyptian construction market and different years of field experiences. Fig. 1 shows experts classification and Fig. 2 shows experts years of experience.

Analysis of questionnaire data

In the previous steps the process of data collection has been clearly discussed. Now, let us discuss how these data will be analyzed. Such analysis includes many important steps that can be summarized at the following:

1. Calculate the importance index for the previously identified 33 factors. Based on pareto analysis for the relative weight given to the different factors through the field survey, a relative importance index was calculated to each of the thirty factors, such Pareto analysis can be expressed by the following formula (4);

$$\text{Importance Index} = \sum(aX) * 100/5$$

where a is a constant expressing the weight given to each response. The weight ranges from 0 to 4 where 0 is the least importance and 4 is the greatest importance, $X = n/N$, n is the frequency of the responses; N is the total number of responses.

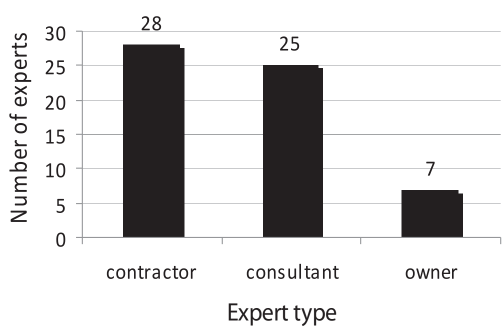


Fig. 1 Experts type classification.

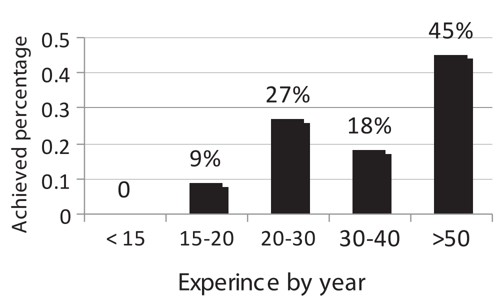


Fig. 2 Expert's experience classification.

Table 3a The most important factors affecting COQ.

Rank	Factor	Important index (%)
1	Project duration	95
2	Planned COQ for the project	80
3	Supervision team experience	78
4	Project size	75
5	Project location	74
6	Awareness of quality for the project team	70
7	Class of contractor	70
8	Client type	68
9	Labor skills	64
10	Project Type	62

2. All factors are ranked in a descending order according to their importance index. Based on the previous analysis, the most important factors were shown in Table 3a which illustrates the most important 10 factors effecting the estimating for cost of quality. Such factors represent the input parameters of the proposed cost of quality model.

The results of the importance index analysis are summarized in Table 3b the 33 COQ factors can be classified into four different groups according to their expected effect in the project cost of quality. The first group factors have an important index greater than (60%). The second group factors have an important index varies between 55% and 40%. The third group factors have an important index of about 35–20%. Finally the last group factors have an important index smaller than 20%.

Projects data collection

In this section, a comparative analysis is performed to show the each effect of the previous factors at the cost of quality for all available projects of completed building construction projects (52 projects). These projects were executed during the 14 years period from 1996 to 2009.

Data of these projects were collected from different areas in Egypt. The comparison is made in terms of cost influence for each factor on the percentage of COQ. It must be illustrated that for all surveyed projects the adapted construction technology was typical traditional reinforced concrete technology, due to the participating expert's opinions, because that technology represents the majority among the adopted building construction technologies in Egypt.

The surveyed building construction projects were classified according to their type as shown in Fig. 3. According to their duration as shown in Fig. 4, the selected projects were classified according to their planned COQ as shown in Fig. 5, and the selected projects were also classified according to their project size as shown in Fig. 6, their labor skills as shown in Fig. 7, their awareness of quality of the project team as shown in Fig. 8, their location as shown in Fig. 9, their class of contractor as shown in Fig. 10, their client type as shown in Fig. 11, and finally their supervision team experience as shown in Fig. 12.

Table 3b Factor affecting COQ.

High effect	Med. effect	Low effect	Not effect
Project duration	Auditing process period	Special construction engineering requirements	Special site preparation requirements
Planned COQ for the project	Suppliers	Design errors	Equipment down time
Supervision team experience	Working shifts (12–24) hours	Plan of improving quality	Contractor(s) – joint venture
Project size	Percentage of rejected submittals	Type of contract	
Project location	Firm(s) need for Work	Accident	Project cash-flow strategy
Awareness of quality for the project team	Working time (8–12) hours	Defected material	Execution errors
Class of contractor	Labor turnover	Wages of labors	Weather condition
Client type			
Labor skills	Sub-contractor(s) nature	External factor	New construction techniques

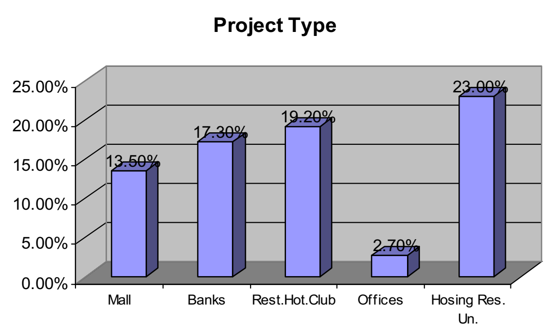


Fig. 3 Classification of projects according to their type.

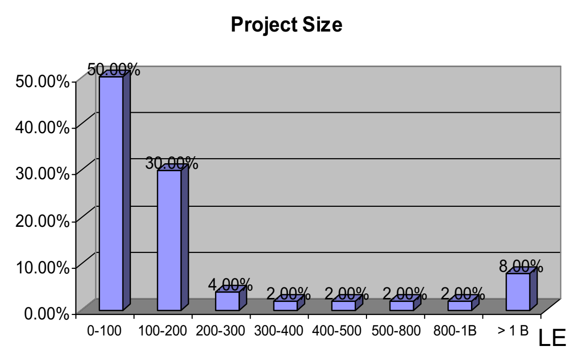


Fig. 6 Classification of projects according to their size.

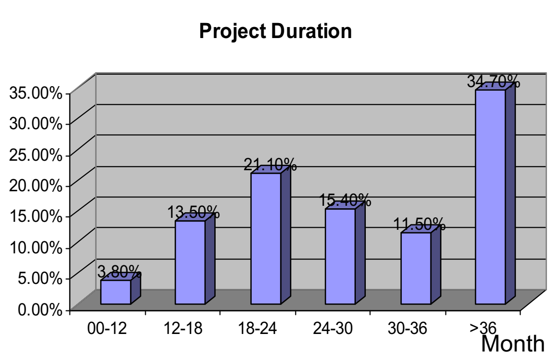


Fig. 4 Classification of projects according to their duration.

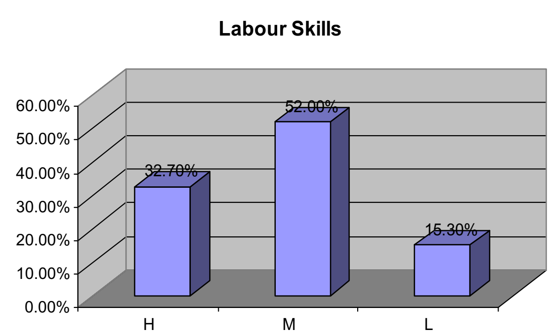


Fig. 7 Classification of projects according to labor skills.

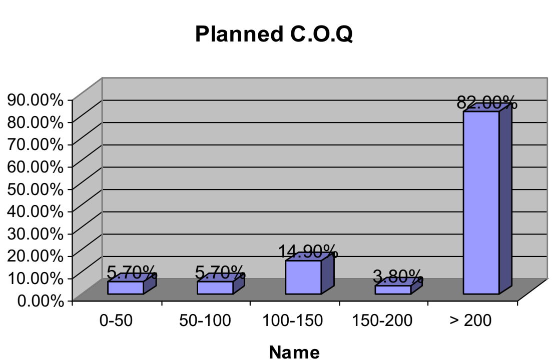


Fig. 5 Classification of projects according to their planned COQ.

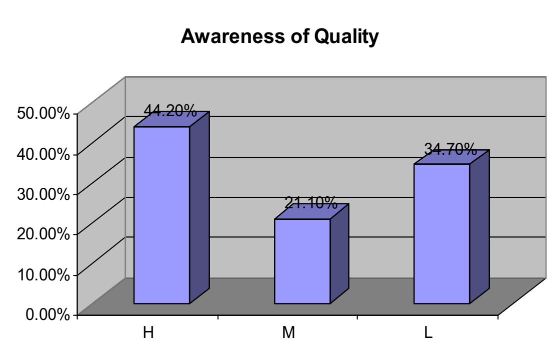


Fig. 8 Classification of projects according to awareness of quality.

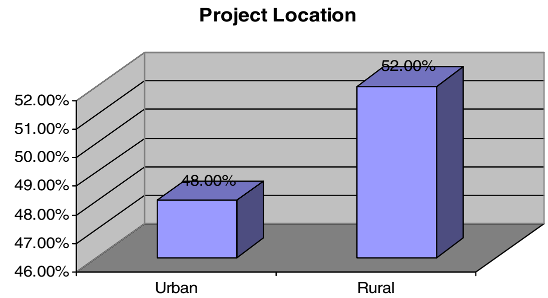


Fig. 9 Classification of projects according to project location.

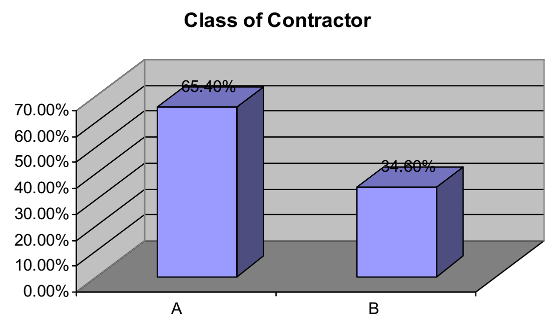


Fig. 10 Classification of projects according to class of contractor.

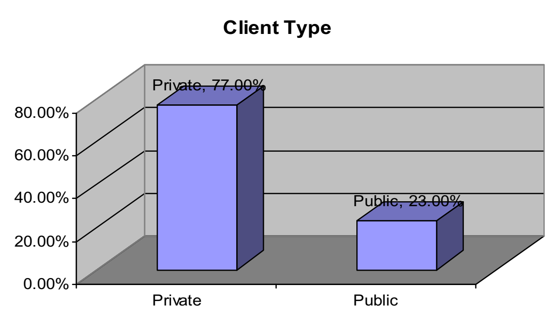


Fig. 11 Classification of projects according to client type.

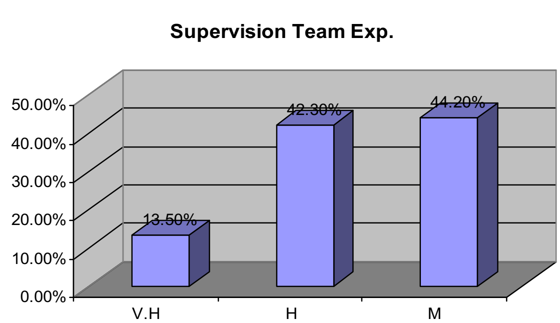


Fig. 12 Classification of projects according to supervision team exp.

Model development

The main purpose of this study is to develop a neural network model to assess the percentage of the expected cost of quality for building construction projects, to guide the decision makers during the bidding document preparation in the Egyptian building construction market.

Neural network and overview

In this paper, Artificial Neural Networks were used as a modeling tool that can enhance current automation efforts in the construction industry. The structure of the neural network model includes an input layer that receive input from the outside world, hidden layers that serve the purpose of creating an internal representation of the problem, and an output layer, or the solution of the problem. Before solving a problem, neural networks must be "trained". Networks are trained as they examine a smaller portion of the dataset just as they would a normal-sized dataset. Through this training, a network learns the relationships between the variables and establishes the weights between the nodes. Once this learning occurs, a new case can be entered into the network resulting in solutions that offer more accurate prediction or classification of the case.

The steps for the design of ANN model will be illustrated to predict the percentage of the expected cost of quality for building construction projects. All factors that have an effect on the expected cost of quality of the building construction projects in Egypt were identified. These factors were considered as the input variables for the proposed neural network model, while the expected cost of quality as a percentage from the total projects contract value is considered as the output variable of this model.

Neural network models are generally developed through the following six basic steps:

Identify the problem, decide what information to be used and what will the network do; come to a decision of how to gather the information and symbolize it; define the network, select network inputs and identify the expected outputs; structure the network; train the network; and analyze the trained network. This engages addressing novel inputs to the network and evaluates the network's results with the authentic life results.

Training the network

All trial models experimented in this research was trained in supervised mode by a back propagation learning algorithm. Inputs were fed to the proposed network model and the outputs were calculated. The differences between the calculated outputs and the actual outputs (data taken from project documents) were then evaluated. The back propagation algorithm develops the input to output mapping by minimizing a root mean square error [RMS] which is expressed by the following equation [9]:

$$\mathrm{RMS} = \sqrt{\frac{\sum_{i=1}^{n}(O_i - P_i)^2}{n}}$$

where n is the number of samples to be evaluated in the training phase. O_i is the actual output related to the sample. P_i is the predicted output.

This value is being calculated automatically by the Neural Connection 2.0 software. The training process stopped when the value mean square error remains unchanged.

Neural networks software

Neural connections program NC version 2.0 was the software used in this research to develop the neural network model. It requires an IBM compatible 386, 486, or Pentium processor. It can be run on Windows 3.1 or greater and requires a minimum of 4 MB of RAM. The program requires 4 MB of disk space, a mouse, and a VGA or SGVA monitor [9].

Creating data file for neural connection

The Neural Connection 2.0 program will need around 73% (34) of the input data(facts) for training, which are the calculated minimum needed number of facts for the program to train properly, which leaves 27% (13) of the facts for justification (program self testing).

1. Start N-Connection icon in the Neural Connection 2.0 folder.
2. Drag the following three small icons from the right hand side icon toolbar on the program main screen, and distribute them on the program main screen in the same sequence of order.
3. Right click on the Input 1 icon and choose connect then direct the arrow to the MLP 1 icon, that will connect between these two icons.
4. Right click on the MLP 1 icon and choose connect then direct the arrow to the Text 1 icon, that will connect between these two icons (Fig. 13).
5. The input data file that will be used, must have been already generated and stored on the partition (C) in the following sequence of order:The file that contains the problem data must be generated as an Excel-Sheet under the following rules:
   - Symbolic, or categorical fields must be converted to numeric formats (Coding the Data) before being applied to a neural model, since different values of symbolic variables usually have no relationship to each other. (Neural Connection 2.0-Users Manual, 1997) [11].

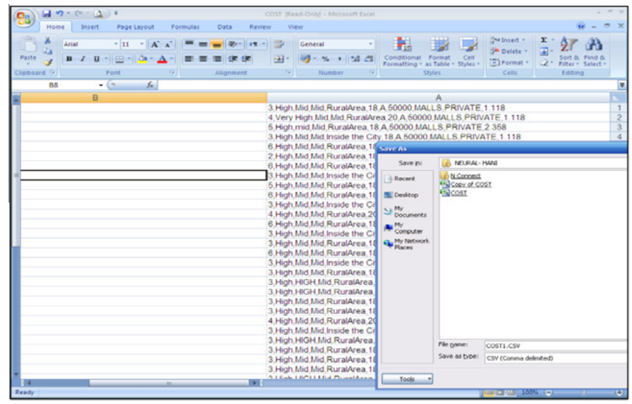


Fig. 14 The original generated data Excel Sheet.

   - The problem of narrow data that can occur during the design of a neural network model, once the training data have been alienated from the test data.
   - Each entire row represents a single problem and the columns are problem variables, while the last column represents the target output variable for each problem.
   - The data file must be stored in a MicroSoft Excel 5.0/95 format on partition (C), under any file name. (Neural Connection 2.0-Users Manual, 1997) (Fig. 14).

6. Open the view from the (Input 1) icon on the program main screen.
7. A novel command screen opens, choose open new folder from the menu bar then highlight flat-file check box and press configure then choose the Excel file name and format that was previously stored on the partition (C) (Fig. 15).
8. Then from the menu bar choose (Data) then (Allocation), configure the amount for each of training, validation, and test file records that the program will use to solve this problem (Fig. 16).
9. Afterwards, from the menu bar, choose file then save as and type the name you will save this Model under in partition C, folder Neural Network the format is set by the program (Fig. 17).
10. Right click on the (MLP 1) icon on the program main screen and choose (Dialog), then choose the number of hidden layers and the number of hidden nodes (neurons)

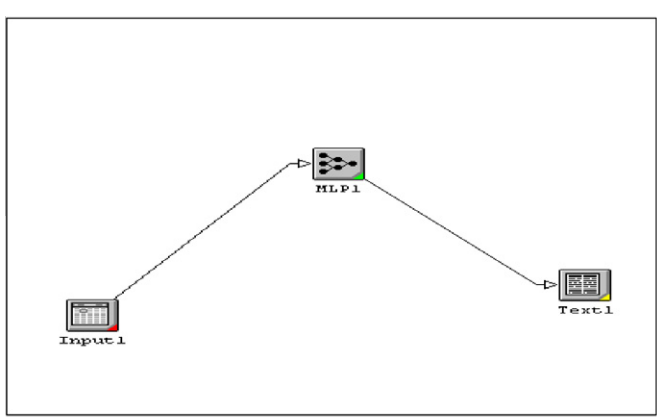


Fig. 13 The main program screen.

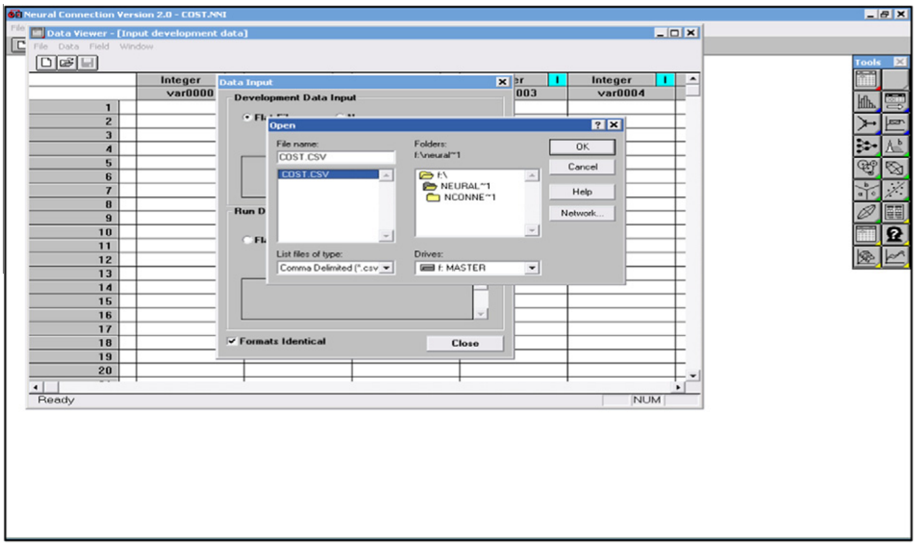


Fig. 15 The Program Data Input Tool.

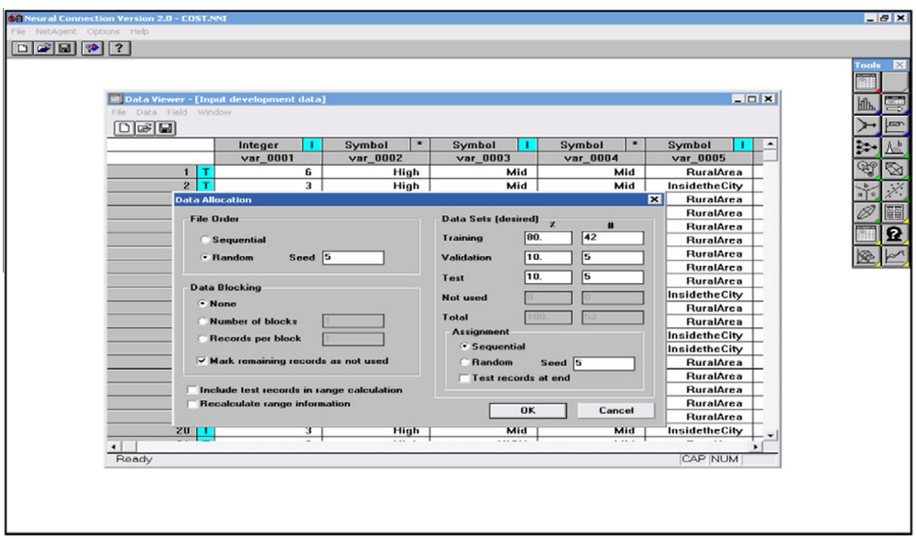


Fig. 16 The Program Desired Data Sets Sizes.

in each layer, and the function type that the program will use (Fig. 18).

11. Right click on (Text 1) icon on the main screen and choose (Dialog), then mark the chick box next to the following: Data Set (Test); Column Diameter (Spaces); and Destination: Output to screen; and Output to File (Fig. 19).
12. Run the program by selecting the option (Run) from the icon titled (Text 1) (Fig. 20).
13. Document the output (RMS, Absolute difference, Absolute difference %), for this first trial, then carry out the trial in the same succession but with different number of hidden layers, number of hidden nodes (neurons) and transfer function for each layer (Fig. 21).
14. Performing this sequence of steps on the program, choose the model (number of hidden layers, number of hidden nodes and transfer function) which escorts to the minimum output (RMS and Absolute difference).

Identify the best structure of the model

The characteristics of the model's learning rule, training and testing tolerance is situated mechanically by the program and the variables that the program necessitates their setting during the design stage are the number of hidden layers (N-Connection 2.0 – software accepts up to two hidden layers), number of hidden nodes in each layer and the type of transfer function (sigmoid or tangent) that the program will use in the following alteration sequences:

A. One hidden layer with Sigmoid transfer function.
B. One hidden layer with Tangent transfer function.
C. Two hidden layers with Sigmoid transfer function for both hidden layers.
D. Two hidden layers with Tangent transfer function for both hidden layers.

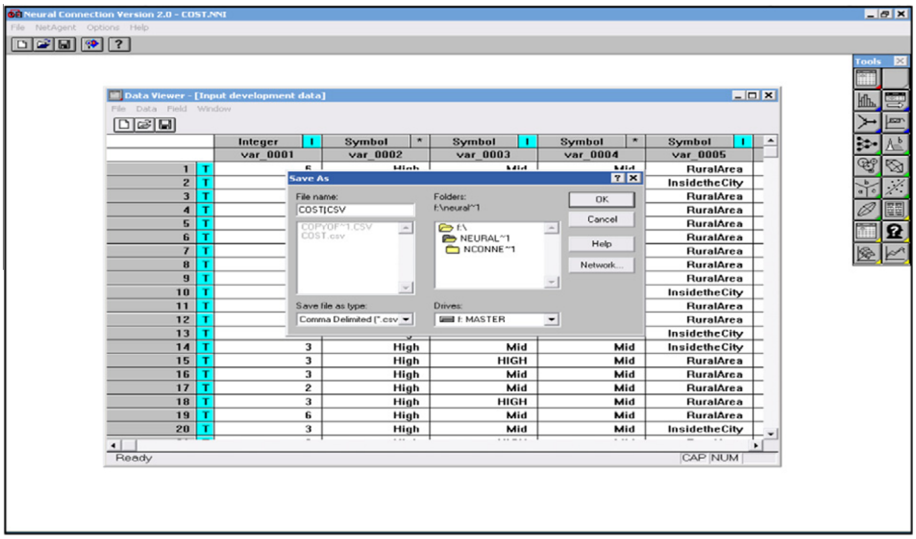


Fig. 17 Saving the Program Data File.

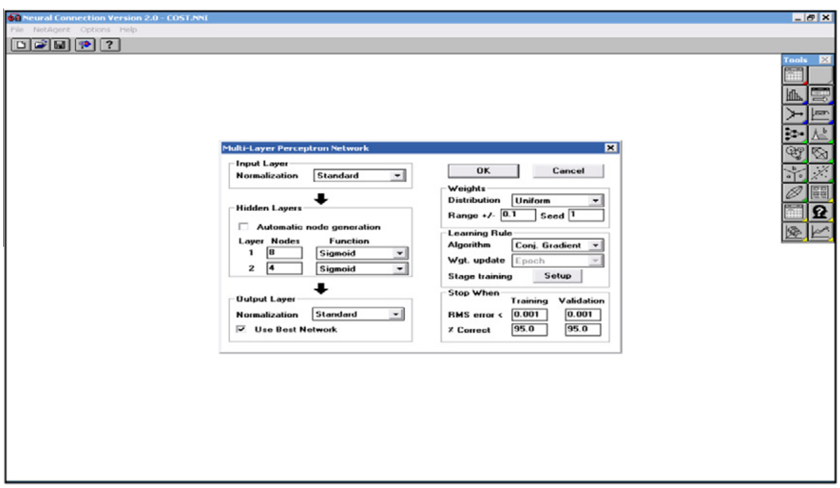


Fig. 18 Designing the Model Parameters.

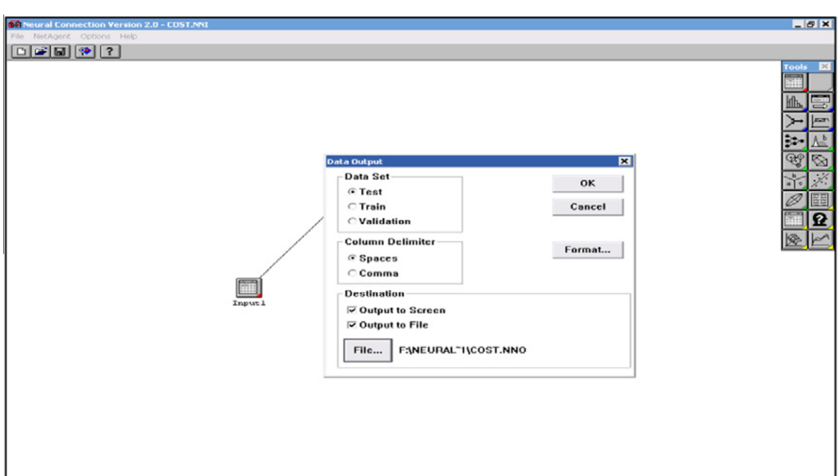


Fig. 19 Choosing the Data Output Locations.

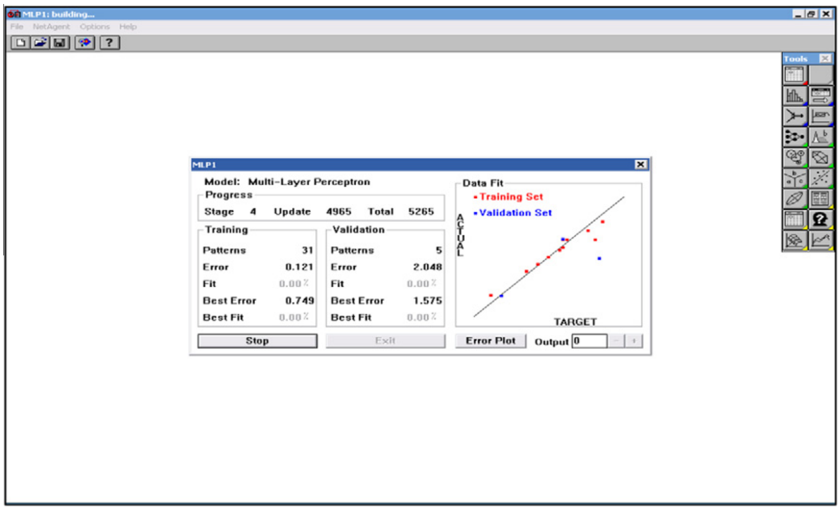
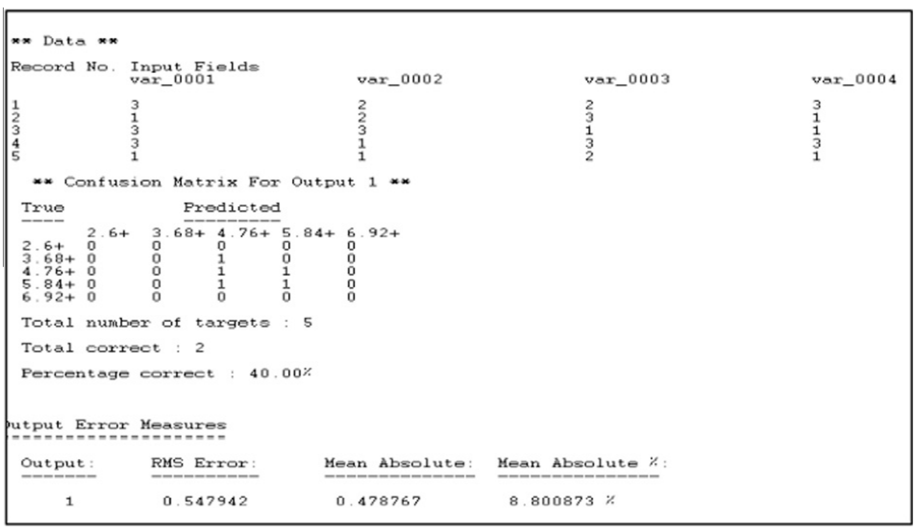


Fig. 20 Running the Program.



** Data **

Record No. Input Fields

Record No.	var_0001	var_0002	var_0003	var_0004
1	3	2	2	3
2	1	2	3	1
3	3	3	1	1
4	3	1	3	3
5	1	1	2	1

** Confusion Matrix For Output 1 **

True	Predicted 2.6+	3.68+	4.76+	5.84+	6.92+
2.6+	0	0	0	0	0
3.68+	0	0	1	0	0
4.76+	0	0	1	1	0
5.84+	0	0	1	1	0
6.92+	0	0	0	0	0

Total number of targets : 5

Total correct : 2

Percentage correct : 40.00%

utput Error Measures

Output:	RMS Error:	Mean Absolute:	Mean Absolute %:
1	0.547942	0.478767	8.800873 %

Fig. 21 Model's Output Sheet.

Table 4 Model trials from 16 to 30 has a Tangent transfer function.

Model No.	Input nodes	Output node	No. of hidden layers	No. of hidden nodes		Absolute variance (%)	RMS
				In 1st layer	In 2nd layer		
16	10	1	1	1	0	23.178	0.668
17	10	1	1	2	0	18.715	0.478
18	10	1	1	3	0	20.389	0.376
19	10	1	1	4	0	22.232	0.462
20	10	1	1	5	0	17.985	0.469
21	10	1	1	6	0	18.428	0.379
22	10	1	1	7	0	18.481	0.424
23	10	1	1	8	0	13.191	0.259
24	10	1	1	9	0	16.065	0.318
25	10	1	1	10	0	16.922	0.412
26	10	1	1	11	0	18.865	0.411
27	10	1	1	12	0	18.308	0.389
28	10	1	1	13	0	16.963	0.329
29	10	1	1	14	0	19.245	0.421
30	10	1	1	15	0	15.012	0.278

Table 5 Characteristics of the best model.

Model	No. of input nodes	No. of hidden layers	No. of hidden nodes		LR	TF	No. of output nodes	RMS
			In 1st Layer	In 2nd layer				
23	10	2	8	0	Back propagation	Tangent function	1	0.259

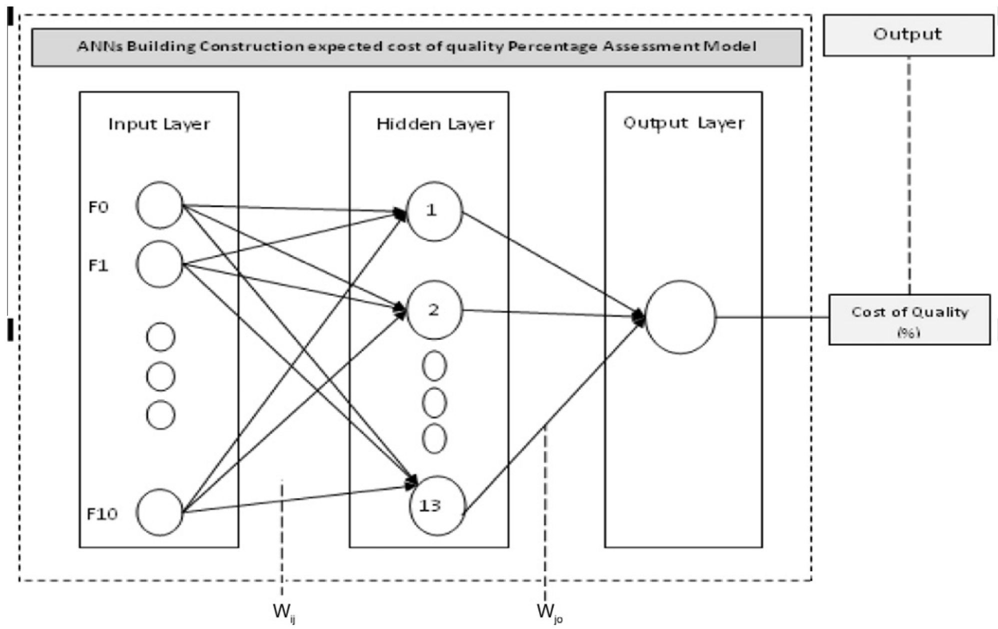


Fig. 22 Structure of the Best model.

Table 6 Actual and Predicted Percentage of Cost of Quality for the Test Sample.

Project no.	Actual real life percentage	Network output (predicted percentage)	Absolute difference (%)	Comments
1	2.243	2.372	(+) 5.44	Correct
2	1.0345	1.079	(+) 4.12	Correct
3	1.998	1.996	(−) 0.10	Correct
4	0.458	0.438	(−) 4.57	Correct
5	1.351	0.793	(−) 70.37	Wrong

E. Two hidden layers with Sigmoid transfer function for both hidden layers.
F. Two hidden layers with Tangent transfer function for both hidden layers.

One hundred and six different trial models were tested to identify the best structure of the proposed model. A sample of these trials was shown in Table 4. The best structure of the model is defined as the model that yields the minimum RMS errors.

The recommend model for this complicated prediction problem is the one with the least RMS value from all the (106) trials and error process. (Neural Connection 2.0-Users Manual Guide, 1997).

As a result, from training and validation phases the characteristics of the satisfactory neural network model that was obtained through the trial and error process are presented in Tables 4 and 5, respectively. Also Fig. 22 presents the structure of the best model. The best structure of the model is the structure that yields the minimum value for the RMS error. A carful inspection to Table 4 clearly shows that trial number 23 represent the best structure of the proposed model. Table 5 summarized the characteristics of this model that can be shown as:

- Trial model number 23 with the following design strictures:

Testing the validity of the model

To assess the prognostic recital of the network, the five projects that were previously arbitrarily chosen and reticent for testing from the total collected projects are introduced to the best model. Percentage of the model will forecast the expected cost of quality. The calculated percentage will be evaluated to the real life projects percentage (stored outside the program) and the disparity between them will be premeditated if it is equal or under the value of the designed model's Absolute Difference. Then it is considered to be a correct calculation. If it exceeds the value of the designed model's Absolute Difference then it is considered to be an incorrect prediction attempt.

(Table 6) presents the actual and predicted percentages for the test sample. The model correctly predicted four (4) of the five (5) testing projects samples (80% of the test sample). The wrongly predicted project had a negative difference between the value of predicted percentage from the model output and the real life percentage of the same project which is equal to (−)70.37%. This means that the predicted outcome is less than the actual real life for that project. The test sample outcome correct percentage is considered to be eighty percent (80%) which is still very good and the model can be accepted.

Conclusion

The survey results illustrated that cost of quality are greatly affected by many aspects. Among these aspects come project duration, planned cost of quality, supervision team experience, project size project location. All of these factors make the detailed estimation of such cost of quality a more difficult task. Hence, it is expected that an ANN's model would be a suitable tool for assessment of cost of quality in construction projects in Egypt.

The following conclusions may be deduced from this study:

- All the way through the literature review, potential factors that control the percentage of cost of quality for building construction projects were recognized. Thirteen factors were identified.
- The analysis of the composed data gathered from a questionnaire survey among the Egyptian construction experts illustrated that project's duration, planned cost of quality, supervision team experience, project size, project location, Awareness of quality for the project team, class of contractor, client type, labor skills and project type are the top 10 factors affecting the percentage of cost of quality for building construction projects in Egypt.
- A satisfactory neural network model was obtained through one hundred and six (106) experiments for predicting the percentage of cost of quality for building construction projects in Egypt for the future projects. This model consists of one input layer with 10 neurons (nodes), one hidden layer having eight hidden nodes with a tangent transfer function and one output layer. The learning rate of this model is set automatically by the N-Connection (version 2.0) while the training and testing tolerance are set to 0.1.
- The results of testing for the best model indicated a testing root mean square error (RMS) value of 0.259.
- Testing the validity of the proposed model was carried out on five (5) facts that were still unseen by the network. The results of the testing indicated an accuracy of (80%). As the model wrongly predicted the percentage of cost of quality for only one project (20%) of the testing sample.

References

[1] H. Abdul-Rahman, The cost of non-conformance during a highway project, Construction Management and Economics 13 (1) (1995) 23–32.
[2] H. Abdul-Rahman et al., Capturing the cost of non-conformance on construction sites, International Journal of Quality & Reliability Management 13 (1) (1996) 48–60.
[3] H. Abdul-Rahman, Some observations on the issues of quality cost in construction, International Journal of Quality & Reliability Management 14 (5) (1997) 464–481.
[4] Philip B. Crosby, Quality Assurance, McGraw Hill Custom Publishing, New York, 1979.
[5] K. Davis et al., Measuring design and construction quality costs, Journal of Construction Engineering and Management 115 (3) (1989) 385–400.
[6] Deming, W. Edwards, Out of the Crisis Quality, Productivity and Competitive Position, Massachusetts Institute of Technology, Cambridge, 2000.
[7] Dennise B., Cost of Quality, Quality Planning and the Bottom Line. Vietnamese Testing Board Site (2000) 1–6.
[8] I. Dikmen et al., Strategic use of quality function deployment (QFD) in construction industry, Building and Environment Journal 40 (2) (2005) 245–255.
[9] A.V. Feigenbaum, Total quality control, Harvard Business Review 34 (6) (1956) 93–101.
[10] Y. Firuzan et al., Assessing contractor quality performance, Construction Management and Economics 20 (3) (2002) 211–223.
[11] Guidelines of N-Connection Professional version 2.0 (1997).
[12] Heng. Li et al., Quantifying the Causes and Costs of Rework in, Construction Management and Economics 18 (40) (2000) 479–490.
[13] Z. Irani et al., A project management quality cost information system for the construction industry, Information and Management 40 (7) (2003) 649–661.
[14] Joseph M. Juran, Quality Control Handbook, McGraw Hill, New York, NY, 1988, ISBN 978-0-07-033176-1.
[15] P. Love, Determining the causal structure of rework influences in construction, Construction Management and Economics 7 (4) (1999) 505–517.
[16] S.P. Low et al., A construction quality costs quantifying system for the building industry, International Journal of Quality & Reliability Management 15 (3) (1998) 329–349.
[17] B. Mwamila et al., Semi-prefabrication concrete techniques in developing countries, Building Research and Information Journal 27 (3) (1999) 165–182.
[18] G. Ofori et al., Impact of ISO 14000 on construction enterprises in Singapore, Construction Management and Economics 18 (8) (2000) 935–947.
[19] L.J. Porter, P. Rayner, Quality costing for total quality management, International Journal of Production Economics 27 (1) (1992) 69–81.
[20] Y. Rosenfeld, Cost of quality versus cost of non-quality in construction, Construction Management and Economics 27 (2) (2009) 107–117.
[21] A. Samadony et al., The cost of quality in the Egyptian construction industry, HBRC Journal 2 (3) (2006).
[22] G. Tesfai, New approach to quality control in construction, Annual Quality Congress 41 (1987) 580–586.
[23] Vernon et al., The role of managerial actions in the cost time and quality performance of high-rise commercial building projects, Construction Management and Economics 3 (1) (1985) 59–87.