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Automated Prediction of Construction Project Efficiency Rating Using Multi-Layered Neural Network with Sigmoid Function

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Abstract— **Time overrun is defined as excess or extra time required to complete the agreed scope of works following what is intended during project planning, or at the beginning of the project. Time overrun is relative in cost overrun, therefore reducing either or both of them is the main driver of any project and construction managers. The research aims to conduct a study regarding the utilization of automated prediction of construction project efficiency to understand the relationship amongst change order, time overrun and project efficiency and predict potential mitigating measures and used as decision-making supplement once factors were observed during project execution. The data collected were analyzed using a multi-layered neural network with sigmoid function using internal parameters of Levenberg-Margquadt for the Training Algorithm, hyperbolic tangent sigmoid (tansig) transfer function and 12 hidden neurons. The questionnaire tool was analyzed on its reliability using the coefficient of internal consistency (Cronbach α) and resulted in an excellent consistency rating. Results indicated that among factors of a change order, the client has the most frequency that affects change order followed by the consultant and finally by the contractor. Also, time overrun was mostly affected by excusable & non-compensable factors which imply of factors that are unforeseeable by all parties, however not compensable as provided in contract clauses. Then followed by the factors of non-excusable & non-compensable and finally by excusable & compensable. Accordingly, between change order and time overrun, project efficiency was mostly affected by time overrun factors. The study generated an automated prediction model using a multi-layered neural network and resulted in an MSE and MAPE of 0.042542 and 6.80846% respectively, which indicates a good model in predicting a construction project efficiency rating. The study concluded by recommending that the tool made in this study be provided with an automated to help the beneficiary in the construction field.**

Keywords*— *Change Order, Time overrun, Neural Network, Construction Project, Project Efficiency

I. INTRODUCTION

Construction has become the most competitive and significant business sector in the industry since many other industries are connected with it. It essentially contributes to becoming an important market by obtaining products and materials to other business sectors. The construction industry contributes 3.9% in the GDP of the Philippines.

The construction industry is varying through the scope, density, and a pressing requirement. The scope itself has a wide range from commercial, industrial, residential building, and many others. Therefore, this industry demands more importance in managing and control the procedure of goes in it.

Many countries have a history of completing projects with significant time and cost overrun. And also, many researchers attempted to divert the trend or even lessen the impact. Indeed, according to Chan and Kumaraswamy (1996), the trend has been significantly rising that construction managers are resorting with action plans in mitigating the time and cost overrun, and to produce timely and efficient completion of the project.

A change or variation order is any significant variance in the agreed condition assigned by both parties in the contract (Arain&Pheng, 2005b). Correspondingly, Charoenngam et al. (2003) recognize that proper change order management resulted in avoiding disruption during project and construction execution, however, it is also recognized that it is hard to achieve. Many disputes between owner and contractor have formed due to improper management of change orders (Charoenngam et al., 2003). Disruption to work is one of the main factors in how change orders affected project delivery, which resulted in additional resources (Chan & Yeong, 1995). Accordingly, a study conducted in Kuwait by Koushki, Al Rashid & Kartam (2003) revealed that change orders released or experienced have resulted in cost and time overrun during the construction phase. They even discovered that the project encountered a 58% increase in its resources as compared to the project that has no experience in change orders. Though projects encounter differently change orders during project execution, particular ones experienced extensively among others. In standard practice, only 10% of budgeted funds are normal in the industry. However, an additional 7% on its project cost and another 30% addition in project duration are experienced in the construction project according to the study conducted by Charoenngam et al. (2003). Undeniably, the more the occurrence of the change order, the higher possibility of the unnecessary cost could be added thus impacted the total cost of construction project.

II. STATEMENT OF THE PROBLEM

The main objective of this research is to develop automated computed based software for predicting the construction project efficiency rating using a multi-layered neural network with sigmoid function.

Specifically, this study will address the following:

1. Test for the reliability of the evaluation tool for assessing construction project efficiency thru the use of the coefficient of internal consistency (Cronbach α)
2. Determine the descriptive statistics of the data set collection for the construction project efficiency rating.
3. Develop a multi-layered neural network with a sigmoid function for the construction project efficiency rating as well as its components and subsets.
4. Create an importance ranking schematic diagram using the relative importance of parameters of developed models using weights generated from the simulation of the network through a connection weight algorithm.
5. Perform sensitivity analysis to determine the influence of change order and time overrun to the construction project efficiency rating.

III. METHODOLOGY AND CONCEPTUAL FRAMEWORK

This research consisted of four phases; the first one was the development of an idea. The study started with a comprehensive review of relevant literature review to acquire basic knowledge about time overruns, change order, and efficiency of construction projects. Related books and journals were also reviewed.

The second phase of this study was to recognize the most inherent delays, change order, and efficiency of construction projects. A survey questionnaire was developed during this phase using the list of factors identified during the literature review on time overrun and change orders. The third phase focused on data gathering and interpretation. The distribution of questionnaires was the highlight of this phase. The data collected were analyzed using descriptive statistics and a multi-layered neural network with a sigmoid function.

The fourth and last phase of the research will focus on developing the automated prediction of the construction project efficiency rating.

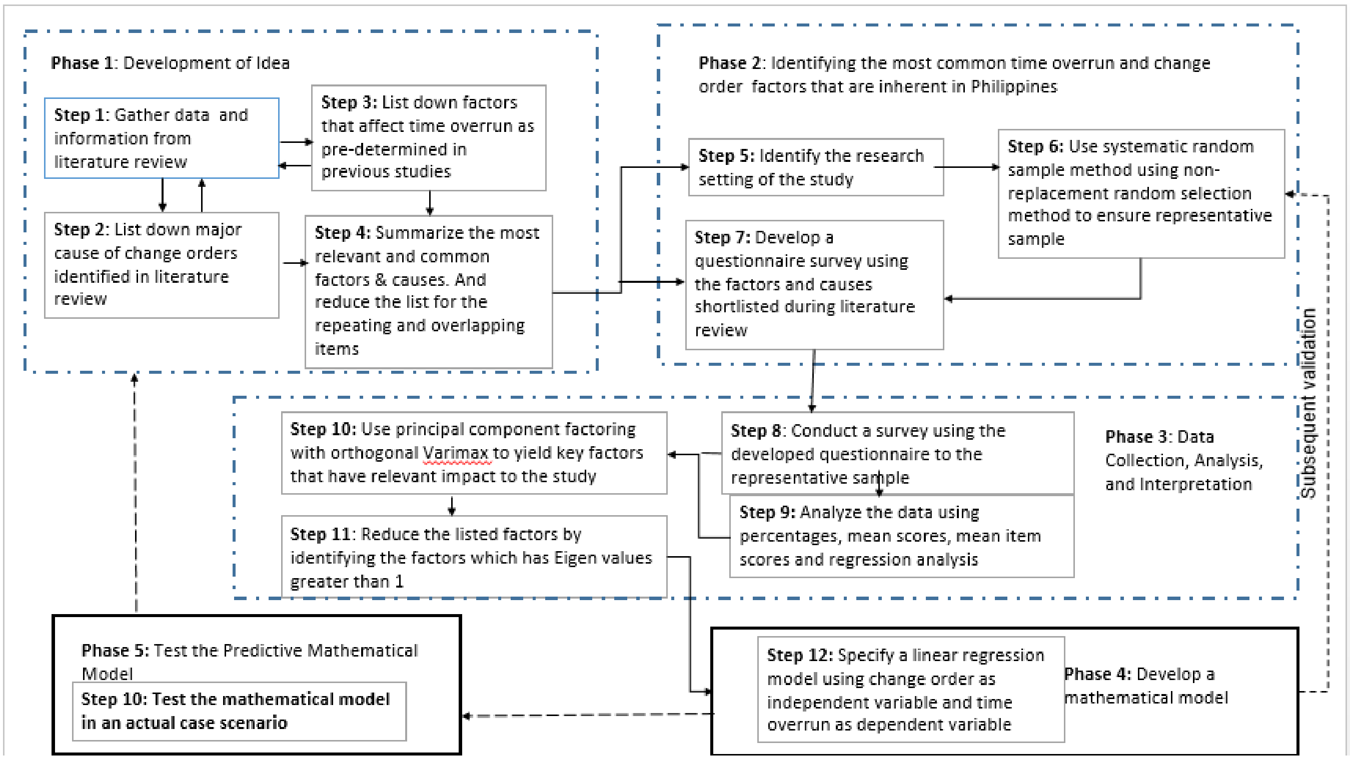


Fig 1

Conceptual Framework

This research used quantitative and qualitative research. Qualitative research includes literature review and case study, meanwhile quantitative research performed by survey questionnaires.

Phase 1: Development of Idea

In the first part to do in research, relevant related literature was reviewed. 30 journals, 18 published and unpublished studies, and 5 books were reviewed. However, only 9 related literature has a significant relation to the study. At the end of the phase, the researcher expected to finalize a list of time overrun and change order which have the most incurring, common, and important factors during the literature review.

Many factors causing construction time overrun which was identified in different studies. A wide array of research was available and utilized inside and outside of the country.

Phase 2: Identifying the most common time overrun and change order factors that are inherent in the Philippines

The second phase of the research identified the most inherent factors and causes of time overrun, change order, and project efficiency. Survey questionnaires developed in this phase using the list of factors identified during the literature review of time overruns and change orders.

Phase 3: Data Collection, Analysis, and Interpretation

Data collection is a vital part of a research study. If done appropriately, it enhances the value of the study. However, it has its advantages and disadvantages depending on the process the researcher will undertake Sekaran (1992).

Data collection very much depends on what data are required in the study or the research setting or scope of research. The researcher may on which data collection like the interview, questionnaires, case study, responses, and others; he may use (Sekaran 1992, Robson 1993).

Phase 4: Develop a Prediction Construction Project Efficiency Rating using the multi-layered neural network

Model equations are utilized to define the pattern of an event and condition, it also simulates certain condition in the real world. Previous studies have been using mathematical models in their research since the 1900s. However, it is ideal that the model should be kept as simple as possible. (Revelle et al, 1993), that is why developing a program to automate the generation of the rating was pushed during the development of research.

To identify the reliability and consistency of the survey tool used during the research, the Pearson's Correlation Coefficient (R_{ALL}), Mean Squared Error (MSE) and Mean Absolute Percentage Error (MAPE) was used. The equations for Pearson's Correlation Coefficient (R_{ALL}), Mean Squared Error (MSE), and Mean Absolute Percentage Error (MAPE) are presented as follows:

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(x_i - p_i)^2 \qquad \text{(Eq. 1)}$$

$$R = \frac{\sum_{i=1}^{n}(x_i - \bar{x}_i)(p_i - \bar{p}_i)}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x}_i)\sum_{i=1}^{n}(p_i - \bar{p}_i)^2}} \qquad \text{(Eq. 2)}$$

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{|\hat{y}_i - y_i|}{y_i} x\, 100 \qquad \text{(Eq. 3)}$$

Phase 5: Develop an Automated Prediction Project Efficiency Rating

The system is designed and coded in Microsoft Visual Basic 6.0 application to integrate the automation of prediction of the construction project efficiency rating. It also integrates the generated equation and analysis of the change order, time overrun and project efficiency ratings.

IV. RESULTS

In light of the development of automated prediction of construction's project efficiency, reliability and internal consistency of the questionnaire tool for construction project efficiency rating as well as its components such as change order and time overrun was determined. Table 1 presents the internal consistency checking results using Cronbach Alpha (α) values.

Table 1
Cronbach Alpha (α) for the Measure of Internal Consistency

No.	**Model**	**Cronbach Alpha (α)**
1	Change Order	0.946
2	Time Overrun	0.852
3	Construction Project Efficiency	0.935

The questionnaire tool for the change order rating model has a total number of items of 40 that produces a sum of item variances of 49.364 and variance of total scores of 637.243. These values contributed to a Cronbach α of 0.946 which implies excellent internal reliability and consistency of the tool. For the time overrun rating model, it has a total item of 19 with the sum of variances and variance of total scores of 22.855 and 118.679, respectively. A Cronbach α with the value of 0.852 which also implies a good internal consistency of the questionnaire tool. Lastly, for the construction project efficiency, there are 27 items in the questionnaire tool that produced the sum of item variances and variance of total scores of 31.249 and 312.536, respectively. Its Cronbach α is 0.935 that signifies excellent internal consistency of the tool.

Table 2
Descriptive Statistics of the Change Order Component Subsets

		C001	**C002**	**C003**	**C004**	**C005**	**C006**	**C007**
N	Valid	51	51	51	51	51	51	51
	Missing	0	0	0	0	0	0	0
Mean		3.294	3.49	2. 9216	3.7 843	3.647	3.471	3.196
Median		3	4	3	4	3	4	3
Mode		3	4	3	4	3	4	3
Std. Deviation		1.137	1.027	1.146	0.966	0.934	0.946	0.98
Variance		1.292	1.055	1.314	0.933	0.873	0.894	0.961
Skewness		-0.273	- . 549	0.242	-0.238	. 165	-0.355	-0.279
Std. Error of Skewness		0.333	0.333	0.333	0.333	0.333	0.333	0.333
Kurtosis		- . 462	-. 148	- . 562	-0.933	-1.008	- .22 0	0.054
Std. Error of Kurtosis		. 656	0.656	. 656	. 656	0.656	. 656	. 656
Range		4.00	4.00	4.00	3.00	3.00	4.00	4.00
Minimum		1.00	1.00	1.00	2.00	2.00	1.00	1.00
Maximum		5.00	5.00	5.00	5.00	5.00	5.00	5.00
Percentiles	25	3.000	3.000	2.000	3.000	3.000	3.000	3.000
	50	3.000	4.000	3.000	4.000	3.000	4.000	3.000
	75	4.000	4.000	4.000	5.000	4.000	4.000	4.000
		C008	**C009**	**C010**	**C011**	**C012**	**C013**	
N	Valid	51	51	51	51	51	51	
	Missing	0	0	0	0	0	0	
Mean		3.745	3.177	3.373	2.961	2.824	3.1569	
Median		4	3	4	3	3	3	
Mode		4	3	4	2	3	4 .00	
Std. Deviation		0.891	1.014	1.199	1.248	1.072	1.04638	
Variance		. 794	1.028	1.438	1.558	1.148	1.095	
Skewness		-0.348	0.23	-0.266	. 013	-0.039	-0.217	
Std. Error of Skewness		0.333	0.333	0.333	0.333	0.333	0.333	
Kurtosis		-0.494	-0.646	-0.933	- 1. 021	-. 34 0	- .56 7	
Std. Error of Kurtosis		. 656	. 656	. 656	. 656	. 656	. 656	
Range		3.00	4.00	4.00	4.00	4.00	4.00	
Minimum		2.00	1.00	1.00	1.00	1.00	1.00	
Maximum		5.00	5.00	5.00	5.00	5.00	5.00	
Percentiles	25	3.000	2.000	2.000	2.000	2.000	2.000	
	50	4.000	3.000	4.000	3.000	3.000	3.000	
	75	4.000	4.000	4.000	4.000	3.000	4.000	

a. Multiple modes exist. The smallest value is shown

Relatively, to understand the descriptive statistics of factors and causes of project efficiency, the IBM SPSS results present the per item statistics of the subsets of the project efficiency rating.

The construction project efficiency has two components: change order (CO) and time overrun (TO). For the change order component, the subsets are as follows: speculation on desired profitability (CO01), value engineering (CO02), technology change (CO03), inadequate working drawing details (CO04), inadequate shop drawing details (CO05), lack of required data

(CO06), ambiguous design details (CO07), design discrepancies (CO08), non – compliant design with owner's requirement (CO09), lack of communication (CO10), financial problems (CO11), inadequate project objectives (CO12) and impediment in the prompt decision-making process (CO13).

The descriptive statistics of the change order subsets were presented in table 2. Only CO05, CO09, and CO11 have positive skewness. Positive skewness indicates that the tail on the right side of the distribution is longer. Considering the kurtosis of the subsets, all subsets have a negative kurtosis except CO07. Negative kurtosis indicates that the distribution is flatter than a normal curve with the same mean and standard deviation.

Table 3

Descriptive Statistics of the Time Overrun Component Subsets

	T001	**T002**	**T003**	**T004**	**T005**	**T006**	**T007**
N Valid	51	51	51	51	51	51	51
Missing	0	0	0	0	0	0	0
Mean	2. 9020	3. 9216	3 .4314	4.098	3.2549	3.098	3.2353
Median	3	4	3	4	3	3	3
Mode	3	4	3	4	4	3.0oa	3
Std. Deviation	1.2 20 7 4	.8681 7	.8 77 6 1	.830 78	l. 163SO	1.11812	1.0879
Variance	1.49	0.754	0.77	0.69	1.354	1.25	1.184
Skewness	-0.081	-0.417	-0.244	-0.624	-0.127	-0.111	-0.007
Std. Error of Skewness	0.333	.33 3	0.333	0.333	0.333	.33 3	0.333
Kurtosis	-. 7 93	-0.47	0.192	-0.171	-0.898	-0.732	-0.764
Std. Error of Kurtosis	0.656	0.656	0.656	0.656	0.656	0.656	0.656
Range	4.00	3.00	4.00	3.00	4.00	4.00	4.00
Minimum	1.00	2.00	1.00	2.00	1.00	1.00	1.00
Maximum	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Percentile s 25	2.00	3.00	3.00	4.00	2.00	2.00	2.00
50	3.000	4.000	3.000	4.000	3.000	3.000	3.000
75	4.000	5.000	4.000	5.000	4.000	4.000	4.000
	T008	**T009**	**T010**	**T011**	**T012**	**T013**	**T014**
N Valid	51	51	51	51	51	51	51
Missing	0	0	0	0	0	0	0
Mean	3.0588	3.666 7	3.1961	2.7843	2	2. 549 0	3.098
Median	3	4	3	3	1	2	3
Mode	2	4	3	3	1	2	3
Std. Deviation	1.2233	1.2111	1.13172	1.0828	1.21655	1.26986	1.2207
Variance	1.496	1.467	1.281	1.173	1.48	1.613	1.49
Skewness	0.02	-0.654	0.114	0.057	0.902	0.618	0.012
Std. Error of Skewness	0.333	0.333	0.333	0.333	0.333	0.333	0.333
Kurtosis	-1.003	-0.514	-.9 22	-0.441	-.32 7	-0.551	-0.891
Std. Error of Kurtosis	0.656	0.656	0.656	0.656	0.656	0.656	0.656
Range	4.00	4. 00	4.00	4.00	4.00	4.00	4.00
Minimum	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maximum	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Percentile s 25	2.00	3.00	2.00	2.00	1.00	2.00	2.00
50	3.000	4.000	3.000	3.000	1.000	2.000	3.000
75	4.000	5.000	4.000	3.000	3.000	3.000	4.000

For the time overrun component, the subsets are as follows: inadequate fund for the project (TO01), design changes during project execution (TO02), delay in response to decision-taking (TO03), variations (TO04), unexpected subsoil/ground condition (TO05), delay in inspection and testing of completed work (TO06), obtaining building permit and approvals (TO07), inadequate tools and equipment (TO08), delay in delivery of materials (TO09), subcontractor incompetency (TO10), unclear or inadequate instructions to operators (TO11), a labor dispute in form of strike or lockout (TO12), community issues (TO13) and temporary work stoppages due to unfavorable condition (TO14).

The descriptive statistics of the time overrun subsets were presented in table 3. Subsets TO08, TO10, TO11, TO12, TO13, and TO14 has positive skewness. Positive skewness indicates that the tail on the right side of the distribution is longer. Considering the kurtosis of the subsets, all subsets have a negative kurtosis except TO03. Negative kurtosis indicates that the distribution is flatter than a normal curve with the same mean and standard deviation.

Since the analysis of descriptive statistics showed significant relevance of factors of change order and time overrun to project efficiency, we are now to proceed in a simulation of the multi-layered neural network model for all the models developed in this study using the data gathered during the survey.

The internal parameters of the model are as follows: Levenberg – Marquardt for the training algorithm, hyperbolic tangent sigmoid (tansig) transfer function, and 12 number of hidden neurons (Hegazy and Moselhi, 1995) as presented in table 4.

Table 4
Neural Network Simulation Results

Model	Training Algorithm	TF	HN	Training	Validation	Testing	All	MSE	MAPE
Change Order	Levenberg –Marquardt	Tansig	7	0.99934	0.99745	0.99034	0.99742	0.002479	0.77825
Time Overrun	Levenberg –Marquardt	Tansig	7	0.98964	0.98772	0.96106	0.98440	0.011932	2.50858
Construction Project Efficiency	Levenberg –Marquardt	Tansig	5	0.95011	0.97877	0.97071	0.95627	0.042542	6.80846

**TF – Transfer Function, HN – Hidden Neurons*

Equations for computing the Mean Squared Error, Pearson's Correlation Coefficient, and Mean Absolute Percentage Error are as presented below:

Change Order

The change order rating model has a final topology of 3-7-1 (Input Neurons – Hidden Neurons – Output Neurons). It has a very high Pearson's Correlation Coefficient (R) value of 0.99742 and extremely low MSE and MAPE of 0.002479 and 0.77825%, respectively.

Time Overrun

The time overrun model has a final topology of 3-7-1 (Input Neurons – Hidden Neurons – Output Neurons). It has a very high Pearson's Correlation Coefficient (R) value of 0.98440 and extremely low MSE and MAPE of 0.011932 and 2.50858%, respectively.

Construction Project Efficiency

The construction project efficiency rating model has a final topology of 2-5-1 (Input Neurons – Hidden Neurons – Output Neurons). It has a very high Pearson's Correlation Coefficient (R) value of 0.95627 and extremely low MSE and MAPE of 0.042542 and 6.80846%, respectively. The correlation plots and the performance plot of the construction project efficiency model were displayed in Figures 2 and 3.

Fig 3
Correlation Plots of the Construction Project Efficiency Rating Model

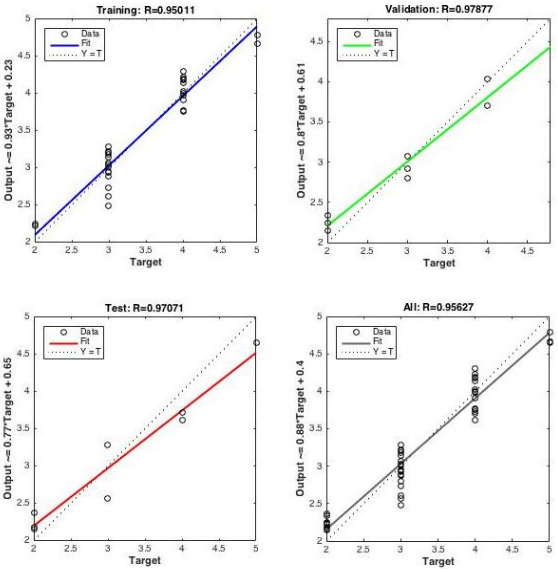
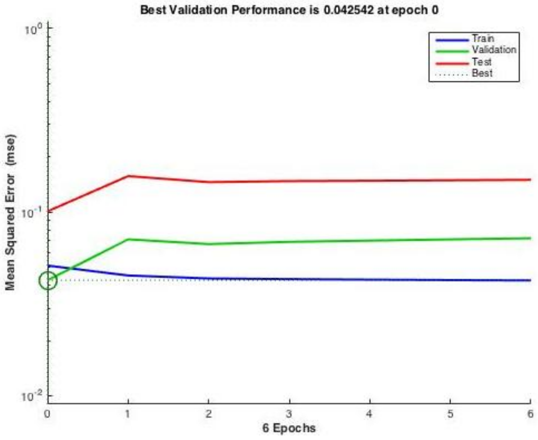


Fig 4
Performance Plots of the Construction Project Efficiency Rating Model



The design and detailed architecture of the governing client component rating model was presented in Figures 5 and 6.

Fig 5
Overview of the Design of the Governing Construction Project Efficiency Rating Model

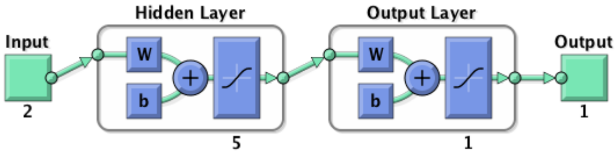
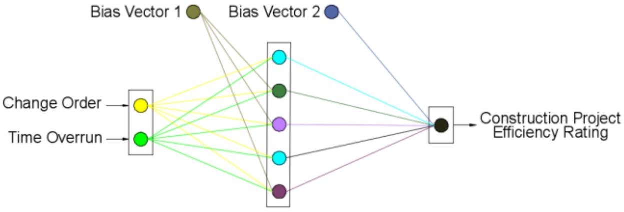


Fig 6
Detailed Architecture of the Governing Construction Project Efficiency Rating Model



Meanwhile, to understand the order of importance of each factor, we used the connection weights algorithm to determine the corresponding ranking of each factor. The analysis results present that the importance ranking for the change order component factor rating is CONSULTANT<CONTRACTOR<CLIENT. The client is the most important factor in the contractor component rating while the consultant is the least important parameter based on the analysis.

Table 4
Product Weights of the Change Order Component Rating

	CLIENT	**CONSULTANT**	**CONTRACTOR**
H1	-0.038	-0.033	-0.001
H2	-0.268	0.196	-0.515
H3	-0.008	0.039	0.041
H4	32.931	8.787	18.485
H5	16.214	12.145	16.407
H6	-1.350	-0.949	-0.894
H7	0.485	0.389	-0.385
R.I	**47.174%**	**20.234%**	**32.592%**

The analysis results present that the importance ranking for the time overrun component factor rating is Excusable and Compensable<Not Excusable and Non – Compensable<Excusable and Non - Compensable. Excusable and Non – Compensable is the most important factor in the time overrun component rating while excusable and compensable is the least important parameter based on the analysis.

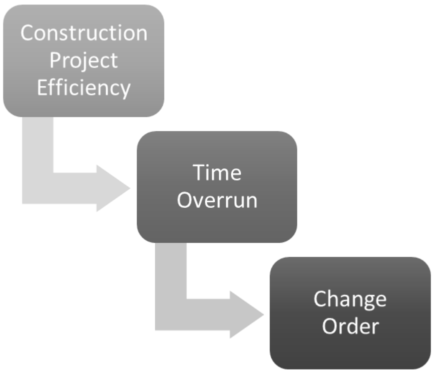
Table 5
Product Weights of the Time Overrun Component Rating

	Excusable and Compensable	**Not Excusable and Non – Compensable**	**Excusable and Non - Compensable**
H1	3.878	0.282	5.228
H2	-3.037	6.859	12.880
H3	0.945	2.460	2.504
H4	-0.011	-1.112	-0.790
H5	4.778	5.757	3.263
H6	0.005	-0.047	-0.002
H7	-8.591	0.067	1.774
Sum	2.034	14.266	24.856
R.I	**4.943%**	**34.662%**	**60.394%**

Time Overrun is the more important factor in the construction project efficiency rating which was presented in figure 7.

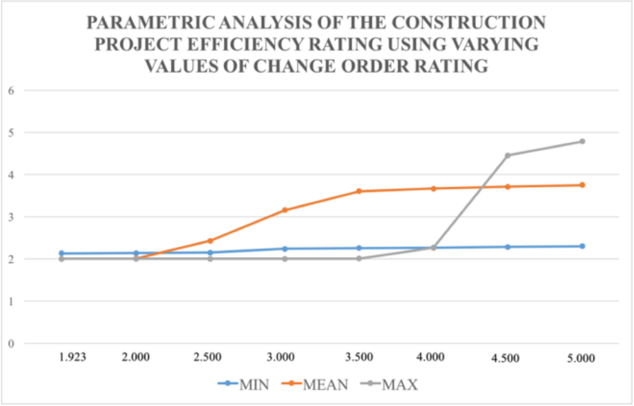
Fig 7

Importance Ranking of Construction Project Efficiency Rating Components



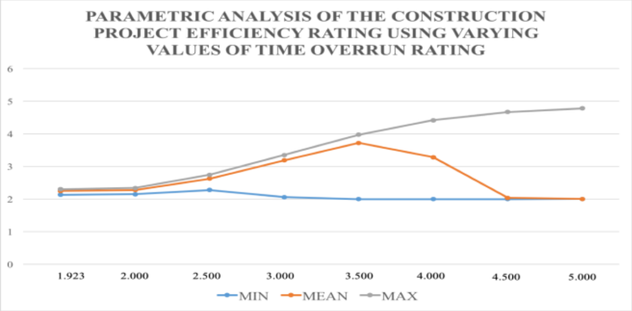
The parametric analysis for the construction project efficiency rating is presented in figure 8. Considering the average and maximum values of the time overrun rating, the parametric testing produces an increasing trend to the values of construction project efficiency. Likewise, considering the minimum values of the time overrun rating, the construction project efficiency rating has a minimal increase to its value.

Fig 8
Parametric Analysis of the Construction Project Efficiency Rating using Varying Values of Change Order Rating



The parametric analysis of the construction project efficiency rating is displayed in figure 9. Considering the minimum value of the change order rating, increasing the time overrun rating has no significant effect on the construction project efficiency rating. In the same manner, as compared with the mean value of the change order rating, the construction project overrun rating increases and reach its peak value when the time overrun rating is 3.50. After this value, the construction project efficiency rating exhibited a decreasing trend. Moreover, considering the maximum value of change order, the construction project efficiency produced an increasing trend.

Fig 8
Parametric Analysis of the Construction Project Efficiency Rating using Varying Values of Change Order Rating



V. CONCLUSION

Results indicated that among factors of the change order, the client has the most frequency that affects change order followed by the consultant and finally by the contractor. Also, time overrun was mostly affected by excusable & non-compensable factors which implied factors that are unforeseeable by all parties however not compensable as provided in contract clauses. Then followed by the factors of non-excusable & non-compensable and finally by excusable & compensable. Accordingly, between change order and time overrun, project efficiency was mostly affected by time overrun factors.

The study generated an automated prediction model using a multi-layered neural network and resulted in an MSE and MAPE of 0.042542 and 6.80846% respectively, which indicates a good model in predicting construction project efficiency rating.

Therefore, the study concluded by recommending that the tool made in this study can provide an automated program which helps to the respective beneficiary in the field. This research study can be utilized as a helpful tool in determining change order, time overrun and project efficiency rating. Further studies and inputs can be added in this study, such as the addition of factors and causes aside from the used factors in this study. This could be further developed in even bigger projects, but it will require a more detailed rubric, more participating groups, and keener observations. This study could be used for the improvement of the construction industry which is alongside blossoming with the real estate industry.

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