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Deterministic Assessment of Continuous Flight Auger Construction Durations Using Regression Analysis

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ABSTRACT
One of the primary functions of construction equipment management is to calculate the production rate of equipment which will be a major input to the processes of time estimates, cost estimates and the overall project planning. Accordingly, it is crucial to stakeholders to be able to compute equipment production rates. This may be achieved using an accurate, reliable and easy tool. The objective of this research is to provide a simple model that can be used by specialists to predict the duration of a proposed Continuous Flight Auger job. The model was obtained using a prioritizing technique based on expert judgment then using multi-regression analysis based on a representative sample. The model was then validated on a selected sample of projects. The average error of the model was calculated to be about (3%-6%).
***Keywords*–**Construction Management, CFA piles, Equipment Management, Productivity

I. INTRODUCTION

Continuous Flight Auger (CFA) piling construction is a complex work package that is exposed to a variety of risks and uncertainties. It is also affected by a variety of factors like; Main Equipment, Secondary Equipment, Soil, Design, Management approach and Site conditions (Fayek, 2004). Accordingly, planners are facing many problems especially on performing time and cost estimates as a result of incomplete and unorganized input data, which will lead to inaccurate estimates resulting in unrealistic schedule and budget that may not be achieved (Fraig, 2010).The main objective of this research is to provide a simple, accurate and reliable tool that can be used by stakeholders in CFA construction. The study motivation was based on the relatively important changes in equipment (new auger designs, wireless vibrators and mini-loaders) and the associated changes methods of construction and management approaches that were introduced to continuous flight auger work package during the last five years. This necessitates the development of a new model that commensurate with these changes, taking into consideration the available tools doesn't consider these changes. The proposed model was structured based on inputs from experts (Project Managers – Project Engineers – Consultants) to prioritize the most important factors that can affect the production rate of Continuous Flight Auger piles construction. These factors will be considered through a data collection approach that will capture real field data to be used as inputs to a multi-regression modeling to build a mathematical relation between those factors and the Production Rate (PR) and hence computing the activity duration.

II. LITERATURE REVIEW

CFA Piles are formed by screwing a continuously flighted auger into the ground to the required depth. Concrete is then pumped under pressure down the hollow stem of the auger to the bottom of the bore. Once pumping starts, the auger is progressively withdrawn bringing soils with it to the surface. Drilling and Concreting operations are monitored in the driver's cab by the most advanced computerized instrumentation system. Whilst these systems record data during the drilling operation they control the concreting operation to ensure a pile is formed correctly in the prevailing conditions. When the auger and soil are finally removed, reinforcement to meet the design requirement is placed in the wet concrete pile.

The advantages of this piling technique are; higher production rates, adjustable auger height, adjustable auger diameter, suitable for many types of soil such as; clay, sand, silt and moderate rocks (Fayek, 2004).Many Studies had been made to investigate the parameters that affect piles installation productivity depending on estimated and/or real field data. Some are concerned with CFA piles and the other are generally dealing with many other pile construction methods(http://www.simplexwestpile.co.uk).

Peurifoy et al. (1996): Regarding bored piles construction productivity, they identified the following productivity factors; Soil type, Drill type, Method of spoils removal, Equipment operator efficiency, Weather conditions, Concrete pouring efficiency, Waiting time for other operations, Management conditions and Site conditions. The study has not been performed using real field data. It was just an initial office trial which was unsatisfactory to get reliable estimates.

Fayek (2004): He has developed another simulation model based on a wider range of 20 factors; Equipment age, Equipment efficiency, Equipment operator efficiency, Labors efficiency, Field area, Number of buildings beside the project, Ground water table, Mixer efficiency, Workability of concrete, Soil type, total number of piles, Pile length, Pile diameter, Piles relations, Pump age, Pump efficiency, Distance between the equipment and pump, Average temperature, Project specifications and Management efficiency. He obtained his data from actual site records which had resulted in a more realistic model of average error of 11%. He recommended increasing the number of factors and projects as the model accuracy will increase by increasing the number of inputs.

Zayed(2005): A simulation model had developed to estimate the pile process productivity and cost of bored pile construction using five factors; Pile size, Pile length, Pouring system, Auger length and Soil type. These factors were selected based on site interviews, telephone calls and questionnaires. Four of these factors were not mentioned by Peurifoy. It was the first time to use simulation for piles construction but it was a general model for many types of piles and based on a small number of factors which still unsatisfactory to get reliable calculations.

Zayed et al. (2005): They presented two neural network models to predict productivity, cycle time and cost for bored pile construction. The input variables used for both networks are the same which include: Soil type: (clay, middle or sand), Construction method: which may be either a dry or wet, Pile depth or Auger height. These neural networks have been used to obtain several charts representing productivity, construction time and cost to schedule and price out bored piles construction projects.

Gabon (2006):Hehad used Artificial Neural Network to provide pile contractors with a planning tool for their projects. Two models were developed: the first model used 12 inputs which include temperature, humidity, ground water table, unit weight of soil, angle of internal friction, cohesion, pile length and diameter, auger height, pile numbers, equipment and pump efficiency. The second model used the same inputs of the first model with the exclusion of pile numbers and the addition of two factors: steel length and steel spacing to predict production rate and the time of each activity in the piling process with an average error of 13%.

Hafez and Elkassas (2009): They used the historical data from previous projects to develop neural network model to provide contractors with a more reliable tool for their estimate. Using trial and error tool, they selected twelve input factors to build the network; Piles number, Average temperature, Average humidity, Equipment efficiency, Pump efficiency, Soil density, Angle of friction, Soil cohesiveness, Ground Water Table, Pile length, Pile diameter and Auger length.

Fraig, et al. (2010): They used records of the 20 factors mentioned by Fayek (2004) in addition to two new factors: Reinforcement Length and Reinforcement installation methods. The collected data was applied to a multi-regression modeling using Statistical Package for Social Science (SPSS) software to build a new mathematical relation between the 22 factors and the Performance Ratio of CFA equipment. The model standard error upon validation was 8.5% which was acceptable but there was a complaint about the difficulty in using such model.

Fraig, et al. (2014): They used Database Normalization approach to extract a simplified model from their previous study. The new simplified model contained four factors; Equipment Efficiency, Driver’s Efficiency, Soil Type and Filed Restrictions. It was an easy used model but the standard error increased to 9% upon validation.

It was observed that the latest model was developed in 2010 which may be inaccurate to deal with the recent modifications of continuous flight auger pile construction. The modifications lead to changes in production rates of mixing and auger waiting time due to shortage of ready concrete which accordingly affected the integrated production rates of such operation. Moreover, these models were applied to a sample of very recent projects and the results were not satisfying to key stakeholders which motivated the researchers to develop the proposed model.

III. RESEARCH METHODOLOGY

The proposed model is a component of an Integrated Management Model (IMM) to manage Continuous Flight Auger piles Construction. The aim of this subsidiary model is to obtain more accurate duration estimate (DE) based on the most important factors considering new factors that arise due to the changes in construction methodologies (mini loader instead of manual loading of ingredients), new augers used in the Egyptian market (Soilmec® SF-40 and SR-60) along with direct data collection and discussion by researchers. The newly proposed factors are; Mini Loader/Mixer efficiency, using ready-mix concrete instead of mixing in site, Surveyor efficiency, Main Loader efficiency and auger crew efficiency. The suggested 25 factors were prioritized through a questionnaire sent to experts to check their importance and usefulness as a first step, and then the factors were considered in a data collection survey focusing on current CFA projects. The model should be obtained through multi-regression modeling using SPSS software upon using the collected data inputs. The model should be validated back to projects to recognize its standard error of estimate.

IV. PRIORITIZATION OF FACTORS

The suggested 25 factors affecting the production rate of CFA pile construction were presented to experts through a questionnaire to assess their importance and prioritize them through a structured questionnaire. The questionnaire was presented to 50 experts with diverse perspectives (10 consultants, 20 project managers and 20 equipment engineers) where only 42 responses were obtained. The sample size was determined using an automated calculator , where the confidence level was 95%, confidence interval is 12 and the population was 202 experts(http://www.surveysystem.com/sscalc.htm). The weighted average technique is used to assess how effective is the factor as follows: no effect, minor effect, moderate effect, basic effect and major effect got 1,2,3,4 and 5 points respectively. The final results are shown in Table (1).

V. FIELD DATA COLLECTION

In this research, the data collection approach is focused on construction projects that include foundation piles especially Continuous Flight Auger piling method. Piles length was ranged from 10 to 35 meters and piles diameter ranged from 50 to 60 centimeters. Forty Projects of different categories (residential, commercial, educational, industrial and walls) were chosen according to these criteria:

1. Retaining and / or foundation vertical piles constructed by C.F.A. method.
2. The soil type is either soft, medium and stiff clay or loose, medium and dense sand.
3. Piles' length is ranged from 10 meters to 35 meters.
4. Piles' diameter ranged from 40 cm to 80 cm.

During a study period of 471 overlapping working days on a scope of 4470 piles. The approach was performed according to the following steps;

Table (1): Experts Prioritization Matrix of Factors

Rank	FACTOR	No Effect	Minor Effect	Moderate Effect	Basic Effect	Major Effect	Score
1	*Equipment efficiency*	0	0	0	7	35	203
2	*Soil type*	0	0	0	11	31	199
3	*Driver's efficiency*	0	0	0	24	18	186
4	*Pump efficiency*	0	0	12	12	18	174
5	*Equipment age*	0	0	12	18	12	168
6	*Temperature*	0	4	8	18	12	164
7	*Pump age*	0	0	16	16	10	162
8	*Side restrictions*	0	5	15A	4	18	161
9	*Pile length*	0	0	10	32	0	158
10	*Workability*	0	6	6	25	5	155
11	*Labor's efficiency*	0	0	17	24	1	152
12	*Site area*	0	6	11	19	6	151
13	*Mini loader/mixer efficiency*	0	0	19	23	0	149
14	*Pile diameter*	0	6	14	16	6	148
15	*Project Management effectiveness*	0	12	12	5	13	145
16	*Main Loader efficiency*	0	9	13	12	8	145
17	*Pump distance*	0	12	10	20	0	134
18	*Reinforcement length*	0	0	37	5	0	131
19	*Using Ready-mix*	0	18	10	10	4	126
20	*No. of piles*	0	13	18	11	0	124
21	*Reinf. Installation*	0	6	35	0	1	122
22	*Design Specs.*	4	11	19	6	2	117
23	*Piles distribution*	0	11	31	0	0	115
24	*Surveyor efficiency*	6	14	10	11	1	113
25	*Ground Water Table*	24	12	6	0	0	66

1. Collecting the available equipment records related to productivity, operating and time.
2. Investigating the previous equipment data.
3. Investigating the equipment manufacturer's instructions.
4. Discussing the different aspects of equipment productivity with the company's Equipment Manager and/or Projects Manager.
5. Interviewing the equipment's engineers, technicians and operators.

The collected data was imported through a data collection sheet to assess the following operating factors:

1- Project Information; Project ID, Project Description and Project Location.
2- Equipment Information; Equipment Type, Age and Efficiency.
3- Crew Information; Efficiency of Operator, Surveyor and Labor.
4- Site Information; Site Area, Side Restrictions, Site Urbanity, Soil Classification and Ground Water Level.
5- Piles Information; Number of Piles, Pile Length, Pile Diameter, Pile Reinforcement and Piles Interrelations.
6- Subsidiary Equipment Information; Mixer Size, Pan Size, Mixer Efficiency, Mixer Age, Main loader, mini loader efficiency, Maintenance and Repair Procedure.
7- Concrete Information; Concrete Workability (slump), Mix Design and Admixtures.
8- Pump Information; Pump Type, Pump Age, Pump Efficiency and Distance between Pump and Piling Equipment.
9- Management Information; Specifications and Conditions, Project Management Efficiency, Equipment Management Systems and Labor Management Systems.

VI. DATA PROCESSING

The imported data assessed the values of the25 factors that supposed to affect the productivity CFA piles construction and the factors were classified to two main categories;

6.1 Quantitative Factors:

Their assessments were quantified according to their real values including: Equipment age, Site area, Ground water level, Number of Piles, Piles' length, Pile's diameter, Concrete Workability, Pump Age, Pump Distance, Average Temperature and Reinforcement Length.

6.2Qualitative Factors:

Their assessments were quantified according to "***Fayek, 2004***" and "***Fraig, 2010***" as shown in the Table (2) including: Equipment Efficiency, Driver Efficiency, Crew Efficiency, Side Restrictions, Soil Classification, Piles Distribution, Mixer/Mini Loader Efficiency, Pump Efficiency, Concrete Type, Main Loader Efficiency, Design Specifications, Project Management Efficiency, Reinforcement Installation Method and Surveyor Efficiency.

Table (2): Factors Description and Classification

Code	Factor	Definition	Type
X_1	**Equipment Age**	The difference between the manufacturing year and observing year in (years).	Quantitative
X_2	**Equipment Efficiency**	It was expressed in four choices: Excellent – Good- Medium – Poor	Qualitative (0.9/0.8/0.7/0.6)
X_3	**Driver's Efficiency**	It was expressed in four choices: Excellent – Good- Medium – Poor	Qualitative (0.9/0.8/0.7/0.6)
X_4	**Crew Efficiency**	It was expressed in four choices: Excellent – Good- Medium - Poor	Qualitative (0.9/0.8/0.7/0.6)
X_5	**Site Area**	It was expressed in m^2.	Quantitative
X_6	**Side Restriction**	The number of direct neighborhood buildings.	Quantitative
X_7	**Soil Classification**	The most common layer is expressed in three choices: Weak – Medium - Strong	Qualitative (0.9/0.8/0.7)
X_8	**Ground Water Level**	The depth of ground water measured from normal ground level (m).	Quantitative
X_9	**Number of Piles**	The total number of piles in a selected project.	Quantitative
X_{10}	**Pile Length**	The total length of a pile in meters.	Quantitative
X_{11}	**Pile Diameter**	The diameter of a pile in meters.	Quantitative
X_{12}	**Piles Distribution**	Shows the positioning relation between piles in field and it was expressed as one of two choices: Grid Aligned – Random Distribution	Qualitative (0.9/0.8)
X_{13}	**Mixer/Mini Loader Efficiency**	It was expressed in four choices: Excellent – Good- Medium - Poor	Qualitative (0.9/0.8/0.7/0.6)
X_{14}	**Concrete Workability**	It was expressed as slump in centimeters.	Quantitative
X_{15}	**Pump Age**	The difference between manufacturing year and observing year in (years).	Quantitative
X_{16}	**Pump Efficiency**	It was expressed in four choices: Excellent – Good- Medium - Poor	Qualitative(0.9/0.8/0.7/0.6)
X_{17}	**Pump Distance**	The average distance between equipment and pump in meters.	Quantitative
X_{18}	**Concrete Type**	It was expressed in two choices: Ready mix – Mix in-site	Qualitative(0.9/0.85)
X_{19}	**Main Loader Efficiency**	It was expressed in four choices: Excellent – Good- Medium - Poor	Qualitative (0.9/0.8/0.7/0.6)

X_{20}	**Design Specifications**	It was expressed in three choices: Loose – Moderate - Restricted	Qualitative (0.9/0.8/ 0.7)
X_{21}	**Project Management Efficiency**	It was expressed in four choices: Excellent – Good- Medium - Poor	Qualitative (0.9/0.8/ 0.7/0.6)
X_{22}	**Average Temperature**	It was measured in Celsius (C^o).	Quantitative
X_{23}	**Reinforcement Length**	The length of steel cage in meters.	Quantitative
X_{24}	**Reinforcement Installation**	It was expressed as one of two choices: By Loader – By Vibrator	Qualitative (0.9/0.8)
X_{25}	**Surveyor Efficiency**	It was expressed in four choices: Excellent – Good- Medium - Poor	Qualitative (0.9/0.8/ 0.7/0.6)

VII. RESEARCH METHODOLOGY

The collected data of the different variables for the selected sample of projects (values of Xn; where n=1,2,3…..25) and the corresponding value of Performance Ratio (Y) for each project were tabulated in the entry table (Appendix 1) to be ready as an input for Statistical Package for Social Science (SPSS) software. Regressions were performed in order to get all the available models in this case. Many trials were done and the best fit was obtained from a linear relation between the equipment performances ratio (the actual production rate divided by the ideal production rate) as a dependent variable (Y) with all independent variables (Xn) as shown in equation (1):

$$Y= 0.308 -0.002X_1+0.553X_2+0.055X_3-0.0251X_4+0.000026X_5-0.001X_6+0.13X_7+0.00005X_9+0.00006X_{10}-0.1X_{11}-0.413X_{12}+0.39X_{13}-0.001X_{14}-0.077X_{16}-0.00004X_{17}+0.291X_{18}+0.027X_{19}+.0147X_{20}-0.089X_{21}+0.001X_{23}+0.029X_{24}-0.136X_{25}. \quad (1)$$

Note: *SPSS software neglected the following factors due to their minor effect; X_8(Ground water level), X_{15}(Pump age) and X_{22} (Average Temperature).*

The model summary was shown by the software output in Figure (1) where the R^2 value is 0.952 (i.e. the coefficient of multiple determination is 0.952; therefore, about 95.2%

The regression equation appears to be very useful for making predictions since the value of R Square is close to 1.0.

Figure (1): Model Summary of SPSS Software

Model Summary [b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.976[a]	.952	.843	.02188

a. Predictors: (Constant), X25, X12, X20, X19, X23, X17, X21, X18, X24, X22, X6, X11, X10, X15, X3, X8, X9, X14, X2, X7, X16, X5, X4, X13, X1
b. Dependent Variable: PR

VIII. MODEL MODIFICATION

Although the model is considered to be useful, but it may be claimed to be long and difficult to use be an inexperienced engineer. The model has no multicollinearity problems since neither of the predictor variables has a Variance Inflation Factor (VIF) greater the ten. The (STEPWISE) entry method was used to remove the factors of low correlation and keep those that are highly correlated to the dependent variable (**Y**). Accordingly, the results shown that the most effective variables are; Equipment Efficiency (**X_2**), Crew Efficiency (X_4) and Mixer/Mini Loader Efficiency (**X_{13}**) as shown in Table (3).

Table (3): Variables Entered/Removed (STEPWISE)

Model	Variables Entered	Neglected Variables	Factor
1	**X_2**	--	Equipment Efficiency
2	**X_{13}**	--	Mixer/Mini Loader Efficiency
3	**X_4**	--	Auger Crew Efficiency

Accordingly, the modified model is obtained as shown in equation 2 as follows:

$$Y^*= 0.264+0.568X_2+0.359X_{13} -0.23X_4 \quad (2)$$

IX. MODELS VALIDATION

The two models were applied back to random specimen of four projects (see Appendix 2) to compute the performance ratios using the main model (*Y*) and the corresponding performance ratios using the modified model (*Y**) and then computing the standard error for each. The validation results are shown in Table (4): The standard error for the main model was (3.12%) and that of the modified model was (5.85%) which was acceptable to the project stakeholders with a recommendation of adjusting the models to reflect these errors using equation (3):

$$Error= (Y_{actual} - Y_{calculated})/ Y_{actual} \% \quad (3)$$

Table (4): Models Validation Results

Project ID	Y actual	Y	Error % (E)	Y*	Error % (E*)
1	0.88	0.91	3.41	0.85	3.41
2	0.86	0.90	4.65	0.81	5.81
3	0.94	0.92	2.17	0.86	8.51
4	0.88	0.9	2.26	0.83	5.68
Average			**3.12%**		**5.85%**

Hence,

Estimated Production Rate = Performance Ratio * Ideal Production Rate (4)

Where: Ideal production rate can be determined by the rig manufacturer based on the working conditions such as temperature, humidity, soil type and equipment age.

It was clear that this model has the least percentage error as compared to the previously developed models as shown in Table (5).

TABLE (5): PERCENTAGE ERRORS OF MODELS

Model	Proposed Model	Modified Model	Fraig 2014	Fraig 2010	Gabon 2006	Fayek 2004
% Error	3%	6%	9%	8.5%	13%	11%

X. CONCLUSION

A mathematical model was obtained using the historical data of forty projects. These data were subjected to a multi- regression analysis using SPSS software. It is used to calculate the equipment performance ratio depending on 25 variables. The model is then reduced and checked using SPSS Software and resulted in a relation between equipment efficiency, Mixer/Mini Loader Efficiency, Crew efficiency and the dependent Performance Ratio. The two models were applied for validation where an Average Percentage Error of 3% was found for the main model and 6% for the modified model. Meanwhile, the feedback shows a high level of customer satisfaction on validating the models because of the small error of the model compared to previous models as shown before.

XI. RECOMMENDATIONS

Recommendations for future studies are; the accuracy of the model could be improved by increasing the input data to SPSS software; the performance of the model may be improved by detecting more factors affecting the productivity; the research work could be extended to predict cost and Risk Management should consider these factors in identifying threats and opportunities.

DECLARATION

This paper is based on PHD Thesis, Prepared by the third author, and supervised by the first twoauthors.

REFERENCES

[1] Fayek, R. " The Use of Simulation to Predict CFA Equipment Productivity". M.Sc. Thesis , Alexandria University (2004).

[2] Fraig, R.F. "Establishing a Mathematical Model to Predict Continuous Flight Auger System Production Rates ". M.Sc. Thesis, Arab Academy for Science, Technology and Maritime Transport, Egypt (2010).

[3] Fraig, R.F.,Hafez S.M. and Elsamadony A. "Predicting Production Rates of Continuous Flight Auger Piles".The Eighth International Conference of Structural and Geotechnical Engineering, Alexandria University (2014).

[4] Gabon, N.A. "Planning Construction Projects of Continuous Flight Auger Piles: Neural Network Approach" . M.Sc. Thesis, Arab Academy for Science, Technology and Maritime Transport, Egypt (2006).

[5] Hafez,S.M. and Elkassas, E.M. "Quantitative Evaluation for Piles Productivity Factors". Port-Said Engineering Research Journal, Vol.13, No. 2, Pp. 61-72, (2009).

[6] Peurifoy,R.L. and Ledbetter,W.L. "Construction Planning, Equipments and Methods". McGraw-Hill, New York (1996).

[7] Zayed,T.. "Productivity and Cost Assessment Model for continuous Flight Auger Piles". Journal of Construction Engineering and Management, ASCE,Vol.131,No.6,Pp.677-688, (2005).

[8] Zayed,T. and Halpin,D.W. " Quantitative Assessment for Piles Productivity Factors". Journal of Construction Engineering and Management, ASCE, Vol.130,No.3,Pp.394-404,(2004).

[9] Zayed,T. and Halpin,D.W. " Pile Construction Productivity Assessment". Journal of Construction Engineering and Management, ASCE,Vol.131,No.6,Pp.705-714, (2005).

[10] Zayed,T. and Halpin,D.W. "Productivity and Cost Regression Models for Pile Construction". Journal of Construction Engineering and Management, ASCE,Vol.131,No.7,Pp.779-789, (2005).

[11] Website: Simplex West Pile company (http://www.simplexwestpile.co.uk) in (16/1/2015).

[12] Website: Survey System(http://www.surveysystem.com/sscalc.htm) in (12/6/2015).