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A Benchmark Model for Construction Durations: The Case of New Cruciform Type Public Housing Blocks

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Abstract
Construction time has been recognized to be one of the most important performance measures of many successful projects. Considerable efforts have been devoted to the issue of how to benchmark best practice measures of construction time performance (CTP) for use in the industry. A research survey was undertaken to determine a set of critical factors that affect the construction durations for primary work packages of high-rise public housing projects in Hong Kong. Data were gleaned from a representative sample of 15 standard 'New Cruciform' type residential blocks via mailed standard questionnaires. Multiple regression technique was applied to data analysis and model development. The predictive accuracy of the developed model was next conducted by comparing the predicted values against the actual data set and confirmed significant. The regression model serves as a useful benchmark tool for an optimum time estimate for delivering such type of public housing projects. A comprehensive study is currently being launched for private sector housing blocks in Hong Kong by adopting similar research methodology, for national and international comparisons.

Keywords
Benchmark Model, Construction Duration, Public Housing, Hong Kong, Multiple Regression

1. Introduction

Housing is a great concern in a land-scarce region such as Hong Kong. Demand for urban housing in Hong Kong has undergone an unprecedented increase throughout the 1990s. The importance of 'construction time performance' (CTP) of projects has been widely recognized by both researchers and practitioners within the construction industry, particularly during the past three decades, with a pioneering investigation by Bromilow (1969) in Australia on building projects.

CTP has been traditionally regarded as one of the three major critical success factors in a construction project (Walker, 1995). Therefore, the variables that significantly influence project duration are worthy of scrutiny. Several research reports and journal articles have been published in the realm of measuring and improving CTP worldwide. Retrospective to the early 1980s, research into the factors that affect construction durations across various categories of projects has been adequately summarized by Chan and Chan (2003a).

This paper aims to develop benchmark measure of industry norms for overall construction period of public housing projects, by modelling the durations of fundamental primary work packages of the building construction process. To facilitate deeper analysis, it was decided to categorize the construction process of a building into the principal phases such as substructure, superstructure, electrical & mechanical (E&M) services, and finishing work (Chan and Chan, 2003b).

Detailed project data from 15 case studies of standard 'New Cruciform' type domestic blocks, were gleaned from the client organization (Hong Kong Housing Authority, HKHA) and their registered building contractors to formulate the prediction model by applying multiple linear regression analysis. Predicted values by the model were then compared to the actual values stipulated in the construction contract and the results were found to be statistically acceptable and reliable. It was believed that the derived model could benefit the client organization, project mangers and contracting firms as a whole for more reliable and realistic in-house construction time planning and control systems.

2. Programming of Construction Activities

There is a general agreement among officers in the client organization (HKHA) and their building contractors, on the categorization of the common primary work packages (i.e. piling, pile cap/raft, superstructure, E&M services and finishes), and the work sequencing of these packages for the construction of a new public housing project. Full definitions of these work packages have been cited in Chan and Kumaraswamy's (1999a) publication.

The 15 detailed case studies, which included site visits and data collected from survey questionnaires, were perceived to strongly substantiate the above captioned statement, via observations of both the 'planned' and 'revised' master construction programmes of some on-going projects. In this investigation, construction duration is measured to be the elapsed period from the commencement of foundation works on-site to the practical completion of the building.

Figure 1 outlines a typical master construction programme comprising the five primary work packages for standard 'New Cruciform' type domestic blocks in Hong Kong. It may be emphasized that the foundation contractor is often responsible for both the piling works and the pile caps, but in some situations where special provisions in the construction contract are set out, the building contractor may need to construct the pile caps prior to the superstructure erection.

Figure 1: Typical Master Construction Programme for Standard Public Housing Blocks

3. Survey Methodology

Questionnaire surveys are the commonly used research methodology in construction management. Surveys glean data in a standardized form from samples of a population and assist the researcher in drawing statistical inferences on the data, often with the aid of specialized computer software.
Before the design of the current survey questionnaire, two previous surveys have been launched in Hong Kong between 1994 and 1995. These two surveys were intended to seek the significant factors influencing project construction durations (Kumaraswamy and Chan, 1995), together with the potential reasons for project delays (Chan and Kumaraswamy, 1996).

The current survey questionnaire covered a total of 84 time-influencing factors – including both qualitative and quantitative items of project data (variables) which were gathered from the outcomes of the two previous surveys, case studies, a search of international literature, and semi-structured interviews with local clients, consultants and contractors. These 84 items were further classified under seven major sections: (1) General organization information; (2) Project characteristics; (3) Client characteristics; (4) Architect/Engineer characteristics; (5) Building contractor characteristics; (6) General assessment of construction speed; and (7) Construction cost/time information. The research focus was on high-rise public housing projects of standard 'New Cruciform' type completed between 1990 and 1996 inclusive. Table 1 gives a summary of the dimensional characteristics of that block design under study.

Table 1: Dimensional Characteristics of Standard Type of 'New Cruciform' Block Design (Source: Chan, 1998)

Block Type	Number of Floors	Height (m)	Total Gross Floor Area (m^2)	Number of Flats per Floor	Total Number of Flats per Block
New Cruciform	38	102.05	21,820	10	370

All the 43 building contractors registered on the HKHA's Lists, accompanied by senior construction professional staff from the client organization, were approached via self-administered questionnaires in June 1996. Senior construction professionals of the client organization and 12 building contractors, were eventually willing to participate in the survey exercise that constituted a representative sample of 15 standard 'New Cruciform' type domestic blocks for deriving the time model.

Despite further follow-up by mailed letters and telephone calls, only a few 'actual' or 'as-built' construction programmes were provided by survey respondents, and thus the detailed duration analysis involving primary work packages was based only on the 'planned' construction programmes. The sample of blocks ranged: from 24 to 40 storeys high; from 14,200 to 24,000 m^2 total gross floor area (GFA); from HK$82.06M to HK$121.15M contract value; and from 28 to 37 months contract period. It should be noted that even though the sample size of 15 was smaller in the present application, it was considered adequate for purposes of this pilot study. So this research should be regarded as indicative rather than conclusive.

4. Development of a Benchmark Schedule Model

Both Nkado (1992) and Walker (1995) established and tested their prediction models for time planning new commercial building projects at early design stages, by using Spearman's rank correlation method and multiple linear regression analysis. Spearman's rank correlation is best used to test the probability of association between any two variables, while multiple regression is used to demonstrate the strength of relationships between variables (Fellows and Liu, 1997). In this study, both techniques were adopted as statistical tools for analysis.

A 'stepwise selection method', available on the computer software – SAS for Windows Version 6.11, with a significance level of 5% was used to select statistically significant variables to be incorporated into the model. Multiple linear regression analysis was conducted with the dependent variables (i.e. primary work package durations and their respective sequential start-start lag times measured in months) against the 84 pre-identified independent (regressor) variables. Data variables were added and deleted one at a time and the regression model was re-run, noting at each step the changes in the coefficient of determination (R^2) value and more importantly the significance level of variables. Only those variables with a significance level (p-value) of less than 5% appeared in the final regression model equations.

The resultant model was further tested, by applying regression diagnostics, for any potential problems of: (1) multi-collinearity using tolerance; (2) non-constant variance by a residual analysis; and (3) 'influential' cases (outliers) using studentized residual, Cook's distance and other relevant indicators

(Belsley et al., 1980). The cut-off criteria for problems by these diagnostic indicators are fully described by Chan and Kumaraswamy (1999a).

5. Presentation and Discussion of Regression Results

Table 2 indicates the outcomes of regression analysis for the five primary work packages, i.e. piling, pile cap/raft, superstructure, E&M services, finishes, and four sequential start-start lag times between these consecutive work packages, for the 'New Cruciform' type domestic blocks in Hong Kong. Durations for site set-up and external works are excluded in the analysis because the former can be quite variable and relatively short, while the latter is not essential in the determination of the overall construction period.

Table 2: Result Overview of Regression Analysis for 5 Work Packages and 4 Lag Times

Work Package	R^2	Adjusted R^2	Mean (months)	S.D. (months)	Significance of F	No. of Valid Cases
PILING	0.9779	0.9336	5.23	0.89	0.0047	13
CAP / RAFT	0.9712	0.9584	3.36	0.83	0.0001	14
SUPERSTR	0.9651	0.9433	17.50	1.32	0.0001	14
SERVICES	0.9352	0.9064	23.43	3.24	0.0001	14
FINISHES	0.8764	0.8077	19.73	1.56	0.0007	15
LAG2	0.9714	0.9656	5.23	0.89	0.0001	13
LAG3	0.9817	0.9634	3.31	0.85	0.0001	13
LAG4	0.9287	0.9093	3.20	2.92	0.0001	15
LAG5	0.9769	0.9699	3.57	2.59	0.0001	14
EST-TIME	0.9786	0.9501	34.93	2.44	0.0002	15

Notes: LAG2 : Start-start lag time between piling and pile cap
LAG3 : Start-start lag time between pile cap/raft and superstructure
LAG4 : Start-start lag time between superstructure and E&M services
LAG5 : Start-start lag time between E&M services and finishes
EST-TIME : Estimated overall construction duration stipulated in contract

A total of 10 regression model equations were derived to model (a) durations of each of the five primary work packages; (b) durations of each of the four sequential start-start lag times between such work packages; and (c) planned overall construction duration. An example of the model equation for one single block is shown below. Interested readers are encouraged to refer to Chan and Kumaraswamy (1999a) for the whole set of regression equations. All the model predictions are calculated in months.

EST-TIME = 9.2685 +
0.6179 * Number of storeys of building
+ Type of foundations (3.1395 for H-pile; 3.4888 for caisson;
2.5000 for bored pile; 2.5000 for precast pile; 0 for raft)
+ Ground conditions (0 for very good; 0.5174 for average;
1.9700 for difficult; 1.9888 for extremely difficult)

The regression equation generated an estimate of the planned overall construction duration in months depending upon the number of storeys of building block, the type of foundations used and ground conditions for construction. Furthermore, the relative strengths of the influences of the independent variables upon the dependent variable (i.e. time) were reflected in the respective coefficients in each of the regression equations. The coefficients demonstrated relative importance and potential sensitivity. On the other hand, since no significant deviation from the underlying assumptions of a linear regression model was revealed by regression diagnostics, all the duration forecasts derived were taken to be reasonably acceptable and reliable. Detailed outcomes of the diagnostic analysis may be referred to Chan's (1998) thesis.

Predictive accuracy investigates the goodness-of-fit of the regression model to the available data. Table 3 and Figure 2 summarize the comparison of the actual (i.e. planned) values provided on the survey form by survey respondents, as against the corresponding predicted values from the model, of the overall construction durations for the 15 sample projects analyzed. Two relative measures of accuracy dealing with percentage errors were used to compare the forecasting performance of the model. The percentage error and mean absolute percentage error were defined by Goh (2000) as follows:

The computed values of these two measures are also tabulated in Table 3. All the overall durations predicted by the model are highly consistent with the planned durations to well within ±2%. Moreover, the model was found to produce extremely accurate forecasts because their MAPE value (i.e. 0.78%) absolutely falls within the acceptable limit of 10% (Goh, 2000). It was further evident from Figure 2 that there were very good overlappings between the actual values (i.e. planned) values and predicted values.

Planned Duration (months)	Predicted Duration (months)	Percentage Error	Absolute Percentage Error
37	36.62	–1.03	1.03
37	37.00	0.00	0.00
36	35.52	–1.34	1.34
36	36.00	0.00	0.00
35	35.17	0.48	0.48
36.5	36.97	1.29	1.29
31.5	31.41	–0.29	0.29
35	35.00	0.00	0.00
28	28.10	0.37	0.37
36	36.40	1.12	1.12
33	33.50	1.52	1.52
34	33.50	–1.47	1.47
36	36.40	1.12	1.12
37	36.40	–1.61	1.61
36	36.00	0.00	0.00
Mean Absolute Percentage Error (MAPE) =0.78%			

Table 3: Comparison between Planned and Predicted Values for Overall Durations

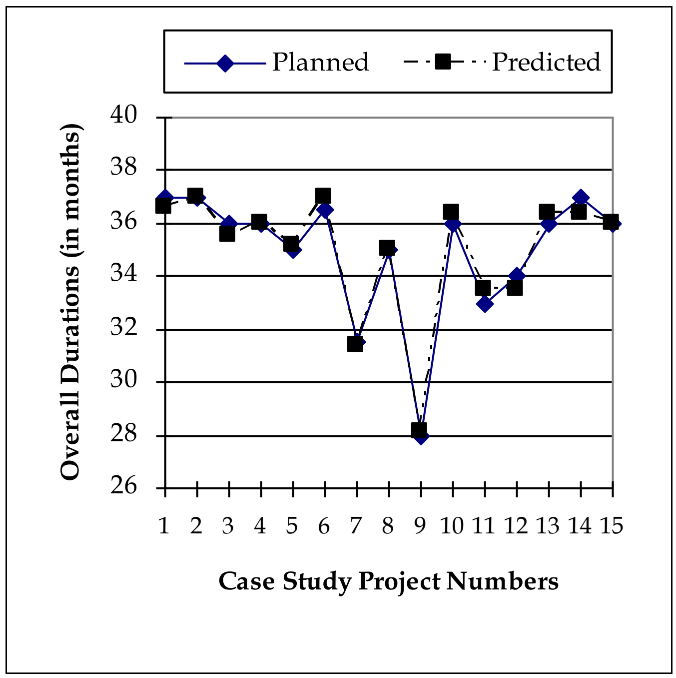

Figure 2: Graphical Comparison between Planned and Predicted Values for Overall Durations

6. Concluding Remarks

A review of the relevant literature sought a set of factors considered to affect project construction time. These identified factors were used to constitute an investigation survey that identified a group of critical factors influencing construction durations of public housing projects in Hong Kong. Detailed project information from a total of 15 standard 'New Cruciform' type domestic blocks was collected to develop the time prediction model, mainly applying multiple linear regression analysis. The derived model can generate benchmark estimates of the predicted/expected overall construction duration of a new project. However, more case studies should be added to increase the sample size to a minimum of 30 in order to further validate the inferences drawn from this pilot study. A parallel study on another standard block type (i.e. Harmony) had been completed for comparison (Chan and Kumaraswamy, 1999b). What is more, a similar investigation has already been undertaken on private sector housing blocks for further analysis (Chan and Chan, 2003a). Research in this area could lead to seeking national or international best practice recommendations, in order to nurture an efficient and productive construction industry.

7. Acknowledgements

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8. References

Belsley, D.A., Kuh, E. and Welsch, R.E. (1980). *Regression Diagnostics: Identifying Influential Data and Sources of Collinearity*, John Wiley & Sons, New York, U.S.A.

Bromilow, F.J. (1969). "Contract time performance – Expectation and the reality". *Building Forum*, 1(3), pp. 70-80.

Chan, A.P.C. and Chan, D.W.M. (2003a). "A research framework for benchmarking project construction durations". *Construction Information Quarterly,* 5(2), pp. 10-15.

Chan, A.P.C. and Chan, D.W.M. (2003b). "A benchmark model for construction duration in public housing developments". *International Journal of Construction Management,* 3(1), pp. 1-14.

Chan, D.W.M. (1998). *Modelling Construction Durations for Public Housing Projects in Hong Kong,* PhD Thesis, The University of Hong Kong, Hong Kong.

Chan, D.W.M. and Kumaraswamy, M.M. (1996). "An evaluation of construction time performance in the building industry". *Building and Environment*, 31(6), pp. 569-578.

Chan, D.W.M. and Kumaraswamy, M.M. (1999a). "Forecasting construction durations for public housing projects: A Hong Kong perspective". *Building and Environment*, 34(5), pp. 633-646.

Chan, D.W.M. and Kumaraswamy, M.M. (1999b). "Modelling and predicting construction durations in Hong Kong public housing". *Construction Management and Economics*, 17(3), pp. 351-362.

Fellows, R. and Liu, A. (1997). *Research Methods for Construction*, Blackwell Science Ltd., Oxford, UK.

Goh, B.H. (2000). "Evaluating the performance of combining neural networks and genetic algorithms to forecast construction demand: The case of the Singapore residential sector". *Construction Management and Economics*, 18(2), 209-217.

Kumaraswamy, M.M. and Chan, D.W.M. (1995). "Determinants of construction duration". *Construction Management and Economics*, 13(3), pp. 209-217.

Nkado, R.N. (1992). "Construction time information system for the building industry". *Construction Management and Economics*, 10(6), pp. 489-509.

Walker, D.H.T. (1995). "An investigation into construction time performance". *Construction Management and Economics*, 13(3), pp. 263-274.