Modeling and Forecasting Construction Labor Demand: Multivariate Analysis

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Abstract: This paper presents the development of advanced labor demand forecasting models at project level. A total of 11 manpower demand forecasting models were developed for the total project labor and ten essential trades. Data were collected from a sample of 54 construction projects. These data were analyzed through a series of multiple linear regression analyses that help establish the estimation models. The results indicate that project labor demand depends not only on a single factor, but a cluster of variables related to the project characteristics, including construction cost, project complexity attributes, physical site condition, and project type. The derived regression models were tested and validated using four out-of-sample projects and various diagnostic tests. It is concluded that the models are robust and reliable, which merit for contractors and HKSAR government to predict the labor required for a new construction project and facilitate human resources planning and budgeting, and that the methodology used may be applied to develop equally useful models in other subsectors, and in other countries.

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Introduction

The construction industry has made significant contributions to the economy in Hong Kong, in terms of output and the share of the workforce involved, and historically accounts for between 8 and 9% of all jobs. The industry is characterized by diversified labor intensive trades (Rowlinson and Walker 1995). Although the shares of higher-level nonmanual occupations such as professional staff and technicians have exhibited apparent growth from the past decades, construction activities still remain essentially craft based. The ratio of site operatives in the industry remains nearly 60% of the total construction employment in 2004 (HKCSD 2005). Skilled operatives are therefore undeniably important assets upon which the construction industry and firms depend.

The project-based nature of the construction process entails the concerns about resources planning at site level. Ensuring adequacy of various construction staff and trades to make up project teams is a vital task (Druker and White 1996). To assess long-term staffing needs, an organization must be able to determine the demand for personnel in each of the various disciplines precisely in advance (Wong et al. 2003). Skilled trades are difficult to be hired off the street as the demand arises. Instead, a method of estimating a project's requirement for personnel would help the organization in human resources planning, budgeting, and would also help each functional group to better plan its work (Persad et al. 1995). As construction gets underway, the contractor needs to closely monitor the volumes of workers employed on site everyday to ensure adequacy of site amenities and safety provision (Uher and Loosemore 2004). Labor requirements should be estimated at preconstruction stage for this purpose. In addition, labor costs make up a significant portion of the total cost of a construction project (Proverbs et al. 1999). It is therefore critical for contractors and government departments to assess the manpower required in executing future projects.

Because of the severe fluctuation of the pool of labor, certain degree of labor shortages and surpluses will occur for brief periods of time in the absence of manpower planning (Uwakweh and Maloney 1991). The planning practice is important to prevent the noncompletion of construction program and the damage to the economy caused by attempting to undertake construction, for which the resources are not available (Briscoe and Wilson 1993). A balanced supply and demand of workers will minimize any sudden surge in labor wages and hence construction cost (Ball and Wood 1995). In particular, the construction industry contains a large number of quite distinct occupations or skill categories. Supply shortages in any particular category can restrict output and reduce productivity; whereas oversupply will result in squander of resources (Kao and Lee 1998).

Attempts to predict the labor requirements in construction represent a continual concern and interest to worldwide researchers and training institute (e.g. CITB 1988; Briscoe and Wilson 1993; Ball and Wood 1995; Chan et al. 2002; Bromberger and Diedrich-Fuhs 2003). Quantitative techniques have been extensively applied in the decision process and modeling, especially in complex problems that involve several variables. To determine the relationships between variables, multiple regression analysis was undoubtedly the most widely used statistical procedure (Chatterjee and Hadi 1988), and was extensively adopted for prediction of

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manpower demand (Kao and Lee 1998; Bell and Brandenburg 2003).

Although a number of studies were conducted to predict the manpower demand at project level, they were merely modeling simple relationships between manpower requirements and construction cost or productivity rates. Other potential determinants and labor demand by occupation were rarely assessed by researchers to improve the reliability of the forecasts. Moreover these studies tend to estimate total labor demand, the estimation of occupational demand is usually overlooked and not adequately addressed. This study attempts to fill this gap by developing statistical models for forecasting the total labor demand, as well as the needs of essential trades for construction activities using multiple regression analysis.

This paper is organized into six sections. Following this introduction, the section presents foregoing forecasting approaches and sets up the framework within which the project-based manpower demand is estimated. The third section discusses the factors affecting the project labor demand, details of the research methodology including sources of data and the modeling techniques adopted is presented next. This is followed by the empirical results by regression analysis. The robustness and assumption of the developed model are verified with diagnostic tests. The next section discusses the applications and implications of the findings. Limitations of the forecasting models are also presented. Concluding remarks are drawn in the last section.

Overview of Forecasting Methodologies

Research shows that there is a strong relationship between the manpower demand and the size of a construction project. Chan et al. (2002) developed a model using a labor multiplier approach, which was based on the premise that, in each project type, projects will demand the same level of labor requirement per unit of project expenditure and follow a standard demand pattern. This forecasting methodology was originally put into practice by Lemessany and Clapp (1978). Utilizing information collected from site returns of daily labor deployment and the project expenditure on past projects, the labor number for each trade in the form of man-day per million dollar (labor multiplier) covering various markets including public works, railway works, and other public utilities were derived as shown in

$$L_{sx}^{J} = \frac{D_{sx}^{J}}{E_{X}^{J}} \tag{1}$$

The estimated labor demand by occupation can then be projected by multiplying the multipliers and estimated project expenditure as illustrated in

$$L_{S}^{D} = \sum_{x} L_{sx}^{J} E_{x(\text{est.})} \tag{2}$$

Aggregating the occupational manpower demand provides the estimation of the overall labor requirements for a construction project. In Eqs. (1) and (2) L_{sx}^{J}=labor multiplier of trade s at stage x of the project type j; L_{S}^{D}=total labor demand of trade s for a particular construction project; D_{sx}^{J}=labor deployment (man-days) of trade s at stage x of the project type j, E_{X}^{J} is project expenditure (HK\$M) at stage x of the project type j, and $E_{x(\text{est.})}$ estimated project expenditure at stage x.

Chan et al. (2003), based on simple regression analysis, further developed a forecasting model to estimate the total labor required for any given type of project using nonlinear labor demand–cost relationship. The forecasting approach complies with Agapiou et al. (1995) that the labor demand for a construction project is strongly related to the labor productivity, type of project and the volume of work within a particular market sector. Poon et al. (1996) adopted similar forecasting approach to estimate the requirement of technicians in the Hong Kong construction industry, which was also based solely on the employment record of technicians and contract sum for compiling the "number of technicians per million dollars per year." Likewise, Rosenfeld and Warszawski (1993) and CWDFC (2002) applied this multiplier approach for forecasting the demand for construction labor in Israel and Alberta, respectively.

Analogous to the above-mentioned labor multiplier approach, Proverbs et al. (1999) presented the findings of an international study of contractors' productivity rates, from which a novel approach to estimating labor requirements at the inception stage is proposed for typical buildings in France, Germany, and the United Kingdom. Planned productivity rates formed the basis of the estimate, being used to generate labor estimator factors. These factors were defined as the man-hour requirements per square meter of the building's gross floor area. Thereby corresponding factors were applied to predict man-hour requirements for concrete framed building once the gross floor area is known.

In the United States, University of Texas researchers developed a system for predicting manpower requirements associated with preconstruction activities for the Texas Department of Transportation. Regression equations were developed, which also used project type and project cost to forecast engineering-design labor hours (Persad et al. 1995). This research concluded that construction cost and project type are excellent predictors of engineering manpower requirements. Following these research findings, Bell and Brandenburg (2003) adopted similar regression analysis to predict overall manpower requirements for the highway construction projects of a given type and cost in the South Carolina Department of Transportation of the United States. Based on the labor demand–cost relationship, the overall requirements were then adjusted to predict manpower requirements for individual employee classifications using task allocation percentages obtained from a questionnaire survey. The output from the model serves as input into commercially available critical path method scheduling software to facilitate manpower planning and resource leveling.

These forecasting methods are designed to establish fixed coefficients for different categories of building, housing and civil engineering works. The categorization could allow different multipliers to reflect the effect of the different technologies and labor mix used for various project types, and thus different labor productivity in order to result in accurate estimation. They utilize a simple relationship between manpower requirements and its determinant, i.e., construction cost or labor productivity rate, for prediction. Forecasts using this coefficient approach have been verified to be reasonably reliable (Persad et al. 1995; Proverbs et al. 1999).

As for most forecasting models, the fixed coefficient forecasting approach has its constraints. The model needs to be updated to take into account any changes in technology and labor mix, which will generate new sets of labor multipliers. This requires considerable effort and expense to regularly update the database (Wong et al. 2004). It is also considered that the time lag to adjust the multipliers would be a severe constraint to the fixed coefficient approach to reflect the changes on technology, competition, legislation, etc. prudently and timely. Regular and frequent updating

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of coefficients is thus critical for resulting in accurate forecasts. Another constraint in using this kind of forecasting methodology is that it depends heavily on the past data and on the plausible assumption making use of the sole relationship between the specific independent variable and the labor demand.

Factors Affecting Labor Demand

These foregoing forecasting models reveal that a specification of the manpower demand function at project level should be based on an equation taking project size (scope and scale of construction) and project type into consideration. It is expected that the larger the size of the project, the more the site operatives required for a particular project type, given the fact that different construction projects tend to have a different product mix, capital–labor ratio and fixed cost structure. However, literature and pilot study have identified a number of additional factors which have an impact on the requirements of construction site operatives. These include construction method, degree of mechanization, project complexity, management attributes, expenditures on electrical, and mechanical services. They are discussed as follows.

Construction Method

The construction method of an individual project determines the site labor input and mix of skills (Lemessany and Clapp 1978). A residential block, for instance, with traditional load-bearing external walls of brick and block requires significantly more site labor to construction than those, that were built using industrialized systems of construction concrete based. The increasing use of prefabrication, production activities off-site, and the use of other engineering demanding construction methods would cause a reduction in the demand for bamboo scaffolders, glaziers, tillers, plumbers, window frame installers trades, etc., but an increase in plant and equipment operators and prefabricated elements erectors (Tang et al. 2003). A recent study by Tam (2002) indicates that the high degree use of prefabricated components results in over 40% reduction in the consumption of site labor.

Degree of Mechanization

Degree of utilization of mechanization and automation also critically influences the labor demand at site level as labor and capital are the major inputs (Ehrenberg and Smith 2003). In general, the more the inputs of capital, the less the labor required because automation tends to be labor saving (McConnell et al. 2003). Another apparent factor affecting labor demand at project level is the complexity of the construction project (Ganesan et al. 1996). For example, the design of the Bank of China in Hong Kong illustrates the contribution that structural design can make toward savings in resources. Simplified connections for the cross-braced steel truss allowed faster erection and savings in costs. Total steel requirements were about half that of a typical building with the same height. The reduction in the use of steel translated into labor savings in fixing and alignment of frames. Similarly, the design of modern sprinkler and hydrant systems minimizes wiring requirements and associated building services labor needs (Fairweather 1986).

Project Complexity

Gidado and Millar (1992) regarded complexity as factors that hinder performance on site. Project complexity can be expressed as technical complexity of the task, amount of the overall and interdependencies in construction stages, project organization, site layout, and unpredictability of work on site. Handy (1985) regards project size as a single variable in determining the appropriate construction team organization. For this study, four attributes including overall technological complexity of overall project characteristics, site physical site condition, buildability level and complexity of coordination works are considered as the important factors which might have an impact on the project labor demand.

Management Attributes

Labor requirement can also be affected by the management skills of the project team. These skills can be further divided into planning, organizing, and controlling skills (Gould 2002). Better coordination and utilization of plant and labor on sites leads to reduction in manpower requirements (Ganesan et al. 1996). Labor saving design can be achieved through enhanced management and interfacing between different trades, such as electrical and mechanical trades. Better planning of site work can also ensure reduction in labor. For example, in laying pipes and conduits, last-minute changes in design often result in abortive labor (Grunebery 1997).

Expenditures on E&M Services

It is generally recognized that the material costs for electrical and mechanical (E&M) services do not derive labor demand. However, these costs can be very significant and represent a huge portion of the total cost in today's construction. Thus, these costs should be deducted from the total project cost in order to obtain a more robust and reliable demand estimating function.

Taking these factors into account, a novel project labor demand estimate is developed, which can be represented by the following function:

$$L_S^J = f(\mathrm{COST}, \mathrm{PREFA}, \mathrm{MECH}, \mathrm{E\,\&\,M}, \mathrm{COM}, \mathrm{MGT})$$

where L_S^J=total labor demand of trade s for the project type j; COST=project cost (HK$M); PREFA=extent of off-site prefabrication of all construction product components; MECH=extent of mechanization/automation; E&M=material cost on E&M services; COM=project complexity attributes; and MGT=main contractor's overall management of the project.

Research Methodology

Data Collection

In order to derive forecasting models for estimating labor demand at project level, the labor deployment records of public works were first obtained from the Census and Statistics Department (C&SD) of HKSAR Government. These records are available because contractors are required to submit "Monthly Return of Site Labor Deployment and Wage Rates in the Construction Industry" (Form GF527) to the C&SD for public works and public housing projects. The record of the site workers is further broken down into 38 specific trades, reflecting the subcontracting practice in the industry. Labor return data for projects completed between 1998 and 2002 was obtained for this study.

A questionnaire was designed to capture the variables as identified in the section entitled "Factors Affecting Labor Demand."

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Table 1. Determinants of Project Labor Demand

Codes	Explanatory variables	Definition
COST	Final contract amount	In HK$ million
TYPE	Project type	Dummy variable: 1=building; 0=civil
PREFA	Approximate percentage of off-site of all construction product component	1=less than 10%; 2=11–20%; 3=21–30%; 4=31–40%; 5=41–50%; 6=51–60%; 7=61–70%; 8=71–80%; 9=81–90%; 10=91–100%
MECH	Approximate percentage of the expenditure on mechanization/automation of the final contract sum	1=less than 5%; 2=6–10%; 3=11–15%; 4=16–20%; 5=21–25%; 6=26–30%; 7=31–35%; 8=36–40%; 9=41–45%; 10=46–50%; 11=more than 50%
E&M	Approximate percentage of the material cost on E&M services of the final contract sum	1=less than 5%; 2=6–10%; 3=11–15%; 4=16–20%; 5=21–25%; 6=26–30%; 7=31–35%; 8=36–40%; 9=41–45%; 10=46–50%; 11=more than 50%
MGT	Main contractor's overall management of the project	1=extremely ineffective; 9=extremely effective
COM	Technological complexity of overall project characteristics	1=extremely simple; 9=extremely complex
COMA	Complexity of the physical conditions of the construction site	1=extremely simple; 9=extremely complex
COMB	Level of buildability	1=extremely low; 9=extremely high
COMC	Complexity of the coordination works between the design and construction team was complicated	1=extremely simple; 9=extremely complex

In designing the questionnaire, a review of labor demand estimating literature was undertaken. In addition, a series of semistructured interviews with 11 experienced practitioners were conducted to verify the validity of the identified factors. Seven of the interviewees have taken part in the Construction Advisory Board assessing the development of manpower forecasting in the construction of Hong Kong. The remaining participants are the industry practitioners who also have experience in carrying out manpower forecasting or planning at project level. Attempts to obtain too much information would be counterproductive (Bromilow et al. 1988), and consequently ten essentials fields were measured in the questionnaire (Table 1). A pilot study was carried out to test the relevance and comprehensiveness of the questionnaires before a full-scale survey was conducted. Feedbacks from academia, industry practitioners, and HKSAR Government officers were incorporated to fine-tune and finalize the questionnaire.

Six Works Departments with the support and assistance of the Environment, Transport and Works Bureau (ETWB) and the Housing Department were requested to provide details of 75 randomly selected projects. Two Railways Corporations and the Hong Kong Housing Society were also approached to provide occupational labor records and details of the recently completed 22 projects. Letters indicated that the objectives of the research were then sent out to relevant government project officers to invite them to participate in the questionnaire survey. Follow-up telephone calls and electronic communication were made, where possible, to elicit more detailed responses and/or provide further clarifications for any unclear/misunderstood items in the survey. Unfortunately contractor's management performance was considered as sensitive information and could not be obtained.

Consequently, 54 project data were received in total, giving rise to a 55.7% response rate. The quantity of distributed and completed questionnaires returned from the organizations is shown in Table 2. Of these 54 cases, 75.9% are civil projects including Roads & Drains, Service Reservoir, Footbridge, Geotechnical Works, Road Maintenance, etc. The remaining one-quarter (24.1%) are building works, which include education and residential development. The characteristics of the sample projects ranged from HK$2.71M to HK$1906.7M in construction cost; from 10 to 63 months in a contract period; and from 1.1 to 330.2 thousand man-days in site operatives requirement. All the cost values were adjusted by Composite Consumer Price Index

Table 2. Distribution of the Questionnaires Survey

Organizations	Number of questionnaires distributed	Number of valid sample	Response rate (%)
Architectural Services Department (ArchSD)	15	11	73.3
Civil Engineering Department (CED)	10	2	20
Drainage Services Department (DSD)	8	8	100
Highways Department (HyD)	10	10	100
Territory Development Department (TDD)	10	0	0
Water Supplies Department (WSD)	12	12	100
Housing Department (HD)	10	0	0
MTR Corporation Limited (MTRCL)	10	9	90
Kowloon–Canton Railway Corporation (KCRC)	10	0	0
Housing Society (HS)	2	2	100
Total	97	54	55.7

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Table 3. Regression Estimates of Total Labor Demand

Variable		Regression coefficient	T-statistic	Prob$>\|T\|$	Tolerance
INTERCEPT		6.539	38.645	0.000	—
$\log_e$ COST		0.884	28.727	0.000	0.852
COM		−0.092	−3.280	0.002	0.735
COMA		0.059	2.335	0.024	0.765
TYPE	Building	−0.178	−1.713	0.094	0.924
	Civil	0	—	—	—
	Regression equation characteristics:				
	$R^2=0.953$	$s=0.3016$	D.W.=2.109		
	Adj. $R^2=0.949$	$F(4,45)=230.399$	$p=0.000$		
	$N=50$	Jarque-Bera stat.=0.770			

(CCPI) before they were entered for analysis. This aims to single out price movements caused by changes in general price levels of the economy.

Developing Labor Demand Models

Multiple linear regression analysis was considered the most suitable technique to derive the relationships between the variables (Chatterjee and Hadi 1988; Kao and Lee 1998). A stepwise selection procedure with a significance level of 5% was used to select statistically significant variables to be incorporated into the model. Data variables were added one at a time and the regression model rerun noting the changes at each step in the coefficient of determination (R^2) value and, more importantly, the significance level of variables. Only those variables with a value of p less than 10% were included in the final regression equations. De Vaus (1996) states that the coefficient (R^2) indicates how much variation in the dependent variable is explained by a group of independent variables; and the higher its value, the more powerful the model. Adjusted R^2, which attempts to more realistically reflect the goodness of fit of the model, was used to compare and identify the best-fit regression model.

The data on construction cost and labor man-days displayed lognormal distributions, i.e., the distribution approached the normal distribution when natural logarithm was taken. This also allows examining the log relationship between the two variables. Apart from estimating the total labor demand for a particular project, regression models were also developed for ten essential trades: bar bender and fixer; carpenter (formwork); concreter; electrician/electrical fitter; excavator; laborer; metal worker/general welder; plant and equipment operator (earthmoving machinery); plasterer; and truck driver. The labor demand values for these trades were also transformed to logarithm form as $\ln(L_s+1)$, where L and s, respectively, indicate the quantitative labor demand (in man-days) and the specific trade. This transformation is necessary as nil demand for some trades was observed in the project labor deployment records.

As part of the analysis, the Cronbach alpha reliability was produced. Cronbach alpha reliability (the scale of coefficient) measures or tests the reliability of the scale used for the study (Norusis 2002). The technique was employed to examine the internal consistency among the responses under the percentage of expenditure on mechanization/automation; the percentage of expenditure on E&M services, the percentage of prefabrication; and the four project complexity attributes. The Cronbach's coefficient alpha is 0.6227 (F statistics=39.0054, $p=0.0000$), indicating that the scale used for measuring the aforementioned factors influencing project labor demand is reliable at the 5% significance level.

Formulating a reliable regression model requires a few more tests for checking its validity and reliability. Examination of residuals is an important diagnostic procedure that assists in checking the underlying assumption in regression analysis, with particular attention to those related to the error term (Montgomery et al. 2001). Therefore, the resultant model was further tested by applying regression diagnostics, for any potential problems of (1) multicollinearity using tolerance value; (2) heteroscedasticity by a residual analysis; (3) normality by examining Jarque-Bera statistics; and (4) "influential" cases (outliers) using Studentized residual, Cook's distance and other relevant indicators (Belsley et al. 1980; Kenkel 1989). With the intention of utilizing as many samples as possible to build the forecasting model and to facilitate effective validation, 50 samples projects formed the modeling data set, whereas the remaining four projects were randomly selected and used to evaluate the performance of the model. The computer software (SPSS for Window Version 11.0) was chosen as the statistical tool for the analyses in the study.

Results of the Analysis

Models Estimation

A total of 11 regression model equations were derived to model the total manpower demand and specific trades for a particular project. The regression results for the total project labor demand are presented in Table 3. The estimated regression equation for total project labor demand is:

$$\begin{aligned}\ln L_{\text{total labor demand}} &= 6.539 + 0.884 \log_e \text{final contract amount in HK \$ M} - 0.092 \text{ overall project technologically complexity} \\ &\quad + 0.059 \text{ complexity of the physical site conditions} + \text{project type (0 for civil projects; } -0.178 \text{ for building projects)}\end{aligned} \tag{3}$$

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The regression model produced an estimate of total labor demand in man-days with respect to the CCPI based at October 1999–September 2000 as issued by the Census and Statistics Department. The results from the best-fit run of multiple regression analysis for each project show a p-value of less and 0.10 and R^2 values of 0.95, which implied a good-fit and robust model. This indicates that 95% of the variation in total labor demand can be explained by this equation. The value of T-statistics reveal that the total project cost is the most important variable in determining the overall labor demand. The demand is also significantly influenced by over project complexity, followed by site condition complexity, and project type. Analogous to the modeling approach for total labor demand, regression equations were derived for the quantitative demand of the ten selected labor trades. The variables included in the equations are presented in Table 4. The results of the F tests verify that the specifications of the regression equations are adequate and significant.

Validity of the Models

To test the validity of the model, the predicted values of labor demand computed from regression equations are compared to actual values projects. The forecasting performances of the models are evaluated using four out-of-sample project records, as shown in Table 5. The mean absolute percentage error (MAPE) for the total labor demand is found to be 10.14%, which marginally falls on the general acceptable limit of 10%. The MAPE of the ten selected trades range from 8.12% (for laborer) to 22.27% (for electrician), given the MAPE for occupational labor demand as 14.84%. It is common to observe that the error at occupational level is higher than that of the aggregated level, due to the variation of the occupational demand. The result of evaluation confirms that the forecasting performance of the developed model is superior to the current model applied by the Education Manpower Bureau of the HKSAR which yields MAPE 21.16% (Wong et al. 2005).

Some diagnostic tests are also performed to check the reliability of the forecasting models. Multicollinearity problem has been checked using the tolerance collinearity statistics among the independent variables in each of the regression model equations. All tolerance values are larger than 0.01, indicating no multicollinearity problem is posed. The influential cases (outliers) have been detected through "influence analysis" following the methodology suggested by Chan and Kumaaswamy (1999), and consequently excluded during the derivation of the respective model equations. Jarque-Bera statistics were examined to test normality as shown in Tables 3 and 4. If the residuals are normally distributed, the Jarque-Bera statistics should not be significant (QMS 2000). The results of the residual analysis indicate that each of the residual series, with the exception of that of Electrician/Electrical Fitter (0.0139), all the probability values of normality test are far greater than 0.05. In addition, residuals variance was scrutinized to inspect the existence of heteroscedasticity. Fig. 1 shows a residual plot for the total labor demand estimation model. It reveals that the residuals are randomly scattered in a band clustered around the horizontal line through 0. Similar patterns were found for various labor demand models. Hence, it can be interpreted that the assumption of homogeneity of variance is met. These diagnoses demonstrate that, in general, the basic assumptions underlying the multiple regression analysis have not been violated.

Table 4. Regression Equations Derived for the Demand Estimation of the Ten Selected Trades

Labor trade	Labor demand regression equations	R^2	Adj. R^2	Sig. of F	Jarque-Bera stat.
Bar Bender and fixer (N=49)	$\ln(L_{\text{bar bender}}+1)=0.169+1.429\ln \text{COST}^{***}-0.337\ \text{COMB}^{**}+0.333\ \text{COMC}^{**}-0.540\ \text{E\&M}^{***}+0.368\ \text{MECH}^{*}$	0.708	0.674	20.871***	2.5468
Carpenter (formwork) (N=47)	$\ln(L_{\text{carpenter}}+1)=3.758^{***}+1.031\ln \text{COST}^{***}-0.174\ \text{PREFA}^{***}+0.116\ \text{COMC}^{***}-0.099\ \text{COMA}^{**}-0.118\text{E\&M}^{**}$	0.929	0.920	106.568***	1.0043
Concreter (N=50)	$\ln(L_{\text{concretor}}+1)=2.495^{**}+1.106\ln \text{COST}^{***}-0.428\ \text{COM}^{***}$	0.434	0.410	18.409***	1.5152
Electrician/electrical fitter (N=50)	$\ln(L_{\text{electrician}}+1)=2.251+0.832\ln \text{COST}^{***}-0.479\ \text{COMA}^{**}+0.382\ \text{COMB}^{*}+0.493\ \text{MECH}^{**}$	0.335	0.276	5.670***	6.3458**
Excavator (N=50)	$\ln(L_{\text{excavator}}+1)=0.815+0.878\ln \text{COST}^{***}-0.494\ \text{COM}^{**}+\text{TYPE}^{**}$ (0 for civil; 2.099 for building)	0.418	0.473	17.136***	0.5105
Laborer (N=50)	$\ln(L_{\text{laborer}}+1)=6.371^{***}+0.772\ln \text{COST}^{***}-0.119\ \text{MECH}^{**}+\text{TYPE}^{**}$ (0 for civil; −1.017 for building)	0.871	0.863	103.740***	0.8746
Metal worker/welder (N=50)	$\ln(L_{\text{metal worker}}+1)=0.0604+1.208\ln \text{COST}^{***}+\text{TYPE}^{*}$ (0 for civil; 1.314 for building)	0.511	0.490	24.583***	1.6297
Plant and equipment operator (N=48)	$\ln(L_{\text{plant operator}}+1)=3.286^{***}+0.990\ln \text{COST}^{***}+\text{TYPE}^{***}$ (0 for civil; −2.047 for building) $-0.262\ \text{PREFA}^{***}+0.168\ \text{COM}^{**}-0.195\text{E\&M}^{*}$	0.807	0.784	12.416***	0.3090
Plasterer (N=50)	$\ln(L_{\text{plasterer}}+1)=2.395^{*}+0.812\ln \text{COST}^{***}-0.444\ \text{COMA}^{**}+\text{TYPE}^{***}$ (0 for civil; 3.708 for building)	0.518	0.487	16.479***	1.3399
Truck driver (N=49)	$\ln(L_{\text{truck driver}}+1)=3.192^{***}+0.632\ln \text{COST}^{***}+\text{TYPE}^{***}$ (0 for civil; −6.096 for building) $+0.275\ \text{COMB}^{**}$	0.721	0.702	38.706***	3.9913

Note: ***=t-statistic significant at 0.01 level; **=t-statistic significant at 0.05 level; *=t-statistic significant at 0.1 level; and N=number of sample projects.

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Table 5. Evaluation of Labor Demand Forecasts

Labor	Project 1 Projected	Project 1 Actual	Project 1 Percentage error	Project 2 Projected	Project 2 Actual	Project 2 Percentage error
Total	81,241	87,294	−6.93	76,614	89,040	−13.96
Bar bender and fixer	6,181	8,110	−23.79	17,285	15,287	13.07
Carpenter (formwork)	1,465	1,560	−6.06	1,005	1,152	−12.73
Concreter	1,598	1,199	33.25	1,397	1,567	−10.84
Electrician/electrical fitter	5,675	7,868	−27.87	4,789	4,515	6.07
Excavator	1,559	1,816	−14.15	7,189	8,842	−18.69
Laborer	12,506	14,327	−12.71	19,856	22,025	−9.85
Metal worker/general welder	3,322	2,831	17.34	4,832	4,734	2.07
Plant and equipment operator	1,571	1,394	12.71	2,748	2,739	0.32
Plasterer	4,489	5,255	−14.57	30	0	—
Truck driver	6	0	—	2,366	2,131.4	10.99

Labor	Project 3 Projected	Project 3 Actual	Project 3 Percentage Error	Project 4 Projected	Project 4 Actual	Project 4 Percentage error
Total	2,936	2,724	7.78	220,824	250,606	−11.88
Bar bender and Fixer	12	15	−20.16	34,441	38,630	−10.84
Carpenter (formwork)	203	185	9.84	25,153	22,246	13.07
Concreter	23	24	−3.32	2,054	1,535	33.80
Electrician/electrical fitter	50	46	8.19	1,596	1,436	11.17
Excavator	1	0	—	16,148	18,988	−14.96
Laborer	1,834	1,691	8.43	47,185	46,498	1.48
Metal worker/general welder	87	73	18.84	2,992	2,378	25.83
Plant and equipment operator	158	193	−18.06	26,349	29,538	−10.80
Plasterer	11	0	—	41	0	—
Truck driver	168	361	−53.57	4,666	4,563	2.25

Note: $MAPE_{\text{total labor demand}}=10.14\%$ and $MAPE_{\text{occupational labor demand}}=14.84\%$.

Discussion of the Results

Significant Variables in the Regression Model Equations

Wong et al. (2005) state that inaccurate estimations might be due to the plausible assumption which is based solely on the relationship between the labor demand and the contract value. The analyses of this study demonstrate that the accuracy and reliability of the labor demand prediction model can be improved by inserting other significant variables. Nevertheless, construction cost is still the most significant determinant of labor demand. It appears in all regression equations of labor demand at 1% significance level. However, the identification of other less significant variables should not be overlooked; an appreciation of the relative strengths of these variables (in terms of their influence on the corresponding dependent variables) is a useful product of the study.

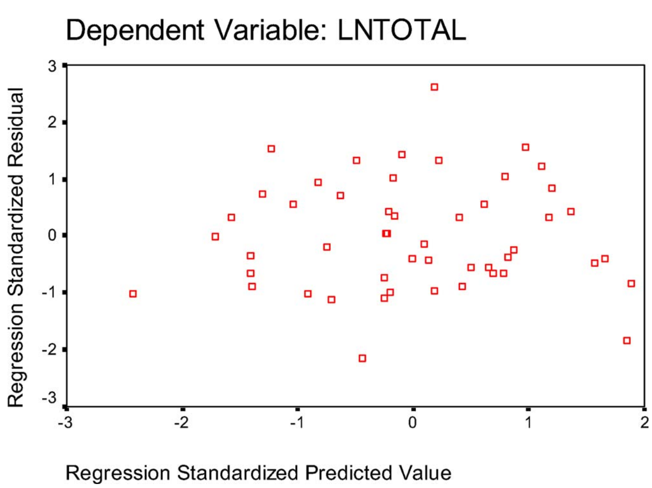

Fig. 1. Residual plot of the dependent variable ln total labor demand

Among the 50 sample projects under scrutiny, regression analysis identified that the total labor demand for a construction project is significantly affected by construction cost, overall project complexity, physical site condition, and project type. This is consistent with the determinants as identified by Agapiou et al. (1995) and Ganesan et al. (1996). It is interesting to note that the project complexity is inversely influencing labor demand, i.e., the more the complex the project, the less the labor required. One possible but profound reason may be the complex projects require more mechanization and capital input than a relatively labor-intensive project as suggested by McConnell et al. (2003).

At occupational level, it was found that project type has an important role to determine the labor requirements. For instance, building projects require more metal workers/general welders but fewer plant and equipment operator as compared with civil engineering projects. The complexity attributes, which include physical site condition, buildability level and complexity of coordination works, also contribute significantly to individual site operative demand such as bar bender and fixer, electrician/electrical fitter, carpenter (formwork), concretor, excavator, truck driver, and plant and equipment operator. The regression analysis

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reveals that the expenditures on E&M services and on mechanization did not significantly affect labor demand. A small amount of bar bender and fixer and laborer is reduced, which is accountable by those expenditures. In addition, it is found that merely plant and equipment operator will be affected if more prefabrication components are used in a project.

Limitations of the Models

Although the models generate some useful and statistically valid results, it is acknowledged that the models are subject to the following limitations.

1. The predictions of the model may at times be imprecise, unless viewed in the context of the parent database. Caution has to be exercised in respect of the magnitude of the possible error in the prediction compared to the standard deviation of the dependent variable, as this suggests a measure of the reliability that can be placed in the forecasts.
2. Every observation in the original data set made an important contribution to the regression fit of the final model equations. As a result, any inaccurate project information or labor deployment records could have caused distortion in the model and thereby its forecasting performance. However, influential analysis on the model helped to identify and exclude such influential cases to overcome this kind of problem.
3. The model must be reviewed and updated from time to time in order to incorporate any innovations or marked changes in the areas of design, technology, construction method, which may affect the labor requirements and the categorizations. It is therefore advisable to expand the database on a regular base and hence enhance its predictive accuracy.
4. The result was derived from a sample of 50 projects, which may not be sufficient to develop meaningful regression models for all project and labor categories.
5. There is time lag of the model for the changes of inter alia, technology mix, as well as legislation. For example, legislation on caisson piling has dramatically changed the types of laborers employed and thus the regression coefficient. Such changes can be reflected by constantly updating the regression equations.

Practical Applications of the Estimation Models

Notwithstanding the limitations identified above, the closeness of fit in both in- and out-of-sample between the predicted and actual labor demand provides sound evidence for the model usefulness and reliability for determining quantitative project labor demand. Construction organizations such as contractors and consultants could gain benefits from formulating and reinforcing their planning and monitoring for labor demand estimates. The estimation equations can serve as convenient tools for predicting the total labor demand and the demand of essentials trades for a construction project promptly, from limited project information at the initial stage. This provides an advanced and objective method of estimating project labor demand to supplement the current practice of estimation based mainly on the individual's experience and unreliable estimation method. The equations also serve as an important benchmark for future research to study the manpower forecasting and labor productivity at project level. The forecasts provide solid information for human resources planning and labor cost estimations.

With the aid of the labor demand estimation equations, the relevant authorities can assess the number of jobs created by their investment on the public expenditure. The labor requirements (in man-days) computed by the equations can be translated to number of jobs created by substituting into

$$\text{Number of jobs created} = \frac{\text{Total labor requirements (man-months)}}{\text{Project duration (months)}} \tag{4}$$

The number of jobs created in a project is defined as the equivalent number of persons engaged full-time throughout the whole project period. It represents the equivalent number of workers to be engaged throughout the individual whole year. Given the severe unemployment problem in the construction industry recently, the HKSAR government could apply this model to check and compare the degree of contribution made to jobs by forthcoming public works projects of various types.

Conclusions

A review of the relevant literature and pilot study sought a set of factors considered to affect project labor demand. These identified factors were used to constitute an investigation survey that investigated determinants of labor demand of construction projects in Hong Kong. Labor records and project information from a total of 50 construction projects were collected to develop the labor demand prediction models, applying multiple regression analysis. 11 manpower demand forecasting models were developed for the total labor and ten essential trades. The models were then verified by comparing the predicted values with the out-of-sample actual values. Accompanied by the results of the diagnostic tests, it was confirmed that the forecasting models are robust and reliable.

This research provides a series of algorithms and models for predicting construction project labor requirements as function of labor demand determinants. The results indicate that project total labor demand depends not only on a single factor but a cluster of variables related to the project characteristics including construction cost, project complexity, physical site condition, and project type. In addition, project cost and project type have an important role in determining the occupational labor requirements. Complexity attributes, expenditures on E&M and mechanization are also found to be significantly influencing individual labor trades. Because data were not available indicating the breakdown of labor demand on each project type and labor category, further investigation is therefore recommended to collect data and update the regression models once enough data points are collected for detailed estimations.

The forecasting models provide practical and advanced tools for contractors and consultants to predict the reasonable labor required for a new construction project at the initial stage, which are valuable to facilitate human resources planning and budgeting. The HKSAR government could also assess the number of jobs created by their investment on the public expenditure. The equations serve as an important benchmark for future research to study the manpower forecasting and labor productivity in the construction industry. The research methodology used may be applied to develop similarly useful models in other subsectors, and in other countries.

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