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MODELLING BUILDING SUB-CONTRACTOR PERFORMANCE: A CASE STUDY OF THE NSW CONSTRUCTION INDUSTRY

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Abstract

The management of building subcontractors, the role they play, their importance and significance in the building process is slowly becoming acknowledged in the management levels of the building industry. The purposes of this paper are: (1) to identify factors influencing the performance of subcontractors (2) to determine the impact of subcontractors performance on the overall project performance; and (3) to develop models for the prediction of building subcontractors performance. Data was obtained from surveying subcontractors (from different trade backgrounds) and builders through the use of questionnaires. The findings show that the performance of subcontractors is a significant factor in the overall performance of building projects. Suggestions are given for further studies.

Keywords: Building subcontractor, Performance, Trade, Modelling, Building industry.

Modeliranje uspješnosti građevinskih podugovarača: studija slučaja firme *NSW Construction Industry*

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Sažetak

Upravljanje građevinskim podugovaračima, uloga koju imaju, i njihov značaj u procesu građenja polako postaju priznati u rukovodećim krugovima u građevinarstvu. Ciljevi rada su: (1) identificirati čimbenike koji utječu na uspješnost podugovarača, (2) utvrditi utjecaj uspješnosti podugovarača na cjelokupnu uspješnost projekta, (3) razviti modele za predviđanje uspješnosti građevinskih podugovarača. Podaci su dobiveni iz upitnika provedenog među podugovaračima (različitih struka) i građevinarima. Nalazi pokazuju da je uspješnost podugovarača značajni čimbenik cjelokupne uspješnosti građevinskih projekata. U radu se sugeriraju dalja istraživanja.

Ključne riječi: građevinski podugovarač, uspješnost, struka, modeliranje, građevinarstvo

1. Introduction

The management of building subcontractors, the role they play, their importance and significance in the building process is slowly becoming acknowledged in the management levels of the building industry.

Several factors are responsible for the neglect of subcontractors in the construction management literature. Firstly, the performance of subcontractors in the achievement of cost, time, and quality objectives is rarely documented. Delays on a construction project resulting from the non-performance of a sub-contractor is normally absorbed by the builder who can only seek extensions of time via a "compensatory" or "excusable" type of delay [1]. Examples of "compensatory" or "excusable" types of delays are additional work, and industrial disputes. There is therefore no substantial need for builders to record or document any delays due to the non-performance of sub-contractors (ie. their ability to meet builder's requirements), since these are non-compensatory or non-excusable delays.

Another factor responsible for the neglect of building subcontractors by researchers in construction management is their position in the construction project hierarchy. Because they occupy a position at the bottom of the hierarchy, subcontractors are looked down upon by other practitioners in the industry.

One of the few research studies on subcontractors is that of [2]. The study examined the management problems encountered in integrating the contributions of sub-contractors into project organisations. The study found that subcontractors valued "integration" and that this had a stronger influence on them than "control"

1.1 Model of building process

[3] proposed a general model of organisation systems comprising of several subsystems which include:

(i) A subsystem of it's broader environment.

(ii) A technical subsystem - People using knowledge, techniques, equipment, and facilities.

(iii) A structural subsystem - People working together on integrated activities.

(iv) A psychosocial subsystem - People in social relationship.

(v) A managerial subsystem - Planning and controlling the overall endeavour; co-ordinating the other subsystems.

[3] further identified two output dimensions of organisational performance - effectiveness and efficiency. Effectiveness is concerned with the accomplishment of explicit or implicit goals while efficiency refers to the ratio of output to input, or benefit to cost.

The general model described above can be applied to the building site organisation system (see Fig.1). The building site organisation system includes not just the builder but all parties involved including but not limited to: the union, safety committee and subcontractors. The system shown in Fig.1 includes subcontractor performance under the goals and values subsystem. Figure 2 illustrates a conceptual model of subcontractor performance system. The figure illustrates factors which influence subcontractor performance. Figure 3 describes the subsystems of the system components.

1.2 Objectives

The purposes of this paper are:

(i) to identify factors influencing the performance of subcontractors;

(ii) to determine the impact of sub-contractors' performance on the overall project performance; and

(iii) to develop models for the prediction of building subcontractors' performance.

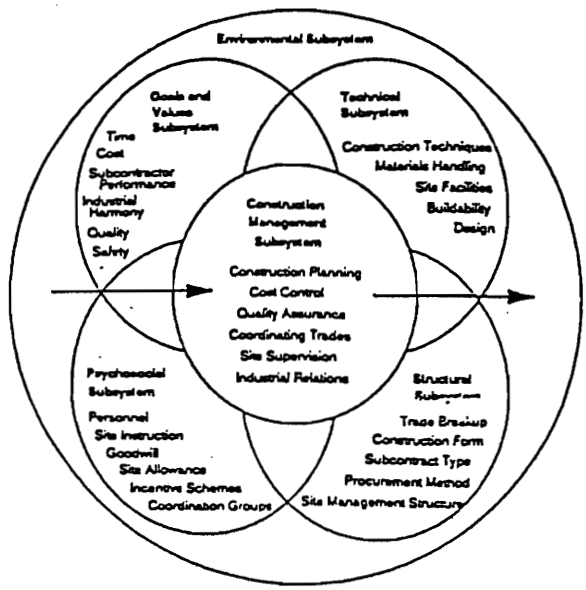

Fig. 1: Author's modification of Kast and Rosenzweig, 1985

Figure 1 - THE CONSTRUCTION SITE ORGANISATIONAL SYSTEM

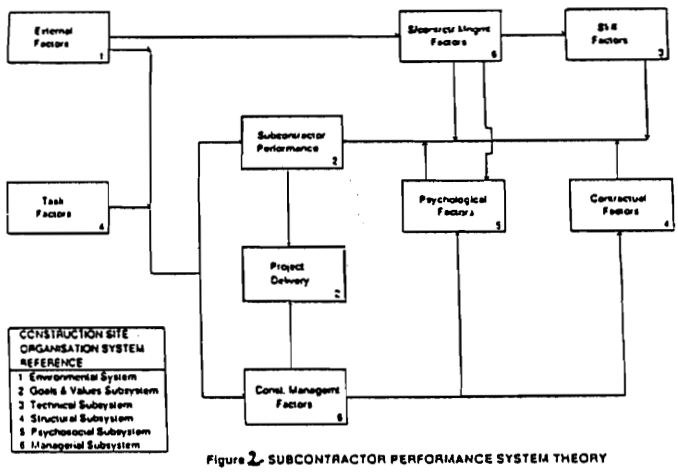

Figure 2 - SUBCONTRACTOR PERFORMANCE SYSTEM THEORY

Fig.2: Author's contribution

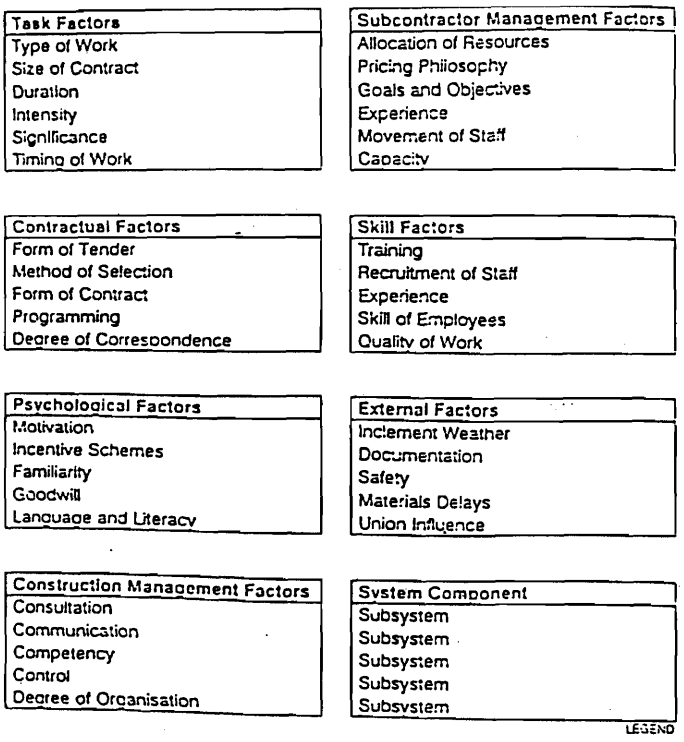

Figure 3 - THE SUBCONTRACTOR PERFORMANCE SYSTEM COMPONENTS AND THEIR SUBSYSTEMS.

Fig.3: Author's contribution

2. Research methodology

Data were collected through the use of two questionnaires. The first questionnaire was sent out to site managers of the construction organisations in New South Wales. 45 were distributed and 33 were returned representing a response rate of 73.3%. The second questionnaire was related to a specific construction project as defined by the person completing it. Questions were asked relating to conditions which existed on the project in relation to seven defined trades: formwork, bricklayer, windows/facade, hydraulic services, electrical services, and lift services. The questionnaire sought to determine the impact of sub-contractors' performance on the overall project performance. Furthermore the questionnaire for building subcontractors were also sent to the managing directors of 100 different trade subcontractors in Sydney. 61 questionnaires were returned representing

response rate of 61%. As with the first questionnaire, the second questionnaire was project specific as defined by the person completing it. The purpose of the questionnaire was to secure data for the development of models for assessing and predicting building subcontractors' performance.

3. Data Analysis and Results

3.1 Trade significance

Tables 1 and 2 show the builders' ratings of the degree of importance to overall project performance of the seven different subcontractor trades identified for study (divided into new work and refurbishment type projects). An index is developed by multiplying the percentages against the selector variable. Table 3 shows a ranking of the trades in order of importance using the index. The results show that of the seven subcontractor trades surveyed, the formwork is the most significant. Next in declining order of ranking are the lift services, facade/window contractors and electrical services. The least three trades vary according to the type of project (ie. new or refurbishment).

Table 1 Builders' ratings of significance of subcontractor trades to overall project performance (new projects)

	Formwork	Bricklayer	Windows	Plumber	Electrical	Mechanical	Lift
Insignificant	0.0%	5.6%	0.0%	0.0%	0.0%	0.0%	0.0%
Minor	0.0%	22.2%	16.7%	11.1%	0.0%	5.6%	6.7%
Average	0.0%	38.9%	16.7%	55.6%	66.1%	38.9%	40.0%
Major	22.2%	22.2%	27.7%	22.2%	16.7%	44.4%	20.0%
Highly significant	77.8%	11.1%	38.9%	11.1%	22.2%	11.1%	33.3%

Table 2 Builders' ratings of significance of subcontractor trades to overall project performance (refurbishment project)

	Formwork	Bricklayer	Windows	Plumber	Electrical	Mechanical	Lift
Insignificant	0.0%	6.7%	0.0%	0.0%	0.0%	6.7%	0.0%
Minor	13.3%	20.0%	13.3%	6.7%	0.0%	13.3%	8.4%
Average	13.3%	26.7%	26.7%	60.0%	60.0%	40.0%	25.0%
Major	40.0%	33.3%	33.3%	26.6%	33.3%	26.7%	33.3%
Highly significant	33.4%	13.3%	26.7%	6.7%	6.7%	13.3%	33.3%

Table 3 Summary of builders' ratings of significance of subcontractor trades to overall project performance

Trade	Index (New Project)	Index (Refurbishment Project)
1. Formwork	4.78	3.94
2. Windows/Facade	3.89	3.92
3. Lift Services	3.80	3.73
4. Electrical Services	3.61	3.47
5. Mechanical Services	3.61	3.33
6. Plumbers	3.33	3.27
7. Bricklayers	3.11	3.27

Furthermore, Table 4 below shows the seven trade profile characteristics of the subcontractor trades in relation to overall project performance.

Table 4 Trade profile characteristics

Trade profile	Number of Questionnaire Sent out	Received	Rate %	Range of trade contracts ($)
Formworker	12	8	66.7	275,000 to 7,300,000
Bricklayer	9	6	66.7	10,000 to 1,500,000
Curtain Wall/Facade	5	5	100.0	655,000 to 3,340,000
Hydraulic Services	11	8	72.7	365,000 to 5,417,000
Electrical Services	10	8	80.0	46,000 to 5,500,000
Mechanical Services	10	8	80.0	328,000 to 7,600,000
Lift Services	7	6	85.7	111,000 to 5,700,000

3.2 Modelling Subcontractor Performance

The analysis of the factors which influence subcontractor performance can only be adequately carried out by looking at trades individually. Due to the great variety of works carried out on a building site, an overall comparison is difficult to obtain in regard to performance appraisal.

Multiple regression analysis was used to develop performance models for each of the subcontractor trades investigated in this study. The performance indicators used is Gross Construction Time.

3.2.1 The Assumptions of the model

The general single-equation linear regression model, which is the universal set containing simple (two-variable) regression and multiple regression as complementary subsets, may be represented as:

$$Y = a + \sum_{i=1}^{K} b_i X_i + u \quad (1)$$

Where y is the dependent variable

$X_1, X_2, \ldots X_i \ldots X_K$ are K independent variables

a and b_i are the regression coefficients, representing the parameters of the model for a specific population, and

u is a stochastic disturbance-term which may be interpreted as resulting from the effect of unspecified independent variables and/or a totally random element in the relationship specified.

3.2.2 Empirical Analysis

The first trade model to be developed and tested is Formworker (Gross Construction Time in Weeks, GCP)

The general function can be represented as

$$GCP = f(COORD, MJOB, BComp, PDOCS, LANG) \quad (2)$$

Where

COORD = Builder's success in coordinating work with other trades

MJOB = Employees attitude to doing a good job

BComp = Competency of builder's staff

LANG = Language and literacy barriers of employees

[4] reported that the general function hypothesis is that the dependent variable and the explanatory variables vary linearly and non-linearly in accordance with the following expressions:

$$GCP = \alpha_1 + \alpha_2(COORD) + \alpha_3(MJob) + \alpha_4(BComp) + \alpha_5 (PDOCS) + \alpha_6(LANG) \quad (3)$$

Where $\alpha_1, \alpha_2, \alpha_3, \ldots \alpha_6$ are coefficients or parameters to be estimated.

The derived expression is:

$$GCP = 319.0 + 836.7(COORD) + 329.9(MJob) - 484.2(BComp) + 174.7(PDOCS) - 138.4(LANG)$$

The above equation reveals that as COORD, MJOB and PDCOS increases, GCP also increases, while GCP decreases as BCOMP and LANG increases. Furthermore, the variables of quality and doing a good job are significant when comparing the overall quality appraisal of this trade. The standard of the structural drawings seem to be important to progress. This trade (Formworker) probably more than any other contains workers of non-English speaking background and this is evident in this trade. The coefficient of determination (Adj R square) of the above equation is shown in Table 5. All the variables in the equation were statistically significant at the 1 percent level.

The second trade model to be tested is trade-Bricklayer

$$GCP = f(BORG, GDWILL, INCL, SELECT) \quad (5)$$

Where BORG = Builder's general organisational ability
GDWILL = Goodwill between builder and subcontractor
INCL = Degree of inclement weather
SELECT = Tender selection method

The general function can be represented by:

$$GCP = \beta_1 + \beta_2 (BORG) + \beta_3 (GWILL) + \beta_4 (INCL) + \beta_5(SELECT) \quad (6)$$

The derived function is:

$$GCP = -2045 + 1407(BORG) - 997(GDWILL) + 476(INCL) + 71(SELECT) \quad (7)$$

The coefficient of determination (Adj. R square) is given in Table 5. The negative regression coefficients show that an increase in Goodwill generally brings about a corresponding decrease in Gross Construction Time, while increases in Builder's general organisational ability, Degree of inclement weather and Tender selection method generally bring about a corresponding increase in Gross Construction Time. The above model suggest an increase in builder's organisational ability and the goodwill between the two parties results in greater performance. As might be expected inclement weather is a factor in the Gross Construction Time.

The third trade to be tested is Curtain Wall/Facade which is a function of the degree of inclement weather, union influence on employees and the success rating of subcontract co-ordination meetings. However, the derived function is:

$$GCP = \delta_1 + \delta_2(INCL) + \delta_3(UWBEM) + \delta_4(MSUC) \quad (8)$$

Equation (8) can be re-written as

$$GCP = 591.5 - 763(INCL) + 443.5(UWBEM) - 315(MSUC) \quad (9)$$

The above equation reveals that GCP decreases as the degree of inclement weather and the success rating of subcontract co-ordination meetings increase, whilst an increase in union influence on employees increase Gross Construction Time. It is very interesting to note that the union influence on this trade is significant, probably due to the safety aspect of the work. Notwithstanding, the nature of the trade lends itself to external influence such as inclement weather.

The fourth trade to be tested is Hydraulic Services.

$$GCP = f(GDWIL, OTHMT, BCOMP, COORD, UWFL) \quad (10)$$

where GDWIL = Goodwill between builder and subcontractor

OTHMT = Other trades present at coordination meetings

BCOMP = Competency of builder's success in coordinating work with other trades

UWFL = Union influence on performance

The above function can be re-written as:

$$GCP = \phi_1 + \phi_2(GDWIL) + \phi_3(OTHMT) + \phi_4(BCOMP) + \phi_5(COORD) + \phi_6(UINFL) \quad (11)$$

The derived final equation is:

$$GCP = 691.5 - 143.6(GDWIL) + 160.9(OTHT) + 126.9(BCOMP) + 470.2(COORD) - 324.8(UINFL) \quad (12)$$

The above equation reveals that the positive signs of regression coefficients show that an increase in other trades present at coordination meetings, competency of builder's staff, and builder's success in coordinating work with other trades generally leads to an increase in Gross Construction Time, while the negative regression coefficients show that an increase in goodwill between builder, subcontractor and union generally brings about a corresponding decrease in overall Gross Construction Time. The resulting coefficient of determination (Adj. R square) is given in Table 5. .Furthermore, the builder seems to have considerable impact on the performance of this trade- Hydraulic Services by such means as continuity, successful coordination, competency and goodwill. This would suggest the reason for programme input being a contributing factor towards performance and highlights the importance of goodwill in the control of building projects.

The fifth trade to be investigated is Electrical Services. The overall Gross Construction Time (GCT) is a function of Familiarity between subcontractor and builder (FAMIL), union influence on performance (UNIFL), continuity of work provided by the builder (CONTN), and the degree to which builder utilised subcontractors tender programme (TPROG), and number of years the subcontractor has been in business (YEARS). The derived function is:

$$GCP = \varpi_1 + \varpi_2(FAMIL) + \varpi_3(UNIFL)\ \varpi_4(CONTN) + \varpi_5(TPROG) + \varpi_6(YEARS) \quad (13)$$

The empirical equation is:

$$GCP = 12463.9 - 2258.2(FAMIL) + 1981.7(UNIFL) - 1631.9(CONTN) - 1531.2(TPROG) - 14.5(YEARS) \quad (14)$$

The negative regression coefficients from the above equation show that an increase in familiarity between subcontractor and builder, continuity of work provided by the builder, degree to which builder utilised subcontractors, tender programme, and number of years the subcontractor has been in business generally brings about a corresponding decrease in overall Gross Construction Time, while increase in gross construction time generally brings about a corresponding increase in union influence on performance. The (Adj. R square) of this equation is shown in Table 5.

Notwithstanding, the greater complexity of the trade is evidenced by the lower direct impact of single variable on performance, and a number of varied factors seem to induce performance including experience and familiarity between the subcontractors and builder.

The sixth trade to be investigated in this paper is Mechanical Services.

$$\text{Gross Construction Time} + f(INCL, UNIFL, BCOMP, MSUC, COORD) \quad (15)$$

where

INCL = Degree of inclement weather

UNIFL = Union influence on performance

BCOMP = Competency of builder's staff

MSUC = Success rating of subcontractor coordination meetings

COORD = Builder's success in coordinating work with other trades

The derived function is:

$$GCP = \varepsilon_1 + \varepsilon_2(INCL) + \varepsilon_3(UNIFL) + \varepsilon_4(BCOMP) + \varepsilon_5(MSUC) + \varepsilon_6(COORD) \quad (16)$$

This equation can be re-written as

GCP = 8081.6 - 609.7(INCL) - 1450.8(UNIFL) - 395.8(BCOMP) + 170.0(MSUC) - 101.9(COORD) (17)

This equation reveals that an increase in INCL, UNIFL, BCOMP and COORD is associated with decrease in GCP, while, increase in GCP is associated with increase in MSUC. The explanatory variables could explain 99% of variation in dependent variable(GCP). Furthermore, the complex nature of the trade provides for a range of factors which collectively and individually relate with the calculated performance levels. Union influence seems to have a positive effect together with the builders' various capabilities.

The final trade (Lift Services) model to be tested combined with tender selection method, the presence of a bonus scheme for early completion, familiarity between subcontractor and builder, and union influence on performance. Gross Construction Time is a function of the above mentioned variables.

GCP = Θ1 + Θ2(SELECT) + Θ3(BONUS) + Θ4(FAMIL) + Θ5(UNIFL) (18)

The derived function is:

GCP = 13595.5 + 2285.7(SELCT) - 4200.7(BONS) - 2378(FAMIL) - 512.3(UNIFL) (19)

Table 5 gives the resulting of coefficient of determination (Adj. R square). The above regression coefficients suggest that an increase in BONS, FAMIL and UNIFL generally brings about a corresponding decrease in Gross Construction Time, while increase in Gross Construction Time is associated with increase in tender selection method. It should be noted here that the value of the work has a definite relationship with performance. The presence of a bonus scheme does seem to provide the desired incentive as does the method of selecting the successful tenderer.

Table 5: Regression Coefficients

Trade	Model	Adj. R square
Formworker	GCP	0.997
Bricklayers	GCP	1.000
Curtain Wall/Facade	GCP	0.998
Hydraulic Services	GCP	0.993
Electrical Services	GCP	0.996
Mechanical Services	GCP	0.990
Lift Services	GCP	0.998
Where GCP = Gross Construction Time Adj. R square = Coefficient of Determination		

Conclusion

The study shown that the performance of subcontractor is a significant factor in the overall performance of building projects.

Consistently throughout the different subcontractor trades the ability to meet programmes dominates the builders' performance appraisal. From the site manager's perspective it is clearly the most significant objective to attain. Other key factors with which builders appraise subcontractor performance are: the quality of work produced by the subcontractor, the skill of tradespeople employed by the subcontractor, the level of goodwill between the two parties, and the ability of the subcontractor to efficiently allocate resources.

In the Gross Construction Time performance models developed, one can see that high coefficients of determination were achieved for all trades. This analytical method of performance determination, if properly adopted, could become a powerful planning mechanism for site managers in the future. Further study in this area can be carried out to enlarge and increase the number of subcontractor trades sampled and routine the measurement techniques of some of the variables. This may involve studying each trade individually or alternatively concentrating on specific projects.

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