SUBCONTRACTOR RESOURCE ALLOCATION IN A MULTI-PROJECT ENVIRONMENT – FIELD STUDY

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ABSTRACT

Various strategic considerations lead construction companies to reduce their core staff and employ subcontractors. Productivity is a critical determinant of profitability for subcontractors working under unit price contracts. When the flow of work on any project is unstable or unreliable, they are forced to adjust their resource allocations across the multiple projects on which they work in parallel. Earlier research explored subcontractors' economic motivation; this research explores project managers' and subcontractors' behaviours de facto, through 57 in-depth interviews with experienced practitioners. The work focused on the decision-making process in allocating limited resources across multiple projects. Motivating factors other than productivity, such as cash flow, financial exposure, motivation and reputation, project work flow, etc. were explored. The main results show that productivity and work flow are in fact the primary motivating factors; that more than 50% of project managers use push control in a way that prevents subcontractors from achieving their desired productivity rates; that subcontractors believe on average that approximately 60% of the work promised will in fact become available on schedule, and therefore engage in overbooking; and that project managers tend to respond by exaggerating their resource demands by an average 20%. These findings support the hypothesis that mistrust and competition, rather than cooperative behaviour, are the norm. They form the basis for continuing research toward a descriptive theoretical model of the multi-project subcontracted environment.

KEY WORDS

Subcontracting, behaviour model, resource allocation, field survey, decision-making.

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INTRODUCTION

Subcontracting is common in construction (Elazouni and Metwally 2000). Although the intent is to make the industry as a whole more productive and efficient, it is not clear that these goals have been achieved. Many authors have questioned why measures of construction efficiency and productivity have remained static or declined, with a majority of projects finishing over-budget and behind schedule (Bertelsen 2002; Egan 1998).

Subcontractors typically work on many projects at the same time, and are most commonly employed through unit price or lump sum contracts. As a result, management of labour allocations in subcontracting firms is focused on maintaining high productivity, which can be seen as local optimization within the framework of individual projects. (Sacks 2004) proposed a simple model of the economic utility for subcontractors that showed how subcontractors protect themselves against low productivity resulting from plan instability in construction projects by providing fewer resources than demanded by project managers for any given task. The relationship between profitability per unit work done to the ratio of work provided to work demanded is plotted in Figure 1 as the profitability curve (k is the ratio of resources supplied to resources demanded). The subcontractor's profitability is dependent on the ratio of the quantity of work that can actually be performed to the quantity of work that was demanded, and declines in non-linear fashion when insufficient work is provided. However, the subcontractor can protect against this dependence by reducing the resources assigned to the project. In this case, the resources allocated to the project are less than what is required (k<1).

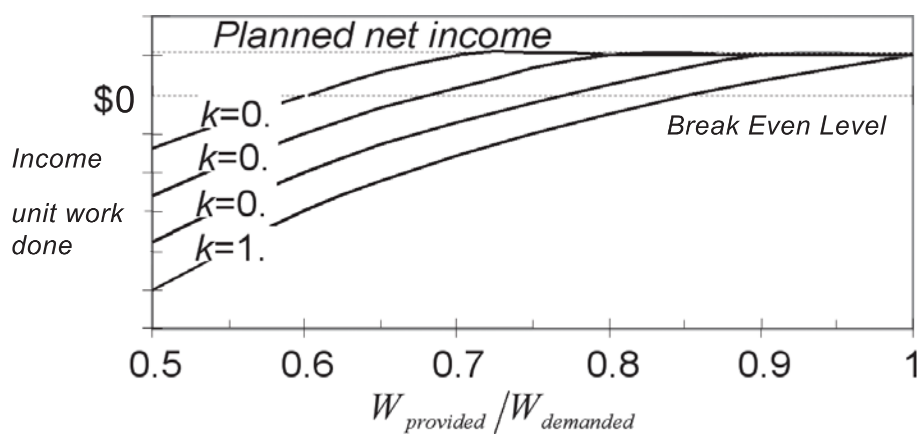

Figure 1. Typical plot of subcontractor's net income per unit of work as a function of the ratio of actual work performed to work demanded (Sacks 2004).

The economic formulation was then used to calculate the expected utilities for subcontractors in a game theory formulation, using the extensive form, to model the respective behaviour of both subcontractors and project managers for general contracting organizations in the periodic setting of demand for resources and their allocation at the project level (Sacks and Harel 2006). In the game theory formulation the players are the work planner and the subcontractor. Each makes 'moves', one after the other, through repeated cycles of the game. In each round of the game, the work planner sets the amount of work to be performed by each subcontractor in each task *i* in each period. In response, each subcontractor evaluates the demand and the amount of work they perceive will actually become available, and then supplies the resources it deems appropriate.

The *extensive form* of game theory analysis (Osborne and Rubinstein 1994) is useful in this situation because the moves are sequential and because both work planner and subcontractor have imperfect knowledge about the outcome in terms of the work that will actually be accomplished (i.e. they cannot predict with certainty how much work will be made available by the upstream contractors, or whether design changes, material delays, weather conditions or other factors will interrupt or slow work). The extensive form can be repeated in order to examine long-term strategies that develop as the parties respond to one another's previous actions and develop a relationship over time, which may facilitate cooperative behaviour (Lazar 2000) The solution of the game theory model (Sacks and Harel 2006) showed how conscious undersupply of resources by subcontractors, and exaggeration of demand by project managers operating in the same conditions, are stable equilibrium behaviour.

However, the economic formulation and the game theory model are based on a single motivating factor for the subcontractor – profitability as a function of productivity. In reality, there are numerous additional factors that influence resource allocation decisions. The component of the research presented here explores additional factors such as cash flow; contract terms such as bonuses or fines; financial exposure risk; future resource allocation commitments; personal motivation; promise of future work; reputation; and workflow stability. The starting assumption is that subcontractors behave rationally within the scope of their decisions, i.e. they are motivated by personal gain and will work to maximize their own utility without consideration of that of any individual project manager in a multi-project environment.

BACKGROUND

A number of strategic factors lead construction companies to reduce their core work force and employ subcontractors for large parts of projects. Among them:

- increased trade specialization required to execute increasingly sophisticated building systems, including greater investment required for equipment and professional training (Elazouni and Metwally 2000; Kumaraswamy and Matthews 2000; Tommelein and Ballard 1998; Walsh et al. 2003).

- the perception that subcontractors execute work at faster rates and lower costs than general contractors working with their own staff (Arditi and Chotibhongs 2005; Coombs and Palmer 1977),

- general contractors wish to spread risks and transfer the risks to other parties (Elazouni and Metwally 2000).

The residential construction sector in particular employs more subcontractors than others (Clough and Sears 1994), with 80%-90% of the work performed by subcontractors (Hinze and Tracey 1994). Despite their importance in construction projects, and their almost exclusive responsibility for productivity in many projects (Adrian 1987; Hsieh 1998), they have not received appropriate attention in research (Shash 1998).

The relationship between subcontractors and project managers of general contractors is generally tense and prone to argument and discord, creating an environment of inherent mistrust (Proctor 1996). Project managers are focused on individual projects and are under constant pressure to perform well in terms of budget and schedule; subcontractors, on the other hand, operate simultaneously across numerous projects and tend to take a broader view toward maximizing their utility across all projects (Sacks 2004).

Pushing subcontractors to perform work even when site conditions do not allow for its completion as planned, such as when one or more of the preconditions are incomplete, reduces productivity (Howell et al. 1993; Thomas et al. 1989). This is nevertheless the practice on many sites, and because it is done without regard for subcontractors' productivity levels, subcontractors do not allocate all potential resources and often hide true resource availability information from the general contractor (Choo et al. 1999).

The basic conflict is made worse in situations where plans are unstable. Many authors have explored the influence of instability on productivity in construction (Hanna et al. 1999; Moselhi et al. 2005; Sacks et al. 2005; Tommelein et al. 1999). Some claim that the construction industry as a whole exploits resources in a dynamic way using a variety of methods to keep resources (labour and equipment) on site under constant pressure, with the result that certain activities are performed even if they are not absolutely necessary in adding direct value to the project (Alves and Tommelein 2004).

METHODOLOGY AND RESULTS

An extensive set of structured interviews was undertaken with the primary goal of determining the factors that influence subcontractors' decision making patterns when making periodic resource allocation decisions. The survey included interviews with 28 experienced project managers (average 12.5 years in construction) and 29 senior managers of subcontracting companies in Israel that function across multiple projects simultaneously (average 23.4 years in construction). The survey population is detailed in Table 1. The survey was implemented using a structured questionnaire. However, the questionnaires were presented to the respondents in face to face interviews in order to allow the interviewer to probe the degree of accuracy and reliability in interviewees reporting of their subjective perception of their own behaviour and the motivations behind it.

Three goals were defined for the survey:

a. to determine the additional decision factors (beyond the profit motive accounted for in the economic model) that determine resource allocation decisions,

b. to determine the relative importance of each decision factor,

c. to establish a broad but detailed basis for developing a more comprehensive economic-behavioural model of subcontractor resource-allocation behaviour.

All of the interviewees reported that traditional lump-sum or unit price contract forms were the norm in their activities. None reported the existence of long-term contractual relationships or partnering arrangements that extended beyond individual projects. The structure of the interviews with project managers and subcontractors are detailed in Tables 2 and 3 respectively.

Due to the need for brevity, only the questions and responses most relevant to the ensuing discussion and conclusions are presented.

Table 1. Survey sample demographics.

Survey sample demographics		Average	Std. Deviation	Minimum value	Maximum value
Project managers for general contractors (N=28)					
Years in present company		6.42	3.62	1	12
Experience in construction (years)		12.50	8.03	1	27
Subcontractors (N=29)					
Years in present company		14.66	10.43	1	35
Experience in construction (years)		23.41	9.83	5	40
Salaried employees	Engineers	7.11	6.21	1	20
	Supervisors	9.84	8.43	2	30
	Skilled workers	25.69	18.06	3	60

Table 2. Structure of project managers' interview form.

Section	**Question subject**	**Question type**	**Number of criteria/statements**
1. Demographic data	Identity, experience, project types	Fill in data	11
2. Attitudes to managing subcontractors	Subcontractor selection criteria Prioritise criteria	"	8
	Subcontractors' perceptions of selection criteria	"	8
	Subcontractors' factors for resource allocation	"	8
	Knowledge, skill and practice of production management	Express degree of consent with statements	4
	Perception of subcontractors' reliability	Select percentage range	
	Perception of own reliability	"	
	Patterns of subcontractor behaviour in allocating resources	Express degree of consent with statements	3
	Patterns of own behaviour in demanding resources	"	2
3. Conditions at the project the interviewee was managing currently	Production planning and management	Express degree of consent with statements	22
	Credit and capital	"	2
	Motivation and human resources	"	6
	Contractual relationships	"	8

Considerations for entering into project relationships.

The results show that economic considerations of profit and risk predominate in the decisions project managers make in selecting subcontractors and in the way that subcontractors consider the projects they will undertake. Table 4 shows that the contract price was the main criterion for subcontractor selection on the part of project managers. 37.9% of project managers ranked this criterion highest in their rank ordering, ahead of reliability, experience, and flexibility in the face of change. On the other hand, the main criterion chosen by the subcontractors in selecting for which projects to bid was the financial stability of the general contractor. This criterion was chosen and ranked highest by fully 64.3% of the interviewees.

Table 3. Structure of subcontractors' interview form.

Section	Question subject	Question type	Number of criteria/ statements
1. Demographic data	Identity, experience, company size	Fill in data	9
2. Attitudes to general contractors	Perception of GC's subcontractor selection criteria	Prioritise criteria	8
	Criteria for selecting jobs to bid on	"	8
	Factors affecting resource allocation	"	8
	Perception of project managers' reliability	Select percentage range	
	Ad-hoc provision of resources	"	
	Patterns of own behaviour in accepting work and allocating resources	Express degree of consent with statements	3
	Perception of project managers' reliability	"	1
	Motivation	"	2
3. Conditions at one typical current project	Project attributes (size, equipment, staff, etc.)	Fill in data	11
	Project manager behaviour	Select percentage range	3
	Production planning and management	Express degree of consent with statements	11
	Credit and capital	"	2
	Motivation and human resources		6
	Contractual relationships		8

Resource allocation behaviour

One of the questions required subcontractors to rate the factors influencing their resource allocation decisions on a sliding scale from 1 to 8. Table 5 provides both the count of top scores given to each factor and a combined average score calculated using all the responses for all of the factors. The two most important factors were productivity and workflow stability.

Table 4: Distribution of highest rank-ordering of criteria for project managers' selections of subcontractors.

Criterion	Occurrence of highest ranking		Average	Standard Deviation
	Number	Proportion of sample (%)		
Lowest price	11	37.9	6.45	1.88
Experience	5	17.2	5.31	1.47
Reliability	3	10.3	5.07	1.79
Financial stability	3	10.3	4.76	2.03
Friendships	3	6.9	4.41	2.58
Work quality	2	6.9	3.72	2.09
Timeliness	2	6.9	3.34	2.45
Flexibility to change	1	3.4	2.90	1.97
Total responses	29	100		

Table 5: Distribution of highest rank-ordering of criteria for subcontractors' resource allocation decisions.

Factors influencing decisions	Frequency of highest score	Percentage of highest scores	Combined Average Score	Std. Deviation
Capacity utilization - productivity	7	25.0	5.57	2.08
Workflow stability	6	21.4	5.43	2.30
Contractual commitments	5	17.9	4.79	2.40
Level of financial exposure	4	14.3	4.68	2.11
Cash flow	3	10.7	5.18	2.02
Reputation and prospects for future projects	1	3.6	4.18	1.83
Commitments to future resource assignments	1	3.6	4.04	2.12
Motivation	1	3.6	2.14	1.74
Total responses	28	100%		

Note: The significance of the differences between the factor ratings was checked using a one-way analysis of variance. Significant differences were found; with $F(7,189)=6.81$, $p<.001$. A Bonferroni test showed that 'Motivation' is rated lower than all other factors.

Mutual perceptions of trust and level of confidence in resource allocations

One of the factors that were found to harm the trust between subcontractors and project managers and so to reduce the stability of projects was the low productivity that subcontractors reported achieving. Subcontractors claimed that in only 55.5% (on average) of situations did project managers enable them to work with the most productive crew possible for any given task. With regard to the need to expedite work on site, just over 50% of the project managers concurred that they frequently force subcontractors to begin work in projects even when the work of the preceding trade teams is not complete to a degree that allows the newcomers smooth and productive work.

A set of two questions to each type of respondent explored the degree of reliability in demanding and allocating resources. Project managers were asked these two questions:

1. *When you demand resources from a subcontractor, what percentage of the work you promise do you think the subcontractor believes that you will actually provide?* The results (Table 6) show that more than 75% of project managers assume *a-priori* that the subcontractors will act on the assumption that they will provide less than 80% of the work planned. This indicates that project managers perceive that their reliability in the eyes of the subcontractors is low, and appears to confirm the behaviour predicted by the economic model.

Table 6. Project managers' perception of subcontractors' trust.

What percentage of the work you promise do you think the subcontractor believes that you will actually provide?	**Number of responses**	**Percentage**
0% - 20%	0	0
21% - 40%	1	3.4
41% - 60%	4	13.8
61% - 80%	17	58.6
81% - 100%	7	24.1
Total	29	100

2. *When you demand resources from a subcontractor, to what degree do you exaggerate your report of the amount of work that will actually be available?* This question is corollary to the first. The responses (Table 7) indicate that many project managers attempt to counter the subcontractors' lack of trust in them, and consequent undersupply of resources, by exaggerating their demands: 48.3% of the respondents confirmed that they exaggerate their demands by at least 20%.

Table 7. Project managers – exaggeration in reporting work ready.

To what degree do you exaggerate your report of the amount of work that will actually be available?	**Number of responses**	**Percentage**
0% - 20%	15	51.7
21% - 40%	9	31.0
41% - 60%	3	10.3
61% - 80%	0	0
81% - 100%	2	6.9
Total	29	100

Two similar questions were posed to the subcontractor managers:

3. *What proportion of the work promised by the project manager do you believe will actually be made ready?* Table 8 shows that more than 85% of the subcontractors believe that less than 80% of the work will be made ready. The average amount of work ready expected was only 60%, with a standard deviation of 19.7%. This shows a lack of trust, and it too is consistent with the behaviour predicted by the economic model.

Table 8. Subcontractor managers – faith in project managers' assessments of work ready.

What proportion of the work promised by the project manager do you believe will actually be made ready?	**Number of responses**	**Percentage**
0% - 20%	1	3.7
21% - 40%	3	11.1
41% - 60%	8	29.6
61% - 80%	11	40.7
81% - 100%	4	14.8
Total	27	100

4. *What proportion of labour demanded 'ad hoc' by a project manager will you typically provide?* This question differs from the previous three in that it relates to a situation where labour is demanded on short notice, not necessarily in direct relation to a planned activity. The average resource level that would be supplied was only 49% of that demanded (Table 9).

Table 9. Subcontractor managers – provision of resources demanded 'ad hoc'.

What proportion of labour demanded 'ad hoc' by a project manager will you typically provide?	**Number of responses**	**Percentage**
0% - 20%	7	25.0
21% - 40%	1	3.6
41% - 60%	11	39.3
61% - 80%	8	28.6
81% - 100%	1	3.6
Total	28	100

The survey results also show that 82% of the project managers agree or strongly agree that subcontractors generate buffers of future available work, in other projects, to an extent where they commit themselves to multiple general contractors beyond the limits of the capacity of their own resources. This practice is commonly termed 'overbooking'. Among the subcontractors, 64% concurred to a strong degree that this practice is common.

It could be argued that one of the reasons for lack of reliability in demanding resources on the part of the project manager is that they attempt to follow the original master plan. However, although most project managers agreed that they are directed by the pre-planned project schedule throughout the project, 41.4% agreed that in practice they schedule resources according to short term needs rather than planning execution over the long term. The conjecture that project managers stick to the original schedule in order to allocate resources appears unfounded.

Although the sample is small, the results show that lack of trust between project managers and subcontractors in negotiating subcontractor resource allocations is a common feature of traditional construction contracting. They also confirm that the assumption that productivity and workflow stability are very important considerations for subcontractors is not unreasonable.

DISCUSSION AND CONCLUSION

The basic assumption behind this work is the observation that in day to day construction work, typical subcontractors must allocate resources to multiple projects on which they operate simultaneously in such a way as to optimize their profitability. Where subcontractors build up an order-book of future work beyond the scope of the resources they control, using an 'overbooking strategy', and function across multiple projects, they can ensure full occupation of their resources and have a better chance of achieving planned levels of productivity by moving resources from project to project.

The fact that project success is dependent to a large degree on appropriate resource allocation makes the subcontractor's problem relevant to the project manager. As such, there is a need to make subcontractors' resource allocation decision-making motivations apparent and well understood by project managers. It is assumed that subcontractors continuously evaluate conditions at all the projects under execution at any given time and then act to allocate resources so as to optimize their expected utility across all projects. But what is the nature of their utility function? The economic model developed by Sacks (2004) is limited in two ways: it evaluates a single project in isolation, and it incorporates only the economic aspect of the subcontractors' utility. The survey reported in this work identified and evaluated additional decision factors that must be included in the utility function and also painted a broader and more accurate picture of the subcontractors' resource allocation behaviour in multiple project environments under traditional short-term construction contracting arrangements.

The economic model and the survey results both support the hypothesis of dissonance and mistrust between project managers and subcontractors which is manifested as opportunistic behaviour (pursuit of a localized optimum), rather than cooperative behaviour, on the part of subcontractors when allocating resources under the conditions that result from traditional short-term construction contracting arrangements. This behaviour appears to be inherent, since each party has substantially different motivations. When project managers promise a certain amount of work, the subcontractors surveyed believed that in the region of 60% of the work was actually available. Additional questions posed in the survey established that subcontractors attempt to cope with this by providing fewer resources than demanded at start and/or by delaying the start of work until buffers of work ready could accumulate. On the other hand, as many as 52% of the project managers surveyed reported consistently exaggerating the amount of work that would be available by an average 31%. It would appear that each is reacting to their perception of the other's behaviour, as predicted by the normal form game theory model.

Because each subcontractor is dependent on the continuing successful completion of work packages by preceding work teams, lack of trust and reliability in resource allocations has a snowball effect and creates a cycle of mistrust in which the project managers' ability to provide stable work conditions is in itself adversely affected by any previous subcontractors' opportunistic behaviour. It is likely that this state of affairs reduces the plan reliability of projects. This could be tested for in future research by measuring the degree of subcontracting present in a large sample of projects for which percent plan complete (PPC) values are available (Bortolazza et al. 2005), and attempting to identify any correlation between the two measures.

The survey results as a whole point to two possible ways of coping with subcontractors' tendency to local optimization of productivity at the expense of global project flow:

- Reduction of subcontractors' risk from low productivity by establishing a 'risk protection' framework as an integral part of the construction subcontracting contract. The goal of such a provision would be reasonable distribution of the risk of plan unreliability between general contractor and subcontractors.

- Improvement of plan reliability over the long term through application of lean construction techniques such as pull flow, using methods such as the Last Planner. The benefit of this approach for subcontractors is strongly indicated by the emphasis placed by the subcontractors in the survey on issues of production control.

In summary, the single-factor economic model and the results of this survey provide a foundation for development of a multi-factor utility function for subcontractor resource allocation behaviour that can form the kernel of a model of subcontractor behaviour in a multi-project environment. In addition, the understanding that they provide may be useful in consideration of contractual changes and their potential impact on subcontractor behaviour, and by extension, on plan reliability of construction projects.

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