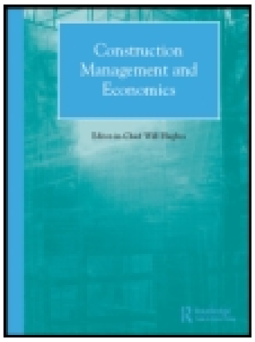

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Application of AHP in improving construction productivity from a management perspective

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Poor productivity of construction workers is one of the major causes of cost overruns and schedule slippages in construction projects. Anecdotal evidence suggests that workers' attitudes towards higher productivity may not be limited to purely financial rewards, but inherently linked to many other latent factors. Some building construction projects in Melbourne are compared to each other to ascertain the factors that influence productivity. The factors and their relative importance impacting on workers' productivity are investigated by using a structured questionnaire survey approach. The survey was formulated with 72 questions covering three broad categories, namely (1) project planning; (2) incentives/disincentives; and (3) job satisfaction. Perceived best practices that impact on improvement of productivity on site were identified from 19 targeted experts. Analytical hierarchy process shows that the biggest influences on productivity are planning and programming. The outcome of this study should assist management decisions in determining the effect on productivity and suggest possible improvements to establish the appropriate management procedures for most productive use of labour resources in construction projects.

Keywords: Analytical hierarchy process, productivity, site management.

Introduction

Construction productivity is a comparison between input and output, and is an increasingly important issue (Allmon *et al.*, 2000). Poor productivity can cause cost overruns and schedule slippages on large, labour-intensive construction projects (Picard, 1998). One of the challenges of assessing productivity is to identify which of the myriad of factors that influence project performance actually caused the variance in construction productivity (Klanac and Nelson, 2004). These factors can include project characteristics, site conditions, project execution, weather effects, supervision effects, management techniques, local labour market conditions and availability of tools and construction equipment (Productivity Commission, 1999). The goal of project management in construction is achieved through the effective utilization of five major resources, namely, machinery, material, manpower, money and management (Allmon *et al.*, 2000). Of these, manpower is the most complex and volatile resource and often difficult to manage. Prediction of manpower levels and productivity targets present a significant challenge to the project management team (Hanna *et al.*, 2005). This research aims to highlight the perceived cause and effects of low labour productivity and to provide possible methods to alleviate these symptomatic problems to the industry.

In construction projects, manpower is the only significant resource that is totally managed in the field (Hargreaves, 1994). Successful manpower and labour productivity management can result in a competitive edge in construction (Teicholz, 2001). In order to identify and analyse dominant management issues affecting productivity in construction, a questionnaire survey approach was adopted. By using the analytical hierarchy process (AHP), prioritized numerical scales are generated representing the relative performance of the perceived solutions to improving productivity (Saaty, 1980).

Background review

Over the past few decades, the increasing popularity of fixed price contracts and liquidated damages for late

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project delivery has led to an integral change in the commercial construction industry (Maloney, 1981). Greater flexibility in working arrangements along with increased use of technology has significantly impacted on construction site productivity (Productivity Commission, 1999). A strong culture of negotiation at industry/trade, enterprise and project levels allows the head contractors, employer associations and unions to make most workplace-related arrangements, leaving limited scope for any change in practices among employers and employees (Moselhi *et al.*, 2005). Where wage increases are negotiated at an industry/trade level without any corresponding productivity improvement, a rise in unit labour cost is inevitable (Klanac and Nelson, 2004). Contractors', unions', employers' and trade associations' influences on work conditions discourage innovative subcontractors from introducing more productive or efficient work arrangements in their enterprises and thus act as a constraint on future productivity growth (Gulezian and Samelian, 2003; Hanna *et al.*, 2005).

A labour-intensive construction industry means that labour-related costs account for around 30–50% of overall project cost (Guhathakurta and Yates, 1993). However, while numerous labour productivity studies have been undertaken, only a few have addressed the productivity issues from the labour management perspective. Based on a study in Nigeria, Olomolaiye *et al.* (1998) suggested the need for establishing productivity output figures through appropriate time study techniques. A study in the construction industry in Singapore by Lim and Alum (1995) indicated that the most important problems affecting productivity were: difficulty with recruitment of supervisors and workers, a high rate of labour turnover and absenteeism, and communication problems with foreign workers. A separate study by Olomolaiye *et al.* (1996), on factors affecting productivity of craftsmen in Indonesia, indicated that only 75% of productive time was spent by the craftsmen on the project. Five specific productivity problems identified were: lack of materials, rework, absenteeism, shortage of tools and equipment. Rojas and Aramvareekul (2003) reported the 10 most significant problems affecting construction productivity in Thailand. They are: lack of materials, incomplete drawings, incompetent supervisors, lack of tools and equipment, absenteeism, poor communication, short instruction time, poor site layout, inspection delay and rework. Motwani *et al.* (1995) reported five factors impeding productivity in the USA, namely, adverse site conditions, poor sequencing of works, conflicting drawings/lack of information, non-availability of tools and materials and poor weather. Lim and Alum (1995) argued that lack of integration of the site management practices only leads to low, if not negative, measures of overall construction productivity.

Factors affecting construction productivity

The level of productivity on a construction site depends on a combination of integrated conditions throughout the project life cycle and the idea of productivity cannot be viewed in isolation. Improving site conditions, management and supervision, proper payment procedures on completed works, avoiding labour density and improved scheduling are some of the important factors when attempting to limit productivity losses on site (Odeh and Battaineh, 2002; Rojas and Aramvareekul, 2003). An essential step towards improvement is a clear appreciation and understanding of the severity of each factor on site (Allmon *et al.*, 2000). Consequently, considerable efforts to understand the concept of productivity have resulted in a wide variety of definitions in the field (Pilcher, 1997; Oglesby *et al.*, 2002; Klanac and Nelson, 2004). Productivity improvement can be viewed as a function of management as changes for improvement can only be implemented at management level (Parham and Zheng, 2006). The short-lived construction project life cycle and project-based management hinder progressive improvements in work conditions and management. The practice quickly gets lost if the contractors move to another site where the same conditions and requirements are not strictly enforced (Borcherding, 1976; Bullinger and Menrad, 2002). However, a study that aims at establishing a best practice model for productivity improvement should be a significant contribution in the industry (Cox *et al.*, 2003). Despite the considerable efforts on this front, researchers have not agreed on a universal set of factors with significant influence on productivity, nor has any agreement been reached on the classification of these factors (United Nations, 1965; Lim and Alum, 1995; Olomolaiye *et al.*, 1998; Teicholz, 2001; Rojas and Aramvareekul, 2003; Enshassi *et al.*, 2007).

The influence of employees on construction productivity has not been found to be widespread (Borcherding, 1976, Edwards and Eckblad, 1984). Many researchers cited ineffective management as the primary cause of poor productivity rather than an unmotivated and unskilled workforce (Sanvido, 1998). There is no doubt that management effectiveness ultimately determines profitability in most cases. Allmon *et al.* (2000) revealed four primary ways of increasing productivity through management, namely (1) planning; (2) resource supply and control; (3) supply of information and feedback; and (4) selection of the right people to control certain factors. Lam and Tang (2003) reported that employees' work environment, the ability to perform their designated role and motivation are the main factors influencing their performance in an organization. Hackman and Oldman (1980) identified five core job characteristics, namely skill variety, task identity, task significance, autonomy and feedback from job, potentially affecting the motivation of a worker. Skitmore *et al.* (2004) concluded that there are a few key factors that demotivate workers on civil engineering works. The factors are poor interpersonal relationships, poor worker attitude, poor workmanship and the work itself. The most dominating demotivator however, was noted as being that of rework, followed by overcrowded work areas, crew interfacing and tool availability and inspection delays. Schein (1992) revealed the workplace culture and differential management practices as the main drivers impacting on construction productivity. Blockley and Godfrey (2000) state that a fear of job loss if productivity increases is substantial among onsite employees and is an important impediment when considering the productivity issue across the global industry sector. Picard (1998) suggested that real productivity improvement programmes are distinguished by measurement and communication of key performance indicators on site. When workers are provided with a sense of purpose and dignity in respect of their work, their attitudes and feeling are positively reflected in their work along with their organizational commitment. Accurate measurements of current practice, trends and productivity would enable improvements in performance. Internal benchmarking is an important assessment measure for organizations to adopt to determine performance, productivity rates and to validate their cost-estimation databases (Sherif, 1996).

From the above review, it is clear that management practice has a distinctive link with construction productivity. There are certainly many critical attributes such as financial/non-financial factors, tangibles and intangibles that influence the employees' work environment in any given project. These attributes, if not understood and handled properly, may be detrimental for the success of future projects (Adrian, 2001).

Research method

The implications of an unproductive workforce are significant because of the resulting consequences such as poor workmanship, poor time management and poor use of resources; an unproductive workforce will also be unsafe and unprofitable. In order to identify the important productivity factors associated with management practice, a questionnaire was prepared based on available literature on the principles of productivity in the workforce (Guhathakurta and Yates, 1993; Lim and Alum, 1995; Olomolaiye *et al.* 1996; Picard, 1998; Wachira, 1999; Adrian, 2001; Teicholz, 2001; Cox *et al.*, 2003; Lam and Tang, 2003; Rojas and Aramvareekul, 2003; Skitmore *et al.*, 2004; Hanna *et al.*, 2005; Doloi, 2007; Enshassi *et al.*, 2007). The input also covers the reviews of research conducted in various areas of labour productivity in different industries for a point of comparison (Borcherding, 1976; Hanna *et al.*, 2005). These factors were divided into three major criteria: (1) planning; (2) incentives; and (3) job satisfaction. Each criterion was further subdivided into nine sub-criteria, which are illustrated in a latter section. The data were then analysed by using the analytical hierarchy process (AHP), which established the prioritized solutions to improving productivity in construction projects. From the analysis, conclusions have been drawn and suggestions for further study have been highlighted.

The framework for analysis

Selecting the most appropriate alternative from a set of alternatives and eliciting the consistent subjective judgement from the decision makers in the selection process require a holistic analysis. In general, computerized decision support systems allow performing such selection process effectively. Some of the past researchers have adopted questionnaire survey approach for data collection in measuring various success and failure attributes and employed mathematical tools such as AHP (Saaty, 1980), artificial neural networks (ANN) (Hyde *et al.*, 2003) and statistical techniques such as factor analysis and multivariate regression (Iyer and Jha, 2005) for analysis and drawing conclusions. Selection of mathematical tools for analysing data depends on the nature of the problem and the availability of reliable data. Learning from the historical dataset is one of the important aspects for application of ANN (Hung and Jan, 1999). Availability of historical information over a long period of time and effective data gathering are the keys in ANN application, which could be a challenging task in the construction industry sector. Use of statistical analysis in identifying critical attributes in construction engineering practice is quite widespread (Hanna *et al.*, 2005; Iyer and Jha, 2005). Statistical analysis mainly relies on the documented evidence of past practices, which requires significant population data from reliable and valid sources.

However, one of the major limitations of the statistical analysis is that it cannot be used decisively for resolving conflicting objectives (Uddamari, 2003). Multi-objective decision-making approaches provide a convenient set of mathematical tools to identify an optimal alternative given a set of competing objectives (Enshassi *et al.*, 2007). AHP is one such multi-objective decision-making technique considered appropriate for this study (Saaty, 1980).

One of the major advantages of AHP is that the analysis does not always require statistically significant sample size (Dias and Ioannou, 1996). AHP uses a number of pairwise comparisons between quantitative or qualitative criteria to assess the relative importance of each criterion (Dey, 2003). These can be arranged in a hierarchical manner known as a 'value tree' for sets of attributes, and qualities (levels) within these attributes. The simplicity of the AHP approach is that, unlike other 'conjoint' methods, the qualities (or levels) of different attributes are not directly compared. The AHP approach thus removes the need for complex survey designs and can even be applied (in an extreme case) with only a single respondent (Saaty, 1980; Zahedi, 1986; Schot and Fischer, 1993). As the input data in AHP analysis are based on an expert's perceived judgement, a single input usually represents a group of representatives in the sample data (Golden *et al.*, 1989; Schot and Fischer, 1993). Other conjoint methods such as choice experiments do not realize statistically robust results unless there is a sizable number of usable survey responses. Most conjoint analyses place quite a high 'cognitive burden' on respondents in that they are asked to make comparisons across options that have a large bundle of attributes and levels of these attributes. In contrast, under AHP, respondents are not asked to make choices between all criteria and thus respondents are less likely to adopt mental short cuts by concentrating disproportionately on one attribute or level (Saaty, 1980; Schot and Fischer, 1993).

Measuring consistency in judgements

In the application of AHP, inconsistency in pairwise comparisons may be introduced as a result of a number of factors such as lack of adequate knowledge, improper conceptualization of hierarchy and even lack of statistically significant sample size, etc. A consistency ratio is generated for each prioritized scale upon completion of carrying out the pairwise comparison. It is used to determine the consistency of the judgements. The consistency ratio is defined as the consistency index for a particular set of judgements divided by the average random index as shown in following equation:

$$CI = {}^{(\lambda \max - n)}/_{(n-1)} \text{ and } CR = {}^{CI}/_{RI} \tag{1}$$

where λ_{max} is maximum eigenvalue, n is size of the judgement matrices, RI is random index. The values of RI for different sizes of judgement matrices are found in existing studies including in Saaty (1980, 1983) and Saaty and Vargas (1991).

Based on the various numerical studies, Saaty (1980) stated that to be acceptable (i.e. for tolerable inconsistency), the consistency ratio (CR) must be less than or equal to 0.10 (irrespective of the nature of the problem); if this condition is not fulfilled, a revision of the comparisons is recommended. Perfectly consistent judgements would be represented by a consistency index of zero, the same as the consistency ratio. It must be stressed, however, that an acceptable CR does not guarantee a good final selection outcome. Rather, it ensures only that no intolerable conflict exists in the comparison made, and that the decision is logically sound and not a result of random prioritization.

AHP framework and the attributes associated with construction productivity

In the AHP method, the first step is to set up the objective of decision making (Saaty, 1983). In this research, the objective is to determine what attributes impact on productivity and how important the individual attributes are for achieving optimal labour productivity on construction sites. Therefore, the main objective, 'improved productivity' was placed at the left-most side of the analytical hierarchy shown in Figure 1.

The second step is to break down the objective into criteria and sub-criteria and organize them within an analytical hierarchy. As stated earlier, the second level hierarchy was divided into three main criteria—planning, incentives and job satisfaction. The breakdown of the criteria to the next level is performed by identifying three sub-criteria for each criterion, with a total of nine sub-criteria. The first criterion 'planning (Cr1)' refers to the issues related to productivity measurement practices, effectiveness of construction planning, activity scheduling and participation of subcontractors and their cooperation towards improved onsite productivity in the project. Thus the three sub-criteria identified are: productivity measurement (Cr1.1); increased planning and programming (Cr1.2); and subcontractors' participation and cooperation (Cr1.3). The second criterion 'incentives' (Cr2) refers to the issues associated with financial reward programmes, bonus payments and non-financial incentives including union support and

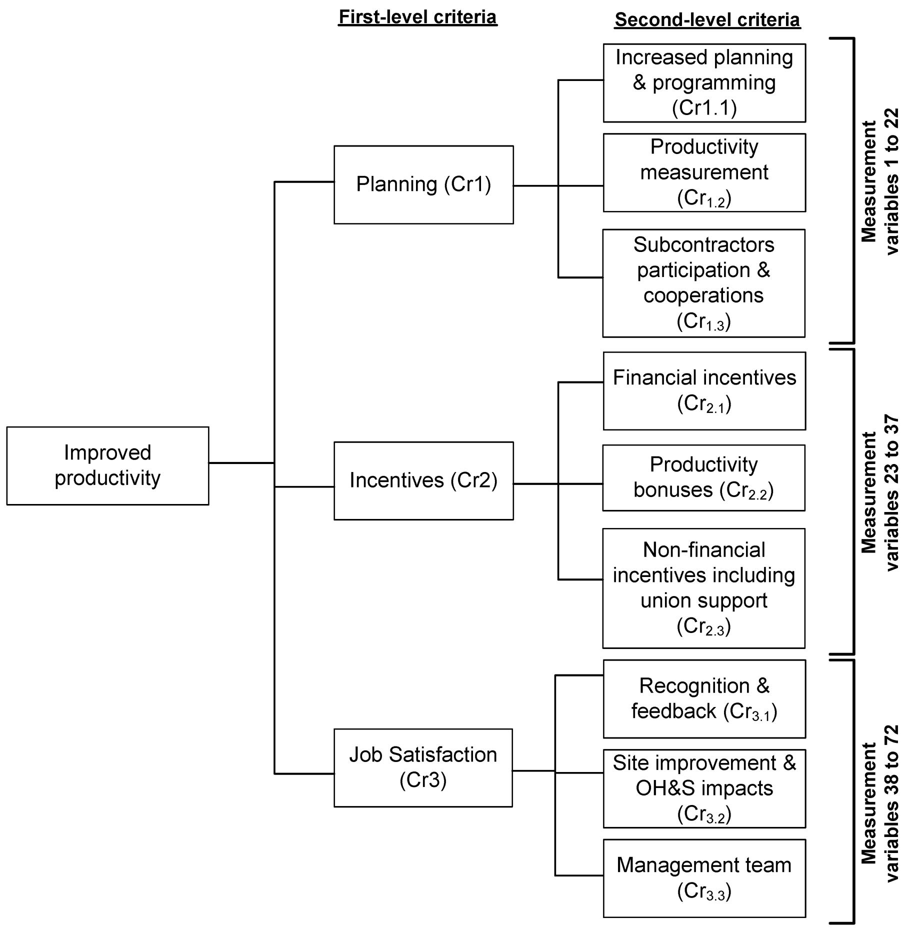

Figure 1 Hierarchical structure of criteria impacting on productivity

welfare payments. The three sub-criteria identified for this second criterion are: financial incentives (Cr2.1); productivity bonuses (Cr2.1); and non-financial incentives including union support (Cr2.3). The third criterion 'job satisfaction' (Cr3) refers to the issues related to recognition by employers, professional development and feedback, site conditions, site improvements and impacts of implementation of occupational health and safety (OH&S0 standards and skills, knowledge and attitude of the site management team on site. The three sub-criteria identified are: recognition and feedback (Cr3.1); site improvement and OH&S impacts (Cr3.2); and site management team (Cr3.3). In the bottom level of the hierarchy, three alternative options have been established on the basis of all the three main criteria and nine sub-criteria. There is no single correct hierarchy for a given system, and several different hierarchies can be built depending on difference of perspectives. A hierarchy of objectives, criteria, sub-criteria and alternatives is constructed in order to gauge the extent to which each option contributes to the fulfilment of the overall objectives.

Once the analytical hierarchy has been established, the next step is to compare the criteria and sub-criteria at the same level in pairs and measure the relative contribution of the factors to the main objective. This pairwise comparison enables the decision maker to evaluate the contribution to the objective of each criterion and the sub-criteria independently, thereby simplifying the decision-making process. In this study, the problem involves using AHP at three levels:

(1) estimation of the relative importance of the main criteria;
(2) estimation of the relative importance of sub-criteria within the main criterion; and
(3) determination of the relative importance of each option on each sub-criterion of evaluation.

Survey design

A survey was conducted to measure how the management team perceives the relative importance of the identified functions associated with construction productivity in the hierarchy as shown in Figure 2. The questionnaire was designed as a tool for assessment of the differing levels of criteria that provide the alternatives for the AHP model. In a questionnaire survey approach, there are several ways of including the views and judgements of each respondent in the priority-setting process. In a common objective context where all respondents have the same objectives, there are four ways to set the priorities: (1) consensus; (2) vote or compromise; (3) geometric mean or the individuals' judgements; and (4) separate models or players (Dyer and Foreman, 1992).

The survey was formulated with 72 questions covering all the nine broad categories (i.e. sub-criteria) namely:

(1) productivity measurement;
(2) increased planning and programming;
(3) subcontractors' participation and cooperation;
(4) financial incentives;
(5) productivity bonuses;
(6) non-financial incentives including union support;
(7) recognition and feedback;
(8) site improvement and OH&S impacts; and
(9) management team.

Each of these sub-criteria was represented with the relevant measurement variables (e.g. relevant questions) for measuring the perceived preferences over one another. A five-point Likert scale was used in each question for respondents to indicate a preferred response. The phrasing of the questions included in the questionnaire is aimed at gaining responses that provide increased clarity to the issues regarding improvement of productivity. The available answers to the questions provide a spectrum indicating the relative importance of each particular issue. A decision maker can express a preference between each pair of criteria as equal, moderate, strong, very strong and extremely preferable (important). The decision to remove the possible selection of 'neither agree nor disagree' provided the respondents with a clear choice of judgement. With reference to the responses provided in the basic questions, a nine-point scale was used to compare the elements of each level of hierarchy with one another in pairs in relation to their respective 'parents' at the next higher level. The nine-point scale is shown in Table 1. Respondents' emphasis and selections directly determine the weighting of the evaluation criteria used in the matrix of the analytical hierarchy process and hence achieved the effectiveness in the data analysis.

Table A in Appendix 1 shows the sample questions covered under the first main criterion. Table B shows the sample questions to capture perceived preferences of the respondents on the sub-criteria for pairwise comparison for AHP constructs. For the sake of brevity, details of the questionnaire showing all the criteria have not been provided in the manuscript.

Survey participants

The survey technique involves the collection of primary data by selecting a representative sample of the target population. The targeted participants were from management levels of construction companies as they are usually responsible for facilitating change within the company. While workers are an integral component of change, the research clearly attempted to consider productivity issues and the associated factors from an organizational and management perspective. The ability to change the forces that drive the labour force is a powerful means within the management structure of construction companies and it is the perceptions of this

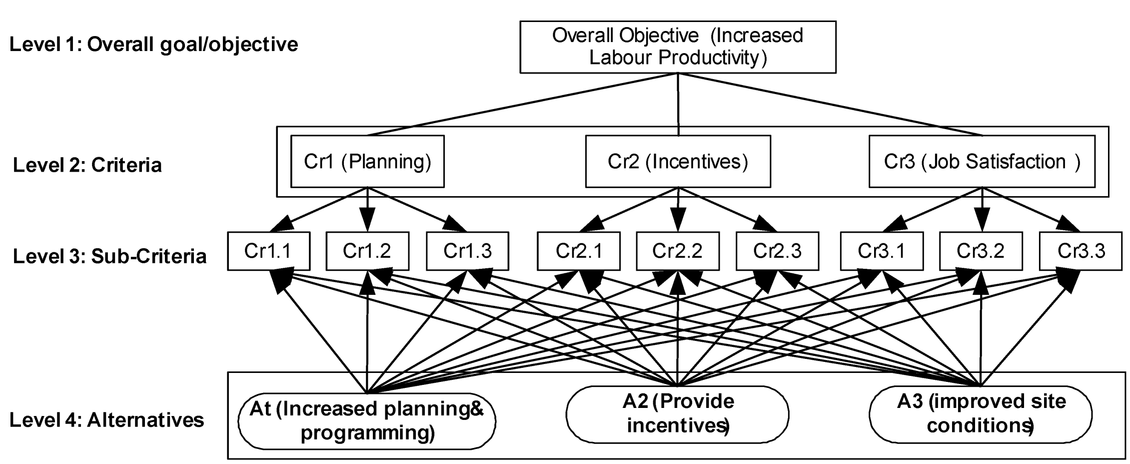

Figure 2 Pairwise comparison framework

Table 1 AHP pairwise comparison scale

Value rating for judgement	Linguistic judgement
1	Elements are equally preferred
3 or (1/3)	One is moderately preferred to the other
5 or (1/5)	One is strongly preferred to the other
7 or (1/7)	One is very strongly preferred to other
9 or (1/9)	One is extremely preferred to the other

Note: 2, 4, 6, 8 are intermediate judgemental values between adjacent scale values.

group of people that will steer the industry in relation to any improved strategy and innovation (Bullinger and Menrad, 2002). Thus the aim was to capture the management level personnel who control and direct the construction labour force on these construction sites and to gain a response from them regarding specific issues that relate to and impact upon productivity. A total of 50 copies of the surveys were distributed to six major construction companies at different sites in Melbourne; of these, a total of 19 were completed and returned. The target group of respondents was identified mostly by means of personal contacts and the responses were collected after clear discussion on the questions and target research outcomes. Table 2 shows the respondents' profiles in terms of their business roles and relevant experience in the project. Table 3 shows the firms' characteristics in terms of project types and respective budgets. While the response was relatively low (38% return), the number of responses received was deemed sufficient to enable meaningful conclusions in the research. As mentioned in the previous section, the small sample size is not an issue from the AHP methodology point of view. Salman *et al.* (2007) used only 12 respondents' input in validating a BOT viability model for large-scale infrastructure projects. In Dias and Ioannou (1996), only 12 and 8 respondents had respectively accepted the invitation and completed the questionnaires. The research questionnaires asked respondents to reflect on the way they believe the different issues impinge upon productivity and to rate in differing degrees of importance, the major implicating factors that limit the level of ongoing attainable productivity. In fact, one can infer some statistical implications of this low

Table 2 Summary of respondents' profiles

Field of work		Experience (years)	
Site manager	25%	<5	12%
Head subcontractor	35%	6–10	18%
Project manager	25%	11–15	16%
Site supervisor	15%	16–20	20%
		>20	34%

response rate. Following the reasoning, the Chebyshev's theorem statistical test was suggested by Saaty (1980) based on which at least 75% of the dataset must lie within the range of average ± 2 standard deviations to accept the dataset (Salman *et al.*, 2007). From the dataset, over 95% of the obtained data were found to be within the above range. This also validates the reliability of the data from the small sample size accepted in this research. Furthermore, the resulting inconsistency ratio of the pairwise comparison matrix as less than 0.1 represents an additional indication of reliability of the obtained responses in the analysis (Salman *et al.*, 2007).

The analytical hierarchy shown in Figure 2 was programmed into an Excel spreadsheet for implementation of the AHP process. The responses from each of the survey participants were used to develop the judgement matrices to calculate the relative importance of the criteria. Based on the relative importance given by individual participants, the mean values of relative importance for the criteria were computed. Pairs of criteria are compared in order to systematically determine the relative influence of the criteria on the attributes positioned one level higher in the hierarchy. The comparisons are performed separately for each set in the hierarchy by reference to the response to a leading question. A typical question of the first level of the hierarchy in Figure 2 would be: 'What might have a greater influence on improving workers' productivity in the project: *effective planning* or *provision of an appropriate incentive programme* and to what extent?' Similarly a typical second level question would be: 'What might have a greater influence on increased planning and programming in the project: *clear scope definition* or *clear client's expectations* and to what extent?' In this way, all the criteria of each level are compared with each other in pairs, resulting in a total of $n.(n\text{-}1)/2$ such comparisons for a set containing n elements. Such pairwise comparisons constitute the input of various project data through which the users express their specific preferences experienced in a given project.

Figure 3 shows an example outcome of pairwise comparisons conducted on two level 2 sub-criteria, 'planning' and 'incentives'. As seen, all three sub-criteria for the criterion 'planning' have been assessed with differential judgements. For instance, the importance of requirements for first sub-criterion 'productivity measurements' relative to 'planning' was assessed as superior to that of the other two sub-criteria by a value of 1/4 compared to 'increased planning and programming' and by a value of 1/3 compared to 'subcontractors' participation and cooperation' (i.e. each is 'favoured less strongly' over 'productivity measurements'). The values in the upper row of the matrix are the reciprocal values of 1/4 and 1/3 respectively. The entries are then normalized and priority vectors are determined for each

Table 3 General organization characteristics

Firm	Project description	Project value (millions)
Firm 1	Redevelopment of existing hotel site of 30-level tower consisting of commercial offices with five-star energy rating	$160
Firm 2	Development of 160 apartments in CBD	$45
Firm 3	Redevelopment of an existing hotel with a total of 300 apartments	$90
Firm 4	Development of new two-level library building incorporating ESD design	$18
Firm 5	Development of commercial office tower comprising 24 levels	$130
Firm 6	Development of shopping centre including associated retail stores of approx. area 130 000 sq. m.	$8

sub-criterion in accordance with the AHP method (Saaty, 1980). Using Equation 1, the consistency ratio (CR) is then calculated to verify the consistency of the decision maker's judgements, which should usually be within 10% acceptance limit. The priority weights for all criteria, sub-criteria and alternatives obtained from AHP analysis are shown in Table 4.

Evaluation of results and findings

Descriptive results

This section focuses on the results of the descriptive statistics of the responses to the questions that formed the criteria and sub-criteria in the AHP analysis.

The main criteria responses indicate that over 65% of the respondents believed that financial incentives are the best means to motivate workers in construction projects. Over 85% believed productivity bonuses effectively give an incentive for the workforce to maintain high levels of productivity. Only 52% believed non-financial incentives are the best means for positive motivation of workers. The strength of the responses to productivity bonuses over financial incentives led to increased weighting in these criteria, with the weighting for non-financial bonuses being somewhat lower owing to the large differences in positive responses.

About 95% of respondents believed that increased pre-planning and appropriate productivity measurement practices on a project can lead to substantial increases in productivity during the construction

Level 2: Estimations by the decision makers on the relative wts within the 3 main criteria for each of their respective sub-criteria

Pairwise comparison matrix with respect to criteria 'Planning'

CR1	**CR1.1**	**CR1.2**	**CR1.3**
CR1.1	1	4	3
CR1.2	1/4	1	1/2
CR1.3	1/3	2	1
Sum	**1 4/7**	**7**	**4 1/2**

Synthisized/normalised column matrix

CR1	**CR1.1**	**CR1.2**	**CR1.3**	***Priority vector***
CR1.1	0.632	0.571	0.667	**0.623**
CR1.2	0.158	0.143	0.111	**0.137**
CR1.3	0.211	0.286	0.222	**0.239**

λ_{max} (Eigenvalue)	=	3.025	
CI (Consistency Index)	=	0.0127	
RC (Random Consistency)	=	0.580	(n=3)
CR (Consistency Ratio)	=	**0.0220**	(CR=CI/RC)
		CR<10%, OK	

Pairwise comparison matrix with respect to criteria 'Incentives'

CR2	**CR2.1**	**CR2.2**	**CR2.3**
CR2.1	1	2	5
CR2.2	1/2	1	3
CR2.3	1/5	1/3	1
Sum	**1 2/3**	**3 1/3**	**9**

Synthisized/normalised column matrix

CR2	**CR2.1**	**CR2.2**	**CR2.3**	***Priority vector***
CR2.1	0.588	0.600	0.556	**0.581**
CR2.2	0.294	0.300	0.333	**0.309**
CR2.3	0.118	0.100	0.111	**0.110**

λ_{max} (Eigenvalue)	=	3.005	
CI (Consistency Index)	=	0.0025	
RC (Random Consistency)	=	0.580	(n=3)
CR (Consistency Ratio)	=	**0.0042**	(CR=CI/RC)
		CR<10%, OK	

Figure 3 Example of pairwise comparison during model implementation

Table 4 Average weights of the alternative options and the criteria

Alternative options	Weights	Evaluation criteria	Weights	Evaluation sub-criteria	Weights
Increased planning and programming (A1)	0.457	Planning (Cr1)	0.683	Increased planning and programming (Cr1.1)	0.625
				Productivity measurements (Cr1.2)	0.136
				Subcontractors participation and cooperation (Cr1.3)	0.238
Provide incentives (A2)	0.275	Incentives/ disincentives (Cr2)	0.200	Financial Incentives (Cr2.1)	0.582
				Productivity bonuses (Cr2.2)	0.309
				Non-financial incentives including union support (Cr2.3)	0.109
Improved site conditions (A3)	0.265	Job satisfaction (Cr3)	0.117	Recognition and feedback (Cr3.1)	0.594
				Site improvements and OH&S impacts (Cr3.2)	0.249
				Management team (Cr3.2)	0.157

process with 81% indicating work scheduling as the most critical factor in ensuring productive use of labour resources on site. About 66% of the respondents thought that the participation of subcontractors and their cooperation in eliminating work interfaces is one of the most critical factors in ensuring seamless workers' output leading to higher productivity on site.

Job satisfaction was perceived to be a critical factor affecting labour productivity by about 76% of the surveyed respondents. Almost 100% of respondents believed that job satisfaction for site labour can significantly reduce if there is little recognition or positive feedback on the work done. About, 90% of the respondents perceived poor working conditions and poor standards of OH&S procedures as major hindering factors for reduction in satisfaction among site labourers. Overall 86% of the respondents indicated that a lack of skills and knowledge on the part of the site management team influences team spirit among workers, which may have an adverse impact on job satisfaction on site. The results of such descriptive statistics led the choice of weighting of these criteria with recognition and feedback being the highest weighted sub-criteria followed by site conditions and OH&S impacts and team spirit among workers in the AHP analysis. These findings clearly support the findings of previous researchers (Guhathakurta and Yates, 1993; Lim and Alum, 1995; Olomolaiye *et al.*, 1996; Picard, 1998; Adrian, 2001; Lam and Tang, 2003; Rojas and Aramvareekul, 2003; Skitmore *et al.*, 2004; Enshassi *et al.*, 2007).

Results obtained from AHP analysis

Figure 4 shows the resulting column vectors derived from the pairwise comparison of all criteria, sub-criteria and the alternatives in the AHP analysis. The right-most column with three row vectors 0.457 (~46%), 0.275 (~28%) and 0.265 (~27%) shows the overall weights for alternatives 1, 2 and 3 respectively. As seen, the optimal strategy of a particular organization in securing highest productivity among construction workers was found to be dependent on effective planning and programming of construction activities. The resultant emphasis placed on the planning and programming alternative

$$\begin{bmatrix} A1 \\ A2 \\ A3 \end{bmatrix} = \begin{bmatrix} 0.691 & 0.678 & 0.067 & 0.068 & 0.054 & 0.097 & 0.644 & 0.637 & 0.615 \\ 0.160 & 0.179 & 0.272 & 0.620 & 0.571 & 0.333 & 0.270 & 0.258 & 0.268 \\ 0.149 & 0.142 & 0.661 & 0.313 & 0.374 & 0.570 & 0.085 & 0.105 & 0.117 \end{bmatrix} x \begin{bmatrix} 0.427 \\ 0.093 \\ 0.163 \\ 0.116 \\ 0.062 \\ 0.022 \\ 0.069 \\ 0.029 \\ 0.018 \end{bmatrix} = \begin{bmatrix} 0.457 \\ 0.275 \\ 0.265 \end{bmatrix}$$

Figure 4 Resulting column vectors

(Alternative 1) was 46% followed by provision of an appropriate incentive programme (Alternative 2) with a score of 28%. The alternative related to site improvement and OH&S issues (Alternative 3) was ranked in third place with an overall score of 27%. As the emphasis of preference between Alternatives 2 and 3 is marginally different (1%), a significant emphasis with additional 18% and 19% has been placed in Alternative 1 over these two alternatives respectively. Management strategies for devising an appropriate incentive programme along with the enhancement of OH&S policies and working environment of construction sites can significantly influence workers for positive motivation leading to higher productivity.

These results should provide a basis for the construction industry to implement changes to its approach to building projects and the allocation of resources at the pre-planning and pre-construction phases. The results also indicate that currently construction firms are not giving enough emphasis to this aspect of the project development life cycle. Consequently, firms are experiencing lower levels of labour productivity along with scope changes and alterations to planning and scheduling in the construction phase.

The findings of the AHP computation are similar to the findings of the descriptive results as discussed in the above section. However, a potential change of overall weight due to change of priority on the criteria and sub-criteria is an important consideration in benchmarking preferred strategies in the AHP exercise (Dyer and Foreman, 1992; Enshassi *et al.*, 2007). Thus sensitivity analysis was performed on Alternative 1 to understand the rational basis on the above findings, which is discussed in the following section.

Sensitivity analysis

In order to analyse the sensitivity of the change of decision makers' preferences across nine sub-criteria, the numerical values of the preferences were altered hypothetically. The percentage values for nine sub-criteria for base case scenarios are Cr1.1=21%, Cr1.2=5%, Cr1.3=8%, Cr2.1=19%, Cr2.2=10%, Cr2.3=4%, Cr3.1=20%, Cr3.2=8% and Cr3.3=5%. A change in priority of preference given in each of these sub-criteria implies a change in numerical values in the priority vectors in Figure 4. The situation is bound to affect the overall results at the synthesis stage since the values of vector of the criteria priorities play a significant role in the computation of the final priority. But the question is what effect will the change of importance in the sub-criteria have on overall priorities at the final stage and by how much? The sensitivity analysis of the sub-criteria is intended to help decision makers to understand the degree of influence of overall results of priorities upon a range of possible changes in the sub-criteria preferences.

Figure 5 shows the possible changes of overall results of priorities in three alternatives due to changes of preferences (or importance) on the most significant 'planning' sub-criteria. Such changes in preferences in the 'planning' sub-criteria affect the priorities of the column vector containing the nine sub-criteria elements in Figure 4 and thus impact on the results of overall priorities. As the decision makers' preferences given on criteria and sub-criteria may vary over project type and the prevailing construction environments, cross-checking on the validity of the numerical values over a changed environment is an important consideration for achieving higher precision in the overall priority

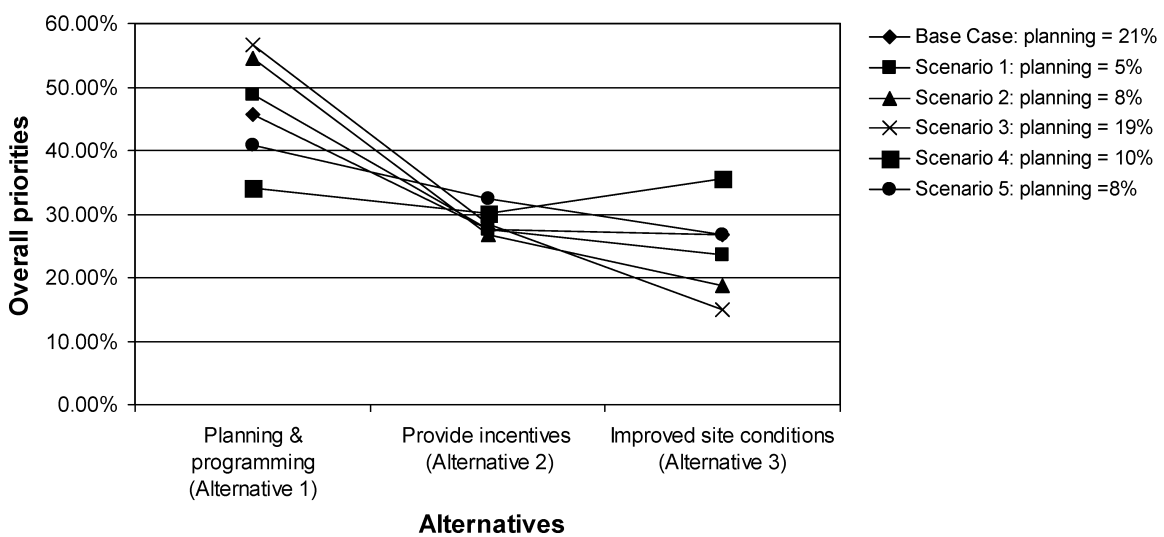

Figure 5 Sensitivity analysis of the planning sub-criteria influencing optimal productivity

weights. Five scenarios have been investigated by varying the preferences in the 'planning' sub-criteria over a range from 5% to 19% and impacts on the results of overall priorities were analysed. Figure 5 depicts six situations including the base case scenarios with the priority on the 'planning' sub-criteria being 21%, where changes of priority on the other sub-criteria relative to the 'planning' sub-criteria were found to have no significant impact on the overall ranking of three alternatives. Comparing resulting vectors for three alternatives in Figure 4 with Figure 5, there are changes in values but such changes are not significant enough to substantially alter the preferred choice of alternative solution(s) or strategy(ies). This shows a clear consistency of the preferred option as expected in this form of analysis.

Limitations and future work

One area of possible weakness identified in the results is on formation of the judgement matrices for the main criteria. All survey respondents were site management staff and therefore the indicative responses received are the issues and concerns perceived to be important to these stakeholders. A different set of results may have been obtained with the participation of the labour staff on site; however, due to the constraints of scope, such a population could not be included in this research. Furthermore, the findings may be verified by extending the questionnaire survey to wider geographic boundaries for demographic representation in the Australian industry. However, the current findings are considered valid for two main reasons. First, most of the major construction firms are confined to five major cities in Australia and thus, samples collected from the selected firms in Melbourne provide a reasonable representation of the practices around Australia. Secondly, results from the sensitivity analysis show that a change in priority of preference in each sub-criterion does not substantially alter the preferred choice of alternative solution.

However, for improving labour productivity, it is believed that changes are required in the industry. The most critical change in this context is for construction companies to increase planning and programming for projects before the start of construction work. This recommendation is difficult to enforce because of the limited time available to construction companies between winning a successful tender and commencing work on site. The practice of immediate start of construction works upon winning the tender greatly impedes the ability for companies to allocate sufficient resources in this very early phase of pre-construction. However, the importance of this time in programming and planning cannot be overlooked particularly with regard to the underlying effect on labour productivity throughout the project.

Conclusions

The research aimed to determine the optimum solution to achieving increased labour productivity focusing on a number of selected construction projects in Melbourne. The findings of the research have provided substantial evidence on the current understanding and perception of labour productivity in the industry and have provided clear pathways for industry to address the current productivity problems. The responses drawn in this research from the construction management professionals of commercial building projects in Melbourne have given an insight into the current issues surrounding labour productivity. The results provide a solid basis for increased focus and participation of the construction management sector in achieving higher productivity in the industry.

The research suggests increased pre-planning and programming as the most critical factor to improving labour productivity on construction projects. Construction pre-planning and programming encapsulates the elements of planning human and capital resources for a project through the construction phase, work scheduling, activity programming, site coordination planning and financial cash flow planning. All these elements must be the initial focus of construction organizations if they are to improve upon current levels of labour productivity.

Furthermore, provision for incentives has been suggested as the second most critical factor for improving labour productivity. Of the incentives investigated, the leading factor was productivity bonuses, with financial incentives being also an important incentive to increase productivity. Productivity bonuses are financial bonuses provided to onsite labour and contracting labour if they are able to achieve project targets ahead of construction programme dates. The bonuses would be attached to the quantity of output achieved to a specified quality above the required contractual performance. The difference between the two most critical factors was reasonable in magnitude and indicated that a greater emphasis will need to be placed on addressing these issues before using organizational resources to focus on further factors.

The alternative that was least preferred to the two alternatives above was the provision of improved site conditions in improving labour productivity. While the research results indicate that conditions of site including the OH&S standards and provisions, site location, a stable workforce, skills of the site management team and establishment of collective project team sentiments are important, they were only important to a certain degree. While they were considered important, the same were not believed to be the most critical factors that could affect and improve labour productivity on site.

The results indicate that increased productivity is achievable through the implementation of the most effective solutions to the construction labour force on the initiation of construction managers, project managers and construction companies having direct influence on labour resources in the project. Through a more complete understanding of the factors that are perceived to affect the workforce, the ability for managers to positively impact upon productivity is largely increased. Without innovative practices and procedures used to understand and monitor the workforce, the large capacity increase available to companies through increased productivity will remain unchanged. The above findings, in principle, support the findings of other researchers (Guhathakurta and Yates, 1993; Olomolaiye *et al*., 1996; Sherif, 1996; Picard, 1998; Lam and Tang, 2003; Rojas and Aramvareekul, 2003; Skitmore *et al*, 2004). However, identification of the effectiveness of the planning and pre-programming as one of the most critical factors for improving productivity shows a clear contrast to most of published research in the field.

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Appendix 1

Sample questionnaires associated with project planning

Table A Measurement variables of sub-criteria associated with the criterion 'planning'

Questionnaire
(Likert scale used: 1=Strongly Agree; 2=Agree; 3=Neutral; 4=Disagree; 5=Strongly Disagree)

Cr1.1 Increased planning and programming

1. Increased pre-planning on a project can lead to substantial increases in productivity during the construction process
2. Our company allocates adequate time for pre-planning projects before moving on to site
3. More time needs to be allocated during the pre-construction phase for planning and programming works
4. Work scheduling is the most critical factor in ensuring labour resources are used productively on site
5. Programming needs to be revised more regularly through the construction phases
6. Our company has adequate procedures for monitoring productivity on a frequent basis
7. Eliminating work interfaces is the most critical factor in ensuring labour resources are used productively on site
8. Our company has adequate communications networks on site to minimize delays occurring
9. Coherent partnerships in projects ensures smooth working environment and allows all parties receiving adequate reward for early project completion

Cr1.2 Productivity measurement

10. Present practices for measuring construction productivity are adequate
11. Increased measures for measuring construction productivity are required
12. Increased training of the workforce is required to improve productivity
13. Poor labour productivity is a direct result of poor management and direction on site
14. Inadequate site supervision decreases productivity on site
15. We currently have sufficient means to measure and track productivity on site

Cr1.3 Subcontractors' participation and cooperation

16. Subcontractors are very conscious of the need to be productive when on site
17. Subcontractors receive adequate and attention and direction from management to minimize possible delays
18. Time lost due to a failure to deliver materials on site is an area of concern
19. Time lost on site due to inadequate tools and equipment is an area of concern
20. Subcontractor foremen drive productivity for their supervised crews and ensure reasonable rates of productivity are maintained
21. It is difficult to enforce productivity upon subcontractors
22. Subcontractors will accelerate works if offered financial incentives

Table B Preference over issues with respect to the main criterion 'planning Cr1'

Importance of one sub-criterion over another

Sub-criteria	Absolutely more important	Strongly more important	Weakly more important	Equally important	**Just equal**	Equally important	Weakly more important	Strongly more important	Very strongly more important	Absolutely more important	**Sub-criteria**
Cr1.1											Cr1.2
Cr1.1											Cr1.3
Cr1.2											Cr1.3