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Construction resource/method factors influencing productivity for high rise concrete construction

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Research among European countries had confirmed variance in productivity rates ascribed by construction planning engineers for identical operations. Similar differences in planned construction resource/method factors also had been identified. It is hypothesized that such variance may be due to differences in contractor preference, resulting from socio-economic and corporate objective impacts. Analysis of variance and correlation tests are used to examine this hypothesis on data obtained from French, German and UK contractors. Numerous construction resource/method factors are tested for their impact on mean productivity rates for principal high rise *in situ* concrete construction operations. Significant productivity rate variations are identified for reinforcement fixing and formwork erection, while variance in concrete placing productivity rates are not found to be dependent upon construction resource/method factors. Contractors seeking to improve productivity might wish to consider solutions for construction resource/method decisions that have been found herein to be related to higher productivity rates and (in some cases) lower costs.

Keywords: Productivity rates, *in situ* concrete work, resource utilization, construction methods, high rise construction

Introduction

Introduction of the Single European Market in January 1993 marked the end of European trade barriers, a relaxation of customs regulations, and enabled free movement within the European Union. This heralded two significant consequences for European contractors. First, it meant that they could tender freely for construction work located anywhere on the European continent, and compete with indigenous and perhaps other 'foreign' firms on an 'equal' basis. Second, it meant that indigenous contractors could expect greater competition for domestic projects, from like-minded 'foreign' contractors looking to secure continental work (Builder Group, 1997).

Recent statistics estimate European construction investment at some 690 billion ECU (approximately sterling £511 billion). This represents approximately 12% of European GDP (ECIF, 1996). Employing more than 7% of Europe's work force, the sector is the largest industrial employer on the continent. Hence, the European construction market provides enormous potential opportunities, for those contractors able to compete successfully with their 'international' counterparts.

While investigations comparing the productivity of international construction industries have been conducted in the past (d'Arcy, 1993; Business Round Table, 1994; DoE, 1995), there exists a dearth of research into the performance of *contractors* internationally. Therefore, where contractors from different nations are competing for the same work, it is unclear as to which are most likely to satisfy clients' objectives if appointed.

In seeking to resolve this uncertainty, this research has investigated European construction (planned)

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productivity. Utilizing a new technique, the performance and practices of UK, French and German contractors are contrasted. Previous findings have indicated those contractors most likely to lead the way in a pan-European construction market (Proverbs *et al.*, 1996, 1999a). International differences in productivity rates (for *in situ* concrete work) and construction resource/method factors (including transportation methods, formwork and access provisions, reinforcement fabrication methods, and various labour factors) have also been reported (Proverbs *et al.*, 1998a,b; 1999 a–e). This paper expands on these previous works by investigating possible construction method/ resource utilization implications and focusing on the investigation of productivity rates and construction method/resource utilization factors. Not least, this confirms those factors having significant impact on contractors' productivity rates (and subsequently their on-site performance). Where differences based on these factors do exist, possible performance enhancing recommendations are also drawn.

Findings reported indicate that certain construction method/resource utilization factors impact the productivity of principal high rise concreting operations (e.g. the choice of formwork system had a significant impact on the productivity rates prescribed for such operations). Although inferences drawn in this respect do not purport to be 'definitive' (due mainly to limitations of sample stratification and size), they nevertheless provide a firm indication. It is further acknowledged that other factors in addition to those considered (such as health and safety, influence of unions and the very culture of the nations involved) are likely to impact productivity also. However, these findings are based on a survey of key European construction players and so represent a valid and informed overview of productivity for high rise concrete construction.

An overview of the research methodology

To facilitate a (desk-based) survey of international contractors, a model high rise building and structured questionnaire were designed. A detailed account of these may be found in Proverbs *et al.*, (1997). These research instruments were distributed to French, German and UK contractors' planning engineers who were to assume that the model was a potentially 'live' project. Part of the questionnaire required respondents to indicate planned productivity rates for three different construction operations (formwork, reinforcement, and concrete placing). Each of these operations was subdivided further into three elements (beams, columns, and floor slabs) so a combined total of nine productivity rates were obtained. These provided the basis for performance evaluation. Respondents were asked also to indicate various construction method/resource strategies which were used as the basis for productivity impact analyses. Before the survey results a brief account of the survey methodology is now given.

The research survey

The survey involved the distribution of 280 questionnaires. One hundred and fifty UK, 75 French and 55 German contractors were targeted. Only those firms experienced in *in situ* concrete work and of sufficient size (i.e. minimum turnover of £7.5 million per annum) were chosen for survey inclusion (national French and German contractor organizations provided assistance in this regard). The survey (refer to Proverbs *et al.*, 1998c, for definitive information) yielded positive responses from 31 UK contractors (representing a 21% response rate), 14 French contractors (19% response), and 10 German contractors (18% response), representing an overall response of 55 contractors (20%).

The sample represented a cross-section of European contractors, sufficient in size, experience and resources to undertake the model project. This was a result of the careful method by which contractors were selected for survey inclusion. Table 1 provides an indication of the size and diversity (in terms of annual turnover) of the participating companies. An even distribution of firms is evident despite slight bias towards medium and large size contractors. The analyses presented herein are based on the aggregate response to the survey (i.e. a total of 55 contractors). The sample size far exceeds the minimum of 30 for 'assumed normality' and homogeneity (Freund and Simon, 1992) and it satisfies the requirements of a robust and valid statistical analysis.

In view of the fact that this research is based on a survey of contractors' planning engineers, the importance of construction method/resource planning is now outlined. Then follows an appreciation of productivity rates prior to the research analyses.

Table 1 Size of participating firms

	Number and percentage of contractors							
	UK		France		Germany		Total	
Company size[a]	No.	%	No.	%	No.	%	No.	%
Small	8	25.8	5	35.7	1	10.0	14	25
Medium	14	45.2	5	35.7	2	20.0	21	38
Large	9	29.0	4	28.6	7	70.0	20	36
Total	31	100	14	100	10	100	55	100

[a]Small, annual turnover ≤ sterling £50 million; medium, annual turnover > £50 ≤ £450 million; and large annual turnover > £450 million.

Construction method/resource planning

Effective construction planning requires complete understanding of each particular project. Only then can detailed methods and resource requirements (plant, labour, materials) be established, enabling the works to be carried out safely, economically and to the quality required to meet client requirements. It was rated by Arditi (1985) as the highest influencing factor for achieving construction productivity improvement. Ackoff (1970) defined planning as a decision making process, performed prior to action, which endeavours to develop effective methods of achieving construction designs. Design in itself also can act as an important determinant of site productivity (Nkado, 1995). 'Buildability' is "the extent to which the design of a building facilitates ease of construction" (CIRIA, 1983), and clearly will impact site output. However, when buildability is considered adequately at design stage, then proper planning becomes more important.

There is some confusion with regard to current planning endeavours (Laufer and Tucker, 1987). A primary responsibility of the planner when considering an *in situ* concrete building is to determine construction methods and resources. Hanna and Heale (1994) recommended that "a complete list of the project's resources" should be made at the planning stage. A thorough evaluation should include consideration of the following aspects: transportation, reinforcement fabrication, temporary works requirements (including formwork and scaffolding), and labour resource issues. For the three countries considered, significant international differences in preferred solutions for each of these factors have been found. Now follows a brief account of their importance.

Transportation is an essential part of construction planning (Masterton and Wilson, 1995). Its analysis was defined by Warszawski (1973) as being essential in the planning of multi activity construction processes (as associated with *in situ* concrete work), and was cited as "a vital factor in the success and profitability of a contract" (*Contract Journal*, 1982). Methods adopted can also impact productivity and motivation (Logcher and Collins, 1978; Borcherding and Garner, 1980), and therefore such decisions are critical to project success.

Reinforcement can account for almost a third of the cost of concrete work. Selecting the most appropriate method of fabrication requires a basic understanding of the construction process and its sensitivity to prevailing conditions, labour demand and practicality. The utilization of some fabrication methods (e.g. prefabricated reinforcement) has been shown to improve quality, reduce necessary labour intensity and provide faster fixing rates (Bennett and MacDonald, 1992).

Temporary works are important also, having a critical effect on the quality, safety and profitability of construction projects (Ratay, 1987), and represent an area of considerable significance within the construction process. For example, in extreme circumstances (such as in the construction of a complex *in situ* concrete bridge structure) temporary works can represent more than 60% of the contract sum (Illingworth, 1987).

Labour requirements and resource issues also are important considerations, especially for labour intensive operations such as *in situ* concrete work. In terms of construction performance, the workforce and management team share a strong and positive relationship (Tam and Harris, 1996). Judicious planning of labour resources can contribute towards controlling project costs, improving quality and optimizing construction output. An evaluation of labour resources therefore requires joint consideration of operatives and management.

To sum up, effective construction planning requires the rational and intelligent selection of construction methods and resources. Planning engineers can play a central role towards achieving project objectives.

Productivity rates

Productivity rates represent essential data for the study of construction productivity (Herbsman and Ellis, 1990). One of their most important applications is in the area of construction planning and scheduling. Other uses include estimating, accounting and cost control. Indeed, Koehn and Brown (1986) used productivity rates to generate international labour productivity factors, and also suggested ways in which they could subsequently be applied to determine comparative international construction costs.

Most planning engineers maintain a library of 'basic' productivity rates. These basic rates are prone to adjustment for each project, taking into consideration specific project factors (such as design aspects) and conditions (e.g. site location) that could impact construction productivity. When calculating these rates, planning engineers need to assess design 'buildability', since this will directly affect the level of productivity achieved. Where design information is either incomplete or perhaps involves complicated processes (such as a number of return visits by certain trades), experienced planners will make due allowance for the expected harmful effects these (and other design implications) will have on productivity. Significantly, Christian and Hachey (1995) in their study of productivity rates found 'substantial agreement' between the average productivity rates actually measured in the field and of those used by planning engineers. Where they did find differences in actual production rates (for similar operations between a number of sites), it was established that these were caused mainly by waiting and idle times (an impact of improper and/or inadequate site supervision or management). However, they reported that planners would very often modify their productivity rates for a specific estimate, in order to reflect anticipated delay times (associated with that project). This latter point underlines the reliability of using planning engineers' productivity rates to assess the performance of contractors both nationally and internationally. Conclusions drawn herein are based on the most accurate planning data available: that supplied by active practitioners, and considered experts, in the field.

Analysis of the survey data

The following analysis is based on the aggregate response to the questionnaire survey, i.e. 55 respondents in total, comprising 31 responses from UK, 14 from French and 10 from German contractors. All statistical analyses were performed using the statistical software package, SPSS for Windows (version 7.0). The focus of the analysis is the impact of preferred construction methods/resource utilization factors indicated by respondents upon the productivity rates provided for the three main concrete operations involved. Average productivity rates for the three elements (columns, beams and floor slabs) involved in the model were used. These were considered 'mean' productivity rates for each of the operations (concrete placing, formwork erection and reinforcement fixing). Construction methods/resource factors were investigated individually for their impact on (mean) productivity rates. These factors are as follows.

Plant/material resource factors
(i) Transportation methods
(ii) Scaffolding systems
(iii) Formwork solutions to columns, beams and floor slabs
(iv) Reinforcement fabrication

Labour resource factors
(v) Working time per day and per week
(vi) Allocated official break/relaxation time per day
(vii) Number of days worked each week
(viii) Numbers of on site supervisors/ managers
(ix) Numbers of (unskilled, semi-skilled and skilled) operatives

Analysis of variance (ANOVA) was employed to test the hypotheses that the mean productivity rates (for concrete placing, formwork erection and reinforcement fixing) attributed to the various solutions for the four plant/material resource factors (previously identified) were significantly different. The results of these tests are provided in Table 2. For example, using the transportation method (based on five main alternatives previously indicated by respondents) as the dependent variable, variance in mean concrete placing productivity rates were investigated. The result (F statistic 2.335, P value 0.068) indicated that mean concrete placing productivity rates were the same for each transportation method (Table 2). This procedure was repeated for each of the plant/material resource factors (i.e. scaffolding systems, formwork solutions and reinforcement fabrication methods) as the dependent variables for ANOVA of mean concrete placing productivity rates. In addition to ANOVA, Tukey's honestly significant difference (HSD) *post hoc* test (refer to Kinnear and Gray, 1994) was subsequently applied to locate specific productivity differences for the solutions investigated. On completion, the process was recommenced substituting the mean concrete placing productivity rates with those for formwork erection and then reinforcement fixing.

The authors acknowledge the assumptions underlying ANOVA (i.e. for the data to be normally distributed and to exhibit homogeneous variance) and that subsequent distribution of data accentuates the risk of violation. To minimize such risk, a 99% significance level was used in the analyses. A summary of the ANOVA results is presented in Table 2, with results significant at this level indicated with an asterisk.

The labour resource factors ((v) to (ix) above) were tested for association (not causation) with productivity rates using Pearson's correlation test (refer to correlation matrix, Table 3). Here, for example, the average productivity rates for 'concrete placing' were tested for correlation with the 'working time per day' (0.010) and 'working time per week' (0.214). Such results indicating a lack of association. This was repeated for each of the labour resource factors for concrete placing productivity rates, and then again for the formwork erection and reinforcement fixing productivity rates. A summary of these results is provided in Table 3, with significant results again indicated with an asterisk.

It is important to note the definition of productivity rates used in this research. The 'more usual' method of defining productivity is output (e.g. m^3 of concrete) divided by input (e.g. operative hours). For example, $5\ m^3$ concrete placed in 10 hours $= 0.5\ m^3$/hour. However, discussions with planning engineers in the UK confirmed that their convention in the use of productivity rates was input divided by output. This convention was adopted in this research, which is also more convenient for comparison purposes. That is, productivity was expressed in terms of operative

Table 2 Summary of ANOVA results

Plant/material resource factors	Mean productivity rates					
	Concrete placing		Formwork erection		Reinforcement fixing	
	F statistic	*P* value	*F* statistic	*P* value	*F* statistic	*P* value
Transportation methods	2.335	0.068	0.314	0.867	2.046	0.102
Scaffolding systems	0.365	0.825	1.299	0.283	0.180	0.948
Formwork solutions						
Columns	2.061	0.100	9.228	0.000*	0.748	0.564
Beams	1.467	0.226	4.071	0.006*	0.542	0.706
Floor-slabs	0.995	0.419	0.504	0.773	2.005	0.108
Reinforcement fabrication methods	1.814	0.174	2.316	0.109	9.187	0.000*

Table 3 Correlation matrix

	Labour resource factors					
	Working time per day	Working time per week	Official breaks	No. of days worked each week	No. of supervisors	No. of operatives
Concrete placing	0.010	0.214	–0.187	0.183	0.214	0.164
Formwork erection	0.059	0.216	–0.106	0.294*	0.195	0.182
Reinforcement fixing	–0.233	–0.146	0.305*	0.028	-0.094	0.075

hours per unit of work, so for the above example: 10 operative hours / 5 m^3 = 2 operative hours per m^3 of concrete.

Now follow the results of these analyses for each of the three main operations. Discussions are limited to significant results only, and therefore some factors are not described in further detail (e.g. scaffolding systems).

Concrete placing productivity rates

Using the mean productivity rates for concrete placing operations (i.e. combined productivity rate for columns, beams and floor slabs) the impact of resource factors were investigated using the methods described. Results were insignificant for the ANOVA tests and correlation analyses as shown in Tables 2 and 3. For example, the mean concrete placing productivity rates were tested for variance using (five) transportation methods (previously identified) as the dependent variable. Results were not significant (*F* statistic 2.335, *P* value 0.068), suggesting that mean concrete placing productivity rates ascribed to different transportation methods are the same. Similar (insignificant) results were derived for the other plant/material resource factors (namely, scaffolding, formwork and fabrication methods), while no significant correlations between concrete placing productivity rates and the labour resource factors were discovered. Hence, this indicates that international differences reported in concrete placing productivity rates (Proverbs *et al.*, 1998c) cannot be explained by differences in individual resource (plant, material and labour) strategies. This is of some surprise since, based on previous findings, concrete placing productivity was impacted by the transportation method adopted (Warszawski, 1973). However, this research did not consider implications of using specific types of plant or construction method (such as particular types of tower crane). Furthermore, certain combinations of these factors (such as the use of tower cranes in conjunction with proprietary forms) could impact the productivity of this type of work. However, such analyses are beyond the scope of this paper.

Formwork erection productivity rates

Plant/material resource factors

Analysis of variance for mean productivity rates for formwork operations (operative-hours per square metre (oh/m^2)) based on plant/material resource factors indicated two significant findings, namely for preferred formwork solutions to columns (*F* statistic 9.228, *P* value 0.000) and beams (*F* statistic 4.071, *P* value 0.006); see Table 2. These formwork solutions were classified as traditional timber (e.g. plywood boards and props/clamps), steel (e.g. steel panels and frames supported on steel props and including flying forms), prefabricated (e.g. GRC column forms and precast concrete shells), proprietary (e.g. adjustable aluminium prop systems), and other forms (as specified).

Tables 4 and 5 provide descriptive statistics for these preferred formwork solutions, together with respective mean, minimum and maximum productivity rates. (Note that the productivity rates indicated for 'other forms' are inappropriate due to sampling inadequacy, and therefore they are ignored in the analyses.) The rankings here indicate the efficiency of the productivity rates allocated to each formwork solution (with those ranked first being more productive), i.e. for Table 4, proprietary and traditional timber solutions were allocated the most and least productive rates, respectively. Details of these differing solutions and international preferences can be found in Proverbs *et al.*, (1999d).

Table 4 indicates that variations in productivity rates for the same solutions (refer to coefficient of variation) appear to be quite high for each type of formwork. A degree of consistency is evident among the mean productivity rates, where the least efficient individual rate is attributed to traditional timber (3.83 oh/m^2) and the most efficient rate is achieved using proprietary solutions. Notably, French contractors were found to be the most productive at this type of work (Proverbs *et al.*, 1998d), preferring proprietary formwork solutions, while UK contractors (found to be the least productive) preferred traditional timber solutions. *Post hoc* HSD results indicated that mean (formwork) productivity rates for traditional timber formwork were significantly different from each of the other methods (excluding 'other' forms). No significant differences between the productivity rates for steel, prefabricated or proprietary forms were found.

Productivity rates for formwork to beams (Table 5) indicate that 'other forms' yield the most productive rates (ranked first). However, only two contractors chose 'other forms' and results may be peculiar to the individual contractor, and not significant. More purposefully, prefabricated forms are ranked second, while traditional timber forms are ranked least productive. Prefabricated solutions yield the most consistent productivity rates (coefficient of variation of 25%). Indicative of this impact, French and UK contractors (found to be most and least efficient at such work, respectively) preferred prefabricated and traditional solutions, respectively (Proverbs *et al.*, 1998d,1999d). The *post hoc* results indicated significant differences between the productivity rates of traditional timber and steel, and traditional timber and prefabricated forms. The rates for proprietary and traditional timber solutions were not found to be significantly different.

Cost implications

In consideration of the model project used in the study, an economic appraisal of these findings is possible. The model project contained 977.76 m^2 and 1600.76 m^2 of formwork to columns and beams, respectively. By multiplying the mean productivity rates for each formwork solution with the relevant quantity an indication of the likely operative-hour requirements can be established. Then a further multiplication with the all-in rate for labour (based on recently published figures) provides the labour costs for this operation (assuming skilled operatives would be deployed). Tables 6 and 7 provide the results of this analysis for column and beam formwork, respectively. The financial implications of these results are significant. For column formwork, the difference

Table 4 Formwork productivity rates for different formwork solutions to columns

Formwork solution	No.	Mean productivity rate[a]	Coefficient of variation (%)	Most efficient productivity rate[a]	Least efficient productivity rate[a]	Rank (1 = most productive)
Traditional timber	14	2.24	36	1.20	3.83	5
Steel	13	1.45	31	0.74	2.40	4
Prefabricated	10	1.15	42	0.44	1.96	2
Proprietary	17	1.11	33	0.23	2.10	1
Other forms	1	1.41	-	1.41	1.41	3

[a]Operative-hours per square metre.

Table 5 Formwork productivity rates for different formwork solutions to beams

Formwork solution	No.	Mean productivity rate[a]	Coefficient of variation (%)	Most efficient productivity rate[a]	Least efficient productivity rate[a]	Rank (1 = most productive)
Traditional timber	14	2.09	34	0.96	3.39	5
Steel	15	1.30	46	0.23	2.40	3
Prefabricated	10	1.22	25	0.86	1.86	2
Proprietary	14	1.44	53	0.87	3.83	4
Other forms	2	0.92	74	0.44	1.41	1

[a]Operative-hours per square metre.

between the most productive (proprietary) and least productive (traditional timber) solutions represents a cost of over sterling £14 000. For beam formwork (ignoring the results for 'other' solutions) the consequences are more costly (a difference of over £17 000 between the least and most productive solutions). Such cost implications for contractors could mean the difference between success and failure of a tender bid.

Solutions preferred

Contractors' preferences for formwork solutions were reported as conforming to certain traits and characteristics associated with respective national construction industries (Proverbs *et al.*, 1999d). A discussion of their equipment usage is now worthy of (brief) consideration. In the French construction industry, contractors mainly own plant and equipment, and the external plant hire market is not as highly developed as in the UK (CCFGB, 1993). It is therefore likely that contractors will utilize their own formwork systems (which may not always be the most desirable or suitable solution), rather than hire particular systems for each individual project. This could explain the reasons for French firms preferring a variety of different formwork systems. A further explanation is the preference of French architects for reinforced concrete, which historically has led to the French construction industry being geared toward this technology (*Chartered Builder*, 1993). Hence, the majority of contractors are equipped for reinforced concrete construction (often owning their preferred formwork systems), and economists tend not to make cost comparisons with other structural materials.

Table 6 Time and cost implications for formwork solutions to columns

Formwork solution	Mean productivity rate[a]	Operative-hours	Labour costs
Traditional timber	2.24	2190.18	£27 881.02
Steel	1.45	1417.75	£18 047.98
Prefabricated	1.15	1124.24	£14 313.92
Proprietary	1.11	1085.31	£13 816.04
Other forms	1.41	1378.64	£17 550.11

[a]Operative-hours per square metre.

Table 7 Time and cost implications for formwork solutions to beams

Formwork solution	Mean productivity rate[a]	Operative-hours	Labour costs
Traditional timber	2.09	3345.59	£42 589.34
Steel	1.30	2080.99	£26 490.98
Prefabricated	1.22	1952.93	£24 860.76
Proprietary	1.44	2305.09	£29 343.85
Other forms	0.92	1472.70	£18 747.46

[a]Operative-hours per square metre.

German firms were found to prefer proprietary forms. The German construction equipment market generally is regarded as being the largest and most innovative in Europe (*Construction Europe*, 1994). It is therefore of little surprise that many German contractors have moved away from traditional forms. Furthermore, German firms do not concentrate solely on hiring out plant to their own sites, but tend to fulfil a much wider role in temporary works fabrication (Biggs *et al.*, 1990). Hence, their solutions are more likely to be designed and developed by each company specifically for individual projects.

Perhaps the most notable observation, was the preference of UK firms towards traditional timber formwork. This was in direct contrast to preferred practices of France and Germany. For concrete operations, the productivity of UK firms has been found inferior to that achieved by similar French and German firms. This would seem to be due, in part, to the formwork methods adopted by UK firms, since these (as demonstrated by these results) have a significant impact on productivity rates.

Labour resource factors

Using correlation tests, the labour resource factors also provided important findings (Table 3). A correlation coefficient of 0.294, at the 5% level of significance was found between the number of days worked each week and the average formwork productivity rates. This indicates that weekly working schedules beyond five days could be counterproductive, and supports previous research findings reporting the harmful effects of overtime (Thomas, 1992). Demonstrating this relationship, UK contractors (found to be least productive of the three nations at such work) were also more likely to work more than five days each week (see also Proverbs *et al.*, 1999e). Interestingly, no significant association was found between the productivity rates and the number of hours worked per day or per week (Table 3). This implies that (for formwork operations) in respect of overtime working, the number of days worked each week is more significant than the number of hours worked. No other significant correlations between the average formwork productivity rates and labour resource factors were found.

Formwork summary

In summary, two plant/material resource/method factors were found to impact the productivity rates for formwork operations, namely preferred formwork solutions to columns and beams. Evidence indicates that contractors choosing proprietary and prefabricated solutions for columns and beams, respectively, achieve better productivity rates. *Post hoc* ANOVA results indicated that traditional timber solutions should be avoided, since these manifest lower productivity. The financial impact of such productivity variation was calculated for the model building and found to be of some magnitude.

For contractors working more than five days each week, the productivity of formwork operations declined. This could be connected to the harmful effects scheduled overtime has on productivity. Scheduled overtime (such as working six or seven day weeks) is known to increase absenteeism, reduce effectiveness (due to fatigue) and reduce the productive output of labour materially (Business Roundtable, 1991). On extended overtime, the reduced productivity of workers for a week's work is equivalent to or greater than the number of overtime hours worked. Results indicated that the number of days worked each week was more significant than the number of hours worked. Contractors are advised to consider such implications before implementing lengthy and regular work schedules, particularly in regard to the number of days worked each week; notwithstanding this, overtime when used for particular purposes and short periods can be beneficial and help achieve desired performance targets.

Reinforcement fixing productivity rates

Plant/material resource factors

Mean productivity rates (oh/tonne) for fixing reinforcement were analysed for each of the plant/material resource factors using ANOVA (Table 2). A significant variation in productivity rates was found for reinforcement fabrication methods only (F statistic 9.187, P value 0.000). No other such resource factors demonstrated significant differences in productivity rates for fixing reinforcement. Table 8 provides descriptive statistics for these preferred fabrication methods, and productivity rates yielded for different solutions. *Post hoc* tests indicated that productivity rates yielded for bent and fabricated on-site methods were significantly inferior to those when pre-bent or prefabricated methods were employed. There was no significant difference between the productivity of pre-bent and prefabricated methods. Much more detailed discussion of these differing solutions and international preferences, can be found in Proverbs *et al.* (1998b).

These results support previous research which has underlined the benefits of using pre-bent and (particularly) prefabricated reinforcement (Bennett and MacDonald, 1992). All three fabrication methods, demonstrate high levels of productivity variation with prefabricated methods yielding the most extreme. For prefabrication to be effective, "significant changes to overall project management", and "considerable off-site management" are required (CIRIA, 1997). Contractors adopting such construction methods must take account of these organizational and managerial impacts, or possibly suffer the consequences of poor productivity. Evidence of such problems is provided by the least efficient individual productivity rate which was provided by a contractor utilizing prefabricated reinforcement. German contractors were found previously to prefer such prefabricated methods (Proverbs *et al.*, 1998b), and also were found to be the most productive at these particular reinforcement operations (Proverbs *et al.*, 1998e). Bending and fabricating of reinforcement on-site was found to occur only in France, and this could explain why French contractors were found to be the most unproductive at such operations.

Labour resource factors

The mean reinforcement fixing productivity rates were tested for correlation with labour resource factors. This resulted in one significant finding only (Table 3). Allocated official break/relaxation time per day correlated significantly with reinforcement productivity rates (correlation coefficient 0.305, at 5% level of significance). This relationship indicates that extended break/relaxation times are counterproductive. Previous research has indicated significant differences in the lengths of break times and daily working times of contractors from Germany, France and the UK (Proverbs *et al.*, 1999e). German contractors (i.e. the

Table 8 Reinforcement fixing productivity rates for different fabrication methods

Fabrication methods	No.	Mean productivity rate[a]	Coefficient of variation (%)	Most efficient productivity rate[a]	Least efficient productivity rate[a]	Rank (1 = most productive)
Pre-bent	34	20.73	33	8.50	40.51	1
Prefabricated	15	27.33	51	9.51	62.00	2
Bent and fabricated on-site	6	32.00	47	15.00	43.00	3

[a]Operative hours per tonne.

most productive at this work) allocated break times which were longer than those allocated by UK firms, but shorter than those allocated by French firms. It would seem therefore that a sensible balance (not too long, not too short) of official breaks is optimum. (Note that break times were not found to be of significance for concrete placing and formwork operations.)

In the context of break allowances, it is pertinent at this point to discuss the daily working schedules of contractors, and view the wider organizational implications of the findings. Table 9 presents an overview of mean (reinforcement fixing) productivity rates, daily working schedules, break allowances and (perhaps more meaningful) the break allowance per hour worked, as allocated by contractors from each country. From a managerial perspective, this indicates the ideal allowance for breaks as 6.24 minutes for every hour worked (the German model), since this appears conducive to productivity improvement. The French adopt a more generous managerial approach, allocating on average 7.44 minutes per hour, and yet this is linked to the lowest level of productivity. In contrast, UK contractors allocate the least time for breaks (5.64 minutes per hour), but do not achieve the same level of output as do German firms. This concurs with the previous findings, suggesting that a suitable medium between break allowances and daily working schedules exists (for reinforcement work).

Reinforcement summary

In sum, productivity rates for reinforcement work were found to be significantly different depending on the method of fabrication employed, with pre-bent solutions being the most efficient (although not significantly better than prefabricated methods). Bending and fabricating on-site yielded the most unproductive rates for reinforcement fixing. The length of allocated break/relaxation times correlated with the productivity rates for this operation, indicating that contractors should be careful to limit such allowances. French firms allocated the longest breaks and were inclined to be the most unproductive at this type of reinforcement work. The German model of allowing 6.24 minutes of relaxation time for every hour worked would seem to be productivity enhancing.

Conclusions

Productivity rates and preferred construction resource/method factors are known from previous studies to be significantly different in France, Germany and the UK. Various construction resource/method factors were investigated for impact on average productivity rates (the product of individual rates for beams, columns and floor slabs) of the three principal construction operations involved in high rise *in situ* concrete work (namely placing concrete, erecting formwork and fixing reinforcement). Hence, significant relationships between productivity rates and construction resource/method factors could indicate those factors found to enhance productivity.

For concrete placing productivity rates, none of the resource factors (material, plant or labour) when considered independently was found to be of significance. Therefore, international variations in concrete placing productivity rates were not connected directly to these individual factors. Implications of using specific types of plant or construction methods as well as various combinations of the resource factors might influence the productivity of this work, but such investigations were beyond the scope of the current research. It is noted that this provides scope for future development on the theme.

Formwork productivity rates were impacted by the type of formwork utilized on column and beam work. The most unproductive rates were related to traditional timber solutions, while proprietary (for column work) and prefabricated (for beam work) solutions were associated with the most efficient (and hence most economic) productivity rates. The preference of French (for proprietary and prefabricated) and UK (traditional timber) contractors mirrored these productivity associations. When working more than 5 days each week, the productivity of formwork operations was found to decline.

Reinforcement fixing productivity rates were found to vary significantly depending on the fabrication method utilized, with pre-bent and prefabricated methods yielding higher productivity levels. Break/relaxation times, when extended, were found also to correlate with lower (reinforcement) productivity rates,

Table 9 Break allowances and productivity rates (reinforcement fixing) by country

Country	Mean productivity rate[a]	Daily working time	Break allowance	Allowance per hour (min)
UK	22.40	9 hrs 26 mins	53 mins	5.64
France	30.35	9 hrs 8 mins	1 hr 8 min	7.44
Germany	17.51	10 hrs 9 mins	1 hr 4 min	6.24

[a]Operative hours per tonne.

and therefore contractors should not be too generous in this regard! A mean allowance of (approximately) 6 minutes per hour worked would apparently be desirable for this type of work. Length of break did not impact the productivity of formwork or concrete placing operations, suggesting that the nature of work involved may also be influential.

Contractors seeking to improve their productivity might wish to consider those solutions linked to increased productivity when undertaking high rise *in situ* concrete work.

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