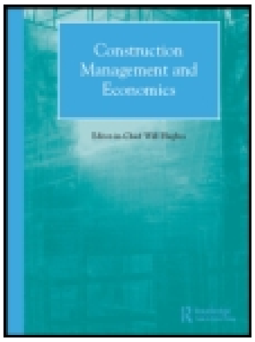

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Trends in productivity improvement in the US construction industry

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Surveys of the top 400 US contractors were conducted in 1979, 1983 and 1993 to identify the areas with potential for productivity improvement in the construction industry. The trends in the findings of these surveys are observed and interpreted. The results indicate that cost control, scheduling, design practices, labour training, and quality control are the functions that consistently over the years are perceived as having considerable room for productivity improvement, whereas materials packaging and foreign developments in construction technologies are perceived consistently as functions that do not have much effect on improving construction productivity. The functions that were identified as needing more improvement in 1993 compared with the previous surveys were prefabrication, new materials, value engineering, specifications, labour availability, labour training, and quality control, whereas those that were identified as needing less improvement than in the previous surveys were field inspection and labour contract agreements. Also, respondents indicated consistently over the years that they are willing to participate in activities related to improving construction productivity but are not interested in funding any such activities.

Keywords: Construction productivity, construction industry, productivity trends, USA

Introduction

There are three productivity measurements used commonly in industry (Oglesby, 1988). First there is an economic model that defines productivity as total factor productivity (TFP), that is the ratio between total outputs expressed in dollars and total inputs expressed in dollars as well. The total inputs include labour, materials, equipment, energy, and capital. This definition is used by policy-maker agencies to make policy and evaluate the state of the economy of the country. The second is the project-specific model that defines productivity as total productivity (TP), that is the ratio between the outputs expressed in a physical unit (for example square feet) and the inputs expressed in dollars. The inputs include labour, equipment, materials, and management. This model is more accurate, and it can be used by both governmental agencies and by the private sector. Third is the activity-oriented model that defines productivity as labour productivity, that is the ratio between outputs expressed in specific physical units (for example tons of steel) and inputs expressed in man-hours. The inputs include labour only. This model is useful for producers in calculating the project cost and monitoring field activity.

Productivity in the construction industry is influenced not only by labour, but also by other factors such as equipment, materials, construction methods, and site management. While labour productivity is useful for contractors in bidding and monitoring field activities, total productivity is used by governmental agencies for specific programme planning and by the private sector for conceptual cost and time estimating on individual construction projects. The term 'productivity' is used in this paper synonymously with total productivity where inputs include labour, materials, equipment, construction methods, and site management.

The output of the construction industry constitutes one-half of the gross capital and is 3–8% of the gross domestic product (GDP) in most countries. Therefore

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productivity improvement in the construction industry may have a significant impact on improving GDP. In the USA, construction is the nation's largest industry sector in terms of yearly dollar volume. However, construction productivity has been on the decline since the 1980s and frequently construction labour efficiency is cited as poor (Adrian, 1987). One of two startling conclusions in the Construction Industry Cost Effectiveness (CICE) project is that construction productivity in the 1980s has either increased at a lower rate than other industries or actually declined. As a consequence, the cost of construction has increased by 50% over the inflation rate in the same period (Oglesby, 1988).

The objective of the study reported in this paper is to analyse statistically the findings of the surveys administered to contracting companies that identified the possible areas for productivity improvement in the construction industry in 1979 by Choromokos and McKee (1981), in 1983 by Nasra (1983), and in 1993 by Mochtar (1994). An interpretation of the perceived trends in the period 1979–1993 is reported in this paper. The results provide some insights into the actions that should be taken in the context of improving productivity in the construction industry.

Methodology

Nasra (1983) conducted a survey of the top 400 US construction contractors in 1983 to identify the potential areas of productivity improvement in the US construction industry. He sent out questionnaires to the top executives of the top 400 contractors. The survey data were analysed by Arditi (1985). The survey questionnaire was an exact duplication of the 1979 survey conducted by Choromokos and McKee (1981). The duplication of the 1979 survey was justified in 1983 by the consideration that economic conditions and the construction climate had changed significantly from 1979 to 1983 and that the trends and correlations needed to be observed again. Based on the same consideration, the questionnaire used in the 1979 and 1983 surveys was slightly modified and sent out in 1993 to the then current top 400 US construction contractors (ENR the top 400 contractors, 1992). A copy of the questionnaire used in the 1993 survey is presented in the Appendix. Data related to the three categories of 'contracting', 'computer utilization', and 'labour productivity improvement techniques' are not analysed in this paper because these three categories were not part of the 1979 and 1983 survey questionnaires, making a comparison impossible.

The objective of the questionnaire was to obtain three main types of information. First, general characteristics of construction companies were sought. These include the type of work the organization undertakes, annual sales, number of permanent and temporary employees, amount of equipment owned and leased, amount of work subcontracted, and geographical location of projects. Second, respondents were asked to indicate the most fertile areas for productivity improvement. In the 1979 and 1983 surveys, these areas were divided into seven categories, namely management, materials, engineering, construction techniques, regulations, labour, and equipment. Each category comprises a set of functions that can be seen in the questionnaire presented in the Appendix. Finally, the types of action that the responding organizations would be willing to take in the interest of improving productivity were investigated.

A respondent could rate the potential for productivity improvement in each function as 'high', 'medium', or 'low'. A high rating indicates that there is considerable room for improvement in a particular function, whereas a low rating indicates that a function is performed quite efficiently. The scoring system is set as 3, 2, and 1 points for high, medium, and low ratings, respectively. The mean score(s) for each function is calculated by means of the following equation:

$$S = \frac{3h + 2m + l}{h + m + l} \tag{1}$$

where S is the mean score, h is the percentage of respondents that gave a 'high' rating to the function, m is the percentage of respondents that gave a 'medium' rating to the function, and l is the percentage of respondents that gave a 'low' rating to the function.

A significance test of the difference between the mean scores obtained in each survey is conducted for each function by means of Duncan's multiple-range test. The value of the least significant range (R_p) is calculated by the following equation:

$$R_p = r_p \sqrt{\frac{S^2\,[N_1 + N_2]}{2\,N_1\,N_2}} \tag{2}$$

where r_p is the least significant studentized range, S^2 is the variance of overall data, N_1 is the number of respondents in the first set of data, and N_2 is the number of respondents in the second set of data.

The values of r_p depend on the desired level of significance (taken as 0.05 in this analysis), the number of degrees of freedom of the overall data, and the number of subset ($p = 2$ or 3 in this study) sample means. The number f of degrees of freedom of the overall data is calculated by the following equation:

$$f = (N_{79} - 1) + (N_{83} - 1) + (N_{93} - 1) \tag{3}$$

where N_{79} is the number of respondents in the 1979 survey, N_{83} is the number of respondents in the

1983 survey, and N_{93} is the number of respondents in the 1993 survey.

If the difference between the mean scores is less than R_p, then the difference is not significant and vice versa.

Comparison of survey findings

Out of the 400 questionnaires mailed to the top 400 US contractors, 139 (or 35%) were returned in the 1993 survey, compared with 15% in the 1983 survey and 20% in the 1979 survey. The relatively low returns in the 1979 and 1983 surveys should not affect the research findings since a similar approach was used in all three surveys.

Table 1 presents the data regarding responding contractors' company characteristics in the 1979, 1983 and 1993 surveys. It indicates that: 1. over 60% of the responding contractors performed one type of construction; 2. over 60% had annual sales ranging from \$50 million to \$500 million; 3. over 55% employed 100–500 permanent employees and over 50% hired fewer than 500 temporary employees; 4. about half of the companies owned less than \$5 million worth of heavy equipment and leased or rented less than 25% of their equipment; 5. about half of the companies subcontracted less than 50% of the total dollar value on an average construction project; and 6. all the companies performed projects almost exclusively in the continental USA. In this question, the responses do not add up to 100% because most companies operate in more than one geographical area.

The trends between the 1979, 1983, and 1993 findings are consistently similar in all except the subcontracting function. The number of respondents that subcontracted less than 50% of the work showed a marked decrease in 1993 (40%) as opposed to 1979 and 1983 (58% and 59% respectively), whereas the number of contractors that subcontracted 75–100% of the work doubled (from 18% in 1983 to 36% in 1993). It appears that in the 1990s more contractors provided only construction supervision, job coordination and perhaps basic site services. The consistent similarity in most other categories indicates that the contracting companies' strategy in business, marketing, and investment did not change considerably between the years 1979 and 1993.

The contractors who took part in the 1979 survey probably were not the same contractors who took part in the 1983 survey, and the contractors who took part in the 1983 survey were probably not the same contractors who took part in the 1993 survey. There are two reasons for this situation. First, the researchers have no control over which of the 400 contractors return the questionnaires; second, the composition of the top 400 contractors changes from year to year with some companies falling out of the list and new companies getting in. A comparison of the perceptions of different populations may, at first sight, appear to be flawed, but given the similarities of the respondents' primary characteristics mentioned in the preceding paragraphs, it should be quite safe to make such a comparison.

The mean scores of perceived productivity improvement in the 1979, 1983 and 1993 surveys and the trends between them are presented in Table 2, where mean scores between 1 and 1.66 are classified as having low potential for improvement, 1.67 to 2.33 as having medium potential for improvement, and 2.34 to 3.00 as having high potential for improvement; these are denoted by L, M, and H, respectively, and the statistical significance of the differences are indicated by a superscript 'c' that denotes a statistically significant change between the 1979 and 1993 surveys at a level of 5%, and a superscript 'd' that denotes a significant change at 5% between the 1983 and the 1993 surveys. Given the relatively short period of time between the 1979 and 1983 surveys, it is not surprising that there are no statistically significant changes between the findings of these two surveys. Note that because the overall degree of freedom f (Equation 3) for all cases is greater than 120, $r_p = 2.77$ for $p = 2$ and $r_p = 2.97$ for $p = 3$. However, because the number of responses N_1 and N_2 (Equation 2) to each question was different in the different surveys, different R_p values for every item on the questionnaire are calculated in each of the three comparisons 1979–1983, 1979–1993, and 1983–1993. To avoid cluttering, Table 2 shows only the results in terms of 'c' and 'd' superscripts that indicate significant differences.

The functions that have been identified consistently as having high potential for improvement (H in at least two of the three surveys), those that have consistently been identified as having low potential for improvement (L in at least two of the three surveys), and the functions that exhibit a statistically significant change over the years (marked with the superscript 'a' or 'b') are discussed in more detail in the following section. The last column of Table 2 presents the averages of the mean scores obtained in all three surveys. These averages are used as a complement to the preceding column on trends to identify functions that are considered to have high potential for improvement. Some of the categories are combined in the following subsections for ease of discussion.

Materials and management

As observed in Table 2, two functions, namely materials packaging (L-L-L) in the 'materials' category and cost control (H-M-H) in the 'management'

Table 1 Company characteristics of responding contractors

Company characteristics	Percent of respondents 1979 Survey	1983 Survey	1993 Survey
Type of project			
Three types	15	15	12
Two types	20	18	20
One type	62	65	68
Other construction	3	2	0
Annual sales ($ million)			
10–50	30	20	12
50–100	40	36	37
100–500	20	38	40
>500	10	6	11
Number of permanent employees			
<100	15	22	21
100–500	55	62	58
500–5000	17	13	18
>5000	3	3	2
Number of temporary employees			
<100	18	20	33
100–500	33	47	37
500–1000	26	18	17
1000–5000	13	8	5
>5000	10	7	3
Dollar value of construction equipment ($ million)			
<5	52	52	48
5–25	28	28	26
25–50	15	8	10
50–200	3	10	9
>200	3	2	7
Percentage of construction equipment leased or rented			
0	11	16	15
<25	44	44	44
25–50	22	12	17
50–75	8	13	7
75–100	15	15	16
Percentage of work subcontracted on average job			
<25	31	28	18
25–50	27	31	22
50–75	31	23	25
75–100	11	18	36
Geographic location of projects			
Northeastern states	36	28	44
Mid-Atlantic states	15	30	46
Southern states	11	51	46
Southwestern states	10	44	40
Central states	5	34	32
Western and northwestern states	4	51	39
Outside continental USA	15	15	7

category have received consistently low (L) and high (H) scores, respectively, whereas the remaining functions received mostly neutral (M) responses.

The consistent perception that there is a 'low' opportunity for productivity improvement in materials packaging might indicate that respondents have already enjoyed good packaging systems or that packaging for materials delivery to the construction site is not a problem. By rating materials packaging 'low', contractors may think that materials packaging is the responsibility of materials manufacturers rather than contractors.

Competitive bid gives the owner the advantage of competitive pricing and also forces contractors to look

Table 2 Potential for productivity improvement in construction functions as perceived by contractors

Functions	Average scores 1979 Survey	1983 Survey	1993 Survey	Trends[a,b]	Mean score of all surveys
Materials					
Procurement	1.91	1.88	2.11	M-M-M	1.97
Delivery	2.19	2.07	2.17	M-M-M	2.14
Storage	1.77	1.86	1.65	M-M-L	1.76
Packaging	1.53	1.65	1.55	L-L-L	1.58
Prefabrication	1.92	2.19	2.31[c]	M-M-M	2.14
Standardization	2.32	2.26	2.35	M-M-H	2.31
Product availability	2.12	1.97	2.00	M-M-M	2.03
New products	2.01	2.00	2.22[c]	M-M-M	2.08
Management					
Estimating	2.08	2.22	2.10	M-M-M	2.13
Cost control	2.40	2.26	2.35	H-M-H	2.34
Scheduling	2.33	2.28	2.37	M-M-H	2.33
Field inspection	2.42	2.31	1.92[c,d]	H-M-M	2.22
Marketing	1.93	2.09	1.95	M-M-M	1.99
Communications	2.20	2.35	2.28	M-H-M	2.28
Engineering					
Design standards	2.18	2.25	2.12	M-M-M	2.18
Design practices	2.39	2.46	2.41	H-H-H	2.42
Systems engineering	2.15	2.18	2.17	M-M-M	2.17
Drafting	1.75	1.72	1.75	M-M-M	1.74
Specifications	1.89	1.80	2.12[c,d]	M-M-M	1.94
Value engineering	1.96	2.11	2.24[c]	M-M-M	2.10
Construction techniques					
Precast elements	2.04	2.16	2.14	M-M-M	2.11
Preassembled modulars	2.05	2.23	2.19	M-M-M	2.16
Foreign developments	1.56	1.73	1.69	L-M-M	1.66
Labour					
Turnover	2.01	2.16	2.19	M-M-M	2.12
Availability	2.11	1.90	2.13[d]	M-M-M	2.05
Labour relations	2.12	2.17	2.12	M-M-M	2.14
Contract agreement	2.24	2.34	1.94[c,d]	M-H-M	2.17
Training	2.37	2.52	2.63[c]	H-H-H	2.51
Quality control	2.17	2.43	2.56[c]	M-H-H	2.39
Regulations					
EPA	2.16	1.88	2.04	M-M-M	2.03
OSHA	2.28	2.07	2.15	M-M-M	2.17
EEO	2.26	1.98	2.01	M-M-M	2.08
Local codes	2.02	2.06	1.90	M-M-M	1.99
Equipment					
Capacity	1.71	1.86	1.89	M-M-M	1.82
Simplicity	1.97	2.04	1.94	M-M-M	1.98
Maintainability	2.13	2.22	2.06	M-M-M	2.14
Utilization	2.12	2.32	2.16	M-M-M	2.20

[a] Status presented in chronological order; 1979, 1983 and 1993 surveys.
[b] L = low opportunity for improvement, range 1.00–1.66; M = medium opportunity for improvement, range 1.67–2.33; H = high opportunity for improvement, range 2.34–3.00.
[c] Change between 1979 and 1993 significant at 5%.
[d] Change between 1983 and 1993 significant at 5%.

for every advantage during construction to control cost and maintain a profitable stance (Arditi and Gunaydin, 1997). Cost control activities include the preparation of a cost plan, the collection of actual cost data, the reporting of cost deviations, and finally the decision and actions to correct variations within acceptable limits (Halpin, 1985). According to Paulson (1995), no cost control system is of any value without accurate, timely input data, so that the use of computers and appropriate software packages are necessary especially in projects of high complexity. The finding that responding contractors perceive the cost control function as having 'high' potential for improvement indicates that they encounter problems in implementing the cost control activities mentioned above; using more efficient cost planning methods, such as more sophisticated computerized systems as suggested by Paulson (1995), could improve their overall productivity.

The differences in the mean scores in the 1979, 1983 and 1993 surveys are statistically significant in three functions, namely materials prefabrication and new products in the 'materials' category, and field inspection in the 'management' category.

In the 'materials' category, there were significant upward trends from 1979 to 1993 in material prefabrication (from 1.92 to 2.31) and the new products functions (from 2.01 to 2.22). Cohenca *et al.* (1989) conclude in their research performed in conjunction with the Business Roundtable's Construction Industry Cost-Effectiveness Project that on-site construction activities for industrial projects are perceived to be the most troubling quality and productivity problem. The troublesome items were identified as concrete, piping, welding, roofing, painting and electrical work. In order to improve productivity in the construction industry, designers could minimize construction activities on-site by increasing the use of prefabricated and precast components. In this way, it becomes easier to manage the issues of quality and project control.

The new products function in the 'materials' category appears to be perceived as needing more improvement in 1993 than in 1979. It is indeed true that, due to the rapid developments in materials science, the number of new products that go into the market is increasing. For example, the use of accelerating admixtures in concrete production is known to have increased site productivity (Jolin *et al.*, 1997) and has allowed the adoption of construction techniques that were not an option before the advent of these materials. Another example is the use of fibre-reinforced polymer composite wraps in rehabilitation projects, which has been proved to increase durability and constructability (Toutanji and Balaguru, 1998). On the other hand, usually the price of new products is relatively higher than that of conventional products. The significant upward trend in the function new products might indicate that although respondents are aware of the very many new products that are available in the market and of their potentially positive effects on site productivity, more effort is called for in order to make these materials more cost-effective.

Still in the 'materials' category, although the change is not statistically significant, it is interesting to note the downward trend in the materials storage function from a 'medium' rating of 1.86 in the 1983 survey to a 'low' rating of 1.65 in the 1993 survey. It is possible that the development of new materials, coupled with sophisticated and computerized stock control and order tracking systems, help to alleviate storage problems in construction sites.

Again in the 'materials' category, even though the change is not statistically significant, there seems to be an upward trend in the material standardization function in the last decade (from 2.26 in 1983 to 2.35 in 1993). There are many material standards that are specified by the Federal Government, state departments of transportation, and a variety of technical societies such as the American Society for Testing and Materials (ASTM), the American National Standards Institute (ANSI), and the American Institute of Steel Construction (AISC). These standards have been devised by specialists in their fields and are well accepted by the industry (Clough, 1986). With the increasing architectural and structural complexity of construction in the 1980s and 1990s, it appears that material standardization has become more effective than before in improving productivity. This finding is supported further by the significant upward trend in the specifications function (in the 'engineering' category). It seems that contractors encounter problems in interpreting specifications, especially regarding materials, so that more stringent material standardization is recommended.

There is a significant downward trend in the field inspection function from a 'high' rating of 2.42 in 1979 to a 'medium' rating of 1.92 in 1993. It seems that field inspection techniques have improved since the 1979 survey. Sweetapple (1985) stated that it is a good practice for the contractor and the engineer to gather regularly to discuss and record clearly the matters requiring attention by one party or the other. The contractor's work should be inspected on a regular basis. If the contractors know that they are accountable for their work efforts, they are likely to be more attentive to the performance of their work and hence be more productive. Also, construction owners should know that their agent's timely, regular and consistent inspections will increase a contractor's productivity. Considering the amount of published information regarding quality assurance and quality control in the recent literature (e.g., Ashford, 1989; Deffenbaugh, 1993; Evans and Lindsay, 1993) and the development and adaptation of work site recording software such as Expedition, a case can be made that field supervision problems have been resolved to a certain extent.

Even though it is not statistically significant, it is observed in the 'management' category that pressures to increase productivity in the scheduling function have increased (the mean ratings went up from 'medium' to 'high') in the last decade. Schedule control is considered to be one of the most significant management functions in the construction process (Rasdorf and Abudayyeh, 1991). It aims at the regular monitoring of achievement by comparing against planned activities, and it is a continuous process throughout the life of the project. Different scheduling techniques are available such as Gantt charts, CPM networks, line-of-balance schedules, progress curves, etc. In order to ensure the efficient performance of the contractor in the construction phase, the project owner should include contract clauses forcing the contractor to manage itself, such as clauses requiring weekly or monthly schedule updates, good field reporting and accounting practices, and short-interval scheduling. CPM scheduling which infiltrated into the construction industry in the late 1960s has been on the rise since then. One of the reasons why respondents feel that the scheduling function needs improvement more than ever lies in the fact that CPM networks are being used indiscriminately on each and every project with sometimes disastrous consequences; for example, it does not make sense to use standard CPM schedules on projects where activities are repetitive. Another reason why scheduling practices in the 1990s are perceived as needing improvement is because projects have become larger in size, more complex and more demanding, whereas not too much attention has been paid to problems in CPM implementation, such as impacts on organizational structure, corporate culture, human interactions, communication patterns, distribution of responsibilities, and legal liabilities. Although existing scheduling techniques should be effective they are not always so because they are not implemented properly. Further improving the scheduling function can be achieved by solving the inherent problems during its implementation.

Engineering and construction techniques

The only function in the 'engineering' and 'construction' categories that received consistently high (H) scores is design practices (H-H-H). There are two functions where the differences in the mean scores in the 1979, 1983 and 1993 surveys were statistically significant, namely, specifications and value engineering. No function received consistently low (L) scores. The remaining functions received neutral (M) scores.

Improvements in design practices can be achieved through constructability reviews. For example, Fisher and O'Connor (1991) concentrated on three major areas in semi-automated piping construction to review constructability issues: material handling, equipment capabilities, and equipment configuration. They found that construction productivity was improved by 24% when constructability issues were reviewed in the design process. Design reviews to improve the technical quality and constructability of drawings and specifications can result in significant savings in project cost, contract modifications and subsequent liability claims (Kirby *et al.*, 1988). The establishment of a formal design review programme conducted by qualified professionals is one of the most effective means of identifying deficiencies and incorporating improvements into the contract documents. The finding that respondents consistently assigned the design practices function high scores in the 1979, 1983 and 1993 surveys indicates that, with the increasing complexity of construction projects, contractors are experiencing greater productivity problems because of design errors and deviations. This finding is supported by the research findings obtained by Burati *et al.* (1992) that the quality deviations in construction projects accounted for an average of 12.4% of the total project costs; design deviations averaged 78% of the total number of deviations and 79% of the total deviation costs. In turn, design errors result in contract claims. These claims reduce overall productivity considerably because the contracting parties waste energy, time and money settling the disagreements. Moreover, the relationship between the parties becomes adversarial and this affects overall productivity negatively (Fondahl, 1991).

One of the final products of the design work is specifications. This is one of the most important contract documents because the contractors build the project based on the information contained in the specifications. The quality of the constructed project is highly dependent on the clarity and completeness of the specifications (Arditi and Gunaydin, 1997). Even though some designers use standard specifications such as the one provided by the Construction Specifications Institute (CSI), the finding that the specifications function shows an upward trend that is statistically significant from the 1979 and 1983 to the 1993 surveys indicates the increasing frustration on the part of responding contractors with the specifications prepared by designers. For example, construction methods are described clearly and in much detail in some project specifications, whereas they are described in general terms only in others. The clarity, consistency, language, level of detail and precision of the specifications not only may make life easier for the contractors but also may minimize the number of interpretation-based disagreements between contractors and designers.

Value engineering has been applied traditionally in the design phase, because recommended changes can be evaluated easily in this phase by comparing the difference in quantities and costs of materials as well as labour and materials required to construct the project. Thus value engineering has its greatest impact during the design phase (Zimmermann and Hart, 1982). In projects where the prospective contractor is known in the design phase, inputs from the contractor are valuable for designers in value engineering their design. In such cases, the designers and the contractor can discuss the most appropriate design and construction methods for the project. In turn, the contractor can build the project in the most efficient way (Mochtar, 1994). Although not specifically recommended in the literature, value engineering could also be applied in the construction phase. The findings of a survey of construction management firms in the US show that value engineering is applied in the pre-bid phases, namely in the design, planning and conceptual phases rather than in the construction phase, (Arditi and Alifen, 1996). The finding that respondents assigned the value engineering function significantly higher scores in the 1993 survey compared with the 1979 survey indicates that they have increasing problems with design documents. It is indeed possible to conclude that the value of the projects they undertake is regarded as not optimal. This finding agrees with the consistently high scores in design practices in the 'engineering' category discussed previously.

Labour, regulations, and equipment

The only functions in the 'labour', 'regulations', and 'equipment' categories that received consistently high (H) scores are labour training (H-H-H) and quality control (M-H-H). No function received consistently low (L) scores. The remaining functions received neutral (M) scores. There are four functions where the differences of the mean scores are statistically significant, namely labour availability, contract agreements, labour training, and quality control, all of them being in the 'labour' category.

The training of labour appears to be the function that needs the greatest improvement, since it received consistently high scores (H-H-H) and the highest mean score (2.51) in the surveys. The decline of union membership and union shop contractors causes a decline in the traditional union training and apprenticeship programmes. The shift to open-shop construction inevitably makes contractors rely on a workforce that may or may not have been trained properly in their respective trades.

A significant upward trend in the quality control function is observed from a medium (M) rating of 2.17 in 1979 to a high (H) rating of 2.43 in 1983 and to a higher H rating of 2.56 in 1993. This finding ties in with the previously discussed trends that proper training of labour is being neglected and that properly trained labour is becoming scarce; inevitably these conditions lead to a crisis in the quality of the work performed. Quality can be defined as meeting the legal, aesthetic and functional requirements of a project (Arditi and Gunaydin, 1997). Quality control is the specific implementation of the quality assurance programme covering activities necessary to provide quality in the work, including labour quality, to meet the project requirements. One way in which more attention will be given to quality control is the development of a project quality control plan. The quality control function involves the various techniques and activities used to monitor the process and to pursue the elimination of sources that lead to unsatisfactory quality performance, such as the quality of labour workmanship. These concepts are integrated parts of total quality management (TQM), which has been applied to a certain extent in the construction industry since the 1970s (Arditi and Gunaydin, 1997). The finding that the quality control function in the 'labour' category received a significant upward trend from 1979 to 1993 indicates that respondents are more cognizant of quality-related issues nowadays because of the heavy emphasis being put on quality by construction owners.

In the 'labour' category, the contract agreements function follows a significant downward trend from a medium (M) rating of 2.24 in 1979 and a high (H) rating of 2.34 in 1983 to a medium (M) rating of 1.94 in 1993. According to Abbasi (1993), open-shop construction started recovering its share in the industry in the early 1970s and expanded rapidly during the last two decades, leading to a decline in union membership. The significant decline on the importance perceived by contractors as to the content and improvement of labour agreements may be attributed to the decline in the bargaining power of unions in this period.

Again in the 'labour' category, it seems that it was more difficult to employ qualified labour in 1993 than in 1979 and 1983. According to Ashford (1989), many buildings and structures have failed to satisfy the legitimate requirements in recent years because they were built by semi-skilled labour. Once the contractor uses unqualified labour in construction, field productivity suffers due to substandard works and frequent rework. This finding agrees with the significant upward trends in labour training (from 2.37 in 1979 to 2.63 in 1993) and labour availability (from 1.90 in 1983 to 2.13 in 1993).

Proposed actions to improve productivity

Table 3 presents the responding companies' attitudes towards participating in productivity improvement programmes. It is seen that over 31% of the companies would assist with the programmes in some ways. Contributing funds to support the programmes is the least popular action. It appears that although

Table 3 Contractors' willingness to participate in improving productivity

Actions to improve productivity	Percent of respondents		
	1979 Survey	1983 Survey	1993 Survey
Serve as a member of a group that identifies productivity problems	43	39	45
Contribute funds to support programmes aimed at improving construction productivity	26	18	19
Develop project aimed at improving construction productivity	26	26	31
Conduct projects aimed at improving construction productivity	40	38	38
Evaluate results of projects aimed at improving construction productivity	54	54	51
Attend conference and meeting on construction productivity	55	49	49
Subscribe to a construction productivity information service	41	36	34

companies surveyed are eager to attend meetings, identify productivity-related problems, and evaluate solutions, they are not interested in spending money for these activities, nor in initiating or conducting such activities. Given the absence of such interest on the part of contractors, it is recommended that professional organizations, trade associations, educational institutions and governmental agencies fill the gap by providing training programmes and by funding research activities to spearhead productivity awareness. The findings of the 1979, 1983 and 1993 surveys are quite similar to each other with no statistically significant differences.

Conclusions

Large US construction companies were surveyed in 1993 by Mochtar (1994), in 1983 by Nasra (1983), and in 1979 by Choromokos and McKee (1981) to identify areas that are perceived as having potential for productivity improvement. The rates of return of all the surveys (35% in 1993, 15% in 1983, and 20% in 1979) were relatively high. One of the reasons for these high rates of return may be that contractors were interested in looking for ways to increase their productivity and consequently position themselves favourably in the highly competitive markets of the 1980s and 1990s.

There are four functions, namely cost control (H-M-H), value engineering (H-H-H), labour training (H-H-H), and quality control (M-H-H) that have been identified consistently by the respondents in all three surveys as having considerable room for improvement. It appears that completing a project within budget, cutting costs without impinging on quality or function, having access to competent labour, and maximizing quality in the constructed facility are the functions whose impacts on total productivity did not change over time. Improving the effectiveness of cost control methods, establishing value engineering as a regular practice in all phases of a project, putting in place the mechanisms that will allow the proper training of the labour force, and instituting formal quality control processes such as total quality management (TQM), may constitute essential steps towards improving total productivity in a construction project.

Another function, scheduling (M-M-H), received the fourth highest mean scores in the three surveys (2.33), indicating that it should be considered, along with cost control, value engineering, labour training, and quality control, as an area where considerable improvement is due. Sophisticated scheduling methods and advanced scheduling software have always been available but they are often not properly and extensively used. Research into developing ways to effectively implement existing scheduling and progress control technologies is long overdue.

Only one function, namely materials packaging (L-L-L) has been identified consistently as not requiring any improvement, possibly because packaging of construction materials is not a big problem and because it is not an activity that is within the contractors' purview. Foreign developments (L-M-M), a function in the 'construction techniques' category, received the second lowest mean score in the three surveys (1.66), indicating that typically US contractors do not rely on foreign construction technologies and therefore foreign technologies have no impact on their productivity.

There are nine functions that were rated differently in the 1979, 1983 and 1993 surveys administered to contractors. These differences were statistically significant. These functions include field inspection, material prefabrication, new products, specifications, value engineering, labour contract agreements, labour training, quality control, and labour availability. It appears that the increasing complexity of construction projects caused the respondents to seek more efficient specifications and design practices, as well as to explore greater use of new products and prefabricated components. The impact of the decline of union membership in the construction industry is also apparent in the findings; while labour agreements do not carry the same importance in the 1993 survey, quality of work, training and availability of workers have emerged as new areas of concern. More research in these specific areas is recommended in the future.

It is concluded from the survey results that generally the responding contractors are not interested in contributing funds to support productivity improvement programmes. On the other hand, they are more willing to participate in and contribute to productivity improvement groups and projects. There was no marked change between the 1979, 1983 and 1993 surveys in the contractors' opinions as to the proposed actions for increasing productivity.

It is recommended that new surveys be conducted periodically to observe and identify the new trends in the construction industry and to steer research in the appropriate direction. Both the effective coordination of such research and the fast communication of the results among all parties in the construction industry, especially designers, construction managers and contractors, are necessary.

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Appendix I

Illinois Institute of Technology
Department of Civil Engineering
Construction Engineering and Management Program

RESEARCH UNIT NO. 6

CONSTRUCTION PRODUCTIVITY QUESTIONNAIRE

COMPANY: ___________________________ _ **NAME** ______________________

TITLE ______________________

1. **TYPE OF CONTRACTOR**
   BUILDING (EDUCATIONAL, COMMERCIAL, ETC.) ☐
   ENGINEERING (HIGHWAY, HEAVY) ☐
   INDUSTRIAL (POWER PLANTS, REFINERIES, ETC.) ☐

2. **ANNUAL SALES (MILLIONS OF DOLLARS)**
   UNDER 25 ☐ 25–50 ☐ 50–100 ☐ 100–500 ☐ OVER 500 ☐

3. **NUMBER OF PERMANENT EMPLOYEES**
   UNDER 100 ☐ 100–500 ☐ 500–1000 ☐ 1000–5000 ☐ OVER 5000 ☐

4. **NUMBER OF TEMPORARY EMPLOYEES**
   UNDER 100 ☐ 100–500 ☐ 500–1000 ☐ 1000–5000 ☐ OVER 5000 ☐

5. **DOLLAR VALUE OF CONSTRUCTION EQUIPMENT (MILLIONS OF DOLLAR)**
   UNDER 5 ☐ 5–25 ☐ 25–50 ☐ 50–200 ☐ OVER 200 ☐

6. **PERCENTAGE OF CONSTRUCTION EQUIPMENT LEASED OR RENTED**
   NONE ☐ UNDER 25% ☐ 25–50% ☐ 50–75% ☐ 75–100% ☐

7. **AMOUNT OF WORK (BY DOLLAR VALUE) SUBCONTRACTED ON AVERAGE JOB**
   UNDER 25% ☐ 25%–50% ☐ 50%–75% ☐ 75%–100% ☐

8. **GEOGRAPHIC LOCATION OF PROJECTS**

NORTHWESTERN US	☐	CENTRAL US	☐	CENTRAL AMERICA	☐
MID-ATLANTIC US	☐	EUROPE	☐	ALASKA	☐
SOUTHERN US	☐	AFRICA	☐	HAWAII	☐
SOUTHERNWESTERN US	☐	ASIA	☐	OTHER (SPECIFY)	☐
WESTERN US	☐	AUSTRALIA	☐	____________________	
NORTHWESTERN US	☐	SOUTH AMERICA	☐	____________________	

9. **RATE THE FOLLOWING AREAS FOR THEIR POTENTIAL WITH RESPECT TO OPPORTUNITY FOR PRODUCTIVITY IMPROVEMENT (H=HIGH M=MEDIUM L=LOW)**

MATERIALS	**H**	**M**	**L**	**LABOR**	**H**	**M**	**L**
PROCUREMENT	☐	☐	☐	TURNOVER	☐	☐	☐
DELIVERY	☐	☐	☐	AVAILABILITY	☐	☐	☐
STORAGE	☐	☐	☐	WORKING HOURS	☐	☐	☐
PACKAGING	☐	☐	☐	LABOR RELATIONS	☐	☐	☐
PREFABRICATION	☐	☐	☐	CONTRACT AGREEMENT	☐	☐	☐
STANDARDIZATION	☐	☐	☐	TRAINING	☐	☐	☐
PRODUCT AVAILABILITY	☐	☐	☐	QUALITY CONTROL	☐	☐	☐
NEW PRODUCTS	☐	☐	☐				

MANAGEMENT

OFFICE
MANAGEMENT ☐ ☐ ☐
ESTIMATING ☐ ☐ ☐
COST CONTROL ☐ ☐ ☐
SCHEDULING ☐ ☐ ☐
RESOURCE ALLOCATION ☐ ☐ ☐
INTEGRATION OF DESIGN/
ESTIMATING/SCHEDULING/
CONTROL FUNCTIONS ☐ ☐ ☐
FIELD INSPECTION ☐ ☐ ☐
SAFETY MANAGEMENT ☐ ☐ ☐
MARKETING ☐ ☐ ☐
COMMUNICATIONS:
-WITHIN COMPANY ☐ ☐ ☐
-WITHIN DESIGNER ☐ ☐ ☐
-WITH SUBCONTRACTORS ☐ ☐ ☐
-WITH RESEARCH ORGS ☐ ☐ ☐

REGULATIONS

EPA ☐ ☐ ☐
EEO ☐ ☐ ☐
OSHA ☐ ☐ ☐
LOCAL CODES ☐ ☐ ☐
OTHER (SPECIFY) ☐ ☐ ☐
______________________ ☐ ☐ ☐
______________________ ☐ ☐ ☐

CONSTRUCTION TECHNIQUES

PRECAST ELEMENTS ☐ ☐ ☐
PRE-ASSEMBLE MODULARS ☐ ☐ ☐
FOREIGN DEVELOPMENTS ☐ ☐ ☐

ENGINEERING

DESIGN STANDARDS ☐ ☐ ☐
DESIGN PRACTICES ☐ ☐ ☐
SYSTEMS ENGINEERING ☐ ☐ ☐
DRAFTING ☐ ☐ ☐
SPECIFICATIONS ☐ ☐ ☐
VALUE ENGINEERING ☐ ☐ ☐

EQUIPMENT

REPLACEMENT ANALYSIS ☐ ☐ ☐
CAPACITY ☐ ☐ ☐
SIMPLICITY ☐ ☐ ☐
MAINTAINABILITY ☐ ☐ ☐
UTILIZATION ☐ ☐ ☐
USE OF ROBOTS ☐ ☐ ☐

CONTRACTING	**H**	**M**	**L**
RISK DISTRIBUTION AMONG PARTIES	☐	☐	☐
BONDING	☐	☐	☐
INSURANCE	☐	☐	☐
SELECTING GENERAL CONTRACTOR	☐	☐	☐
SELECTING DESIGNER	☐	☐	☐
SELECTING SUBCONTRACTORS	☐	☐	☐
DESIGN BUILD CONTRACTING	☐	☐	☐
CONSTRUCTION MANAGEMENT CONTRACTING	☐	☐	☐
INCENTIVE/DISINCENTIVE CLAUSES	☐	☐	☐
DISPUTE RESOLUTION METHODS	☐	☐	☐
OTHER (SPECIFY) ______________________ _	☐	☐	☐

COMPUTER UTILIZATION IN:	**H**	**M**	**L**
OFFICE MANAGEMENT	☐	☐	☐
DRAFTING	☐	☐	☐
SPECIFICATIONS	☐	☐	☐
MARKETING	☐	☐	☐
STRUCTURAL DESIGN	☐	☐	☐
ARCHITECTURAL DESIGN	☐	☐	☐
COST ESTIMATING	☐	☐	☐
SCHEDULING/PLANNING	☐	☐	☐
COST ACCOUNTING	☐	☐	☐
PERSONNEL MANAGEMENT	☐	☐	☐
SAFETY MONITORING	☐	☐	☐
MATERIAL MANAGEMENT	☐	☐	☐
EQUIPMENT MANAGEMENT	☐	☐	☐

LABOR PRODUCTIVITY IMPROVEMENT TECHNIQUES	**H**	**M**	**L**
WORK SAMPLING	☐	☐	☐
GOAL SETTING	☐	☐	☐
QUALITY CIRCLE	☐	☐	☐
MOTION ANALYSIS	☐	☐	☐
TIME STUDY	☐	☐	☐
OTHER (SPECIFY)			
______________________	☐	☐	☐

OTHERS (SPECIFY)

______________________ ☐ ☐ ☐
______________________ ☐ ☐ ☐

INTEGRATING DESIGN/ ESTIMATING/SCHEDULING/ CONTROL FUNCTIONS	☐	☐	☐
INTEGRATED COMMUNICATIONS			
-WITHIN COMPANY	☐	☐	☐
-WITH DESIGNER	☐	☐	☐
-WITH SUBCONTRACTORS	☐	☐	☐
-WITH RESEARCH ORGS	☐	☐	☐

10. **INDICATE THE TYPES OF ACTION YOUR ORGANIZATION WOULD TAKE IN THE INTEREST OF IMPROVING PRODUCTIVITY**

SERVE AS A MEMBER OF A GROUP THAT IDENTIFIES PRODUCTIVITY PROBLEMS	☐
CONTRIBUTE FUNDS (TOGETHER WITH OTHER COMPANIES) TO SUPPORT PROGRAMS AIMED AT IMPROVING CONSTRUCTION PRODUCTIVITY	☐
HELP DEVELOP A PROJECT AIMED AT IMPROVING CONSTRUCTION PRODUCTIVITY	☐
CONDUCT (OR PARTICIPATE IN) A PROJECT AIMED AT IMPROVING CONSTRUCTION PRODUCTIVITY	☐
EVALUATE THE RESULTS OF A PROJECT AIMED AT IMPROVING CONSTRUCTION PRODUCTIVITY	☐
ATTEND CONSTRUCTION PRODUCTIVITY CONFERENCES AND MEETINGS	☐
SUBSCRIBE TO A CONSTRUCTION PRODUCTIVITY INFORMATION SERVICE	☐
OTHER (SPECIFY) ______________________________ ____________________________ _	☐

11. **YOUR COMMENTS RELATIVE TO PROBLEMS OR SOLUTION DIRECTIONS FOR CONSTRUCTION PRODUCTIVITY WOULD BE APPRECIATED. PLEASE MAKE THESE COMMENTS ON A SEPARATE PIECE OF PAPER AND ENCLOSE IN THE ENCLOSED POSTAGE PAID ENVELOPE AND RETURN WITH YOUR COMPLETED QUESTIONNAIRE.**

THANK YOU FOR YOUR COOPERATION