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RESEARCH ARTICLE

Work practices of onsite construction crews and their influence on productivity

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Abstract

The nature of construction work processes allow crews and workers to follow their own practices in how they plan, organise and coordinate work. However, there is little research into the nature of crew work practices. This paper aims to unveil the influence of onsite crew work practices on productivity. An exploratory case study investigated work practices on a residential project involving two separate crews (of 18 and 23 workers) engaged in rebar placement for 112 columns each, which included a high-performing and an average-performing crew. A triangulated mixed methods approach to data gathering utilised site observations, individual and group interviews, and time measured work studies, to assess productivity of the crews. The findings indicate that the high-performing crew achieved 44% higher productivity than the average-performing crew and this manifested across specific tasks including rebar cutting, bending, stirrup fabrication and tieing. Five broad work practices were observed to considerably influence the above productivity differences: work preparation and execution strategy; group formation and stability; avoiding duplication of tasks; crew social cohesion; and internal and external leadership practices. These five practices are proposed as dimensions that can be used to measure crew productivity in ongoing research. In-depth understanding of crew based work practices will enable training of foremen and work crews in such practices to systematically develop high-performing crews.

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Keywords

Construction work crews, productivity, work practices, time study, case study research, mixed methods approach

Introduction

Productivity is defined as the relationship between output produced and one or more of the inputs used in the production process (National Research Council 1979). The subject of construction productivity and its relationship to project success has long been investigated and reported in academic journals and industry reports. On an analysis of trends in construction research by Abudayyeh et al., (2004), productivity is the 2nd top research area next to scheduling within the construction management domain. However, sluggish productivity growth is apparent in the construction industry compared to other industries such as the manufacturing and services sectors, over the past two decades (McKinsey Global Institute, 2017, Caldas et al., 2014). Conversely, practitioners believe that construction costs and schedules can be reduced by 15%, by boosting productivity, particularly construction labour productivity (CLP) (McKinsey Global Institute, 2017).

This is so important because, in labour-intensive building construction projects, site labour can consume 30-50% of project costs, thus demonstrating the impact of CLP on the industry (Harmon and Cole, 2006). Also, many construction operations have reminded craft-based over the years because labour-intensive operations are usually the cheapest option in the short term in many economies around the world (Chiang, 2009; Ng and Tang 2010). For instance, in developing economies such as Brazil, China, India, South Africa where demand for housing and commercial construction is high, onsite construction activities remain labour-intensive. Indeed, local construction in developed economies is also reliant on labour-intensive, in-situ construction methods (Tang 2001; Ng and Tang 2010). Thus, the reliance on construction labours is more evident in building projects. Nevertheless, studies indicate labour is used to only 40-60% of its potential efficiency and up to 50% of labour cost goes to labour waste due to poor workforce and crew management practices (Harmon and Cole, 2006; Tulacz and Armistead, 2007). Therefore, there is a fundamental need to better understand the operations of work crews as distinct from purely keeping them busy (Ballard et al., 2003).

Apart from complex operations, work crews usually follow their own practices in how they plan, organise and coordinate work (Mitropolous et al., 2009). Quite often, however, managers on construction projects fail to follow historically successful or innovative practices that lead to better crew productivity (Gurmu and Aibinu 2017; Caldas et al., 2014). Also, there is little research into the nature of crew work practices. That said, the wealth of research on the influence of broader construction management practices on productivity, (Gurmu and Aibinu 2017; Bernold and AbouRizk 2010) contrasts the relative paucity of attention given to this aspect of trade crew work practices (Memarian and Mitropolous 2014; Mitropolous and Cupido 2009)This paper hence aims to unveil the influence of trade crew work practices on onsite construction productivity. The study hence aims to explore:

1. What work practices do trade crews follow while executing their work?
2. Why and how do those practices emerge?

The study focuses on rebar placement crews, given both the labour intensive work and the potential for improvement in reinforced concrete construction, being one of the most common construction activities worldwide (Forsythe, 2014). The outcomes of this study can be generalised to the extent that similar labour-intensive construction activities will likely encounter a degree of similarity in generic work practices.

A critical analysis of factors affecting construction labour productivity

While trade crew work practices are not specifically discussed and developed into a knowledge area within the extant CLP literature, the importance of this area is apparent in the literature sub-streams on *factors affecting* CLP. Volumes have been written about factors affecting CLP, hence the need to efficiently distill the issues involved. For this, a two-staged cascade type content analysis approach was formulated to critically analyse existing literature on factors affecting CLP. Cascade type content analysis is where the outputs of first stage of the content analysis leads as input to the second stage for further analysis. The content analysis was carried out using NVivo software.

Stage-1 focused on marshalling productivity articles on factors affecting CLP from the six top-ranked academic journals in construction management, as ranked by Wing (1997); examples include *Journal of Construction Engineering and Management* or *Construction Management and Economics*. The search focused on the period between 1995 and 2015 and collected content from 23 different developed and developing countries (e.g. Australia, India, Kuwait, Singapore, UK, and USA). This review revealed 302 issues causing a positive/negative impact on CLP in different countries.

In stage-2, critical content analysis was carried on the 302 issues to categorise core content. In practice, this made use of existing analysis frameworks proposed by authors including Jarkas and Bitar (2011) and Yi and Chan (2014) for analysing CLP research at industry, project and activity level. The content analysis was undertaken using NVivo software to code and analyse repetitive issues according to the industry, project and activity typology. This served to distill 44 common factors affecting CLP from the abovementioned 302 issues. For example, a factor was created for *communication difficulties between supervisors and workers* which represented the issues of poor communication; clarity of instructions and information exchange; communication system which occurred across the different studies analysed. Table 1 presents the outputs of the empirical analysis with indicative references in the literature for each factor. It can be seen in Table 1 that 43% of the factors (19 out of 44) are directly crew and human-related, while 32% are project-related, 20% industry-related and 5% external-related. This supports the significance of crew and human-related factors in CLP.

Table 1 Critical analysis of factors affecting CLP

Factor No.	Factor category	Source
	A. Industry-related factors (20% of all factors)	
A-1	Advancement in construction technology	*Thomas and Sudhakumar (2015); Jarkas and Bitar (2011)*
A-2	Constructability of the design	*Naoum (2015); Jarkas and Bitar (2011)*
A-3	Leadership and competency of construction management	*Naoum (2015); Jarkas and Bitar (2011)*

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Table 1 continued

A-4	Management of migrant work force (internal migrant and immigrant work force)	*Thomas and Sudhakumar (2015); Lim & Alum (1995)*
A-5	Difficulty in recruitment of supervisors and foreman	*Thomas and Sudhakumar (2015); Lim & Alum (1995)*
A-6	High labour turnover	*Thomas and Sudhakumar (2015); Lim & Alum (1995)*
A-7	Compatible contract documents and statutory compliance	*Jarkas and Bitar (2011); Dai et al., (2009)*
A-8	Mechanization of activities and tasks	*Thomas and Sudhakumar (2015)*
A-9	Shortage of skilled labour	*Thomas and Sudhakumar (2015); Jarkas and Bitar (2011)*
	B. Project-related factors (32% of all factors)	
B-1	Site layout	*Jarkas and Bitar (2011); Hughes & Thorpe (2014)*
B-2	Clarity of technical specifications	*Jarkas and Bitar (2011); Dai et al., (2009)*
B-3	Methods of working	*Jarkas and Bitar (2011); Dai et al., (2009)*
B-4	Availability of drawings onsite	*Thomas and Sudhakumar (2015); Hughes & Thorpe (2014)*
B-5	Availability of tools and equipment	*Thomas and Sudhakumar (2015); Hughes & Thorpe (2014)*
B-6	Availability of materials	*Naoum (2015); Jarkas and Bitar (2011)*
B-7	Equipment breakdown	*Thomas and Sudhakumar (2015); Hughes & Thorpe (2014)*
B-8	Inspection delay	*Hughes and Thorpe (2014); Jarkas and Bitar (2011)*
B-9	Unbalanced distribution of resources	*Thomas and Sudhakumar (2015); Jarkas and Bitar (2011)*
B-10	Over time works	*Thomas and Sudhakumar (2015); Jarkas and Bitar (2011)*
B-11	Poor planning and scheduling of activities and tasks	*Naoum (2015); Thomas and Sudhakumar (2015)*
B-12	Payment issues to workers	*Thomas and Sudhakumar (2015); Dai et al., (2009)*
B-13	Lack of incentive scheme for workers	*Thomas and Sudhakumar (2015); Dai et al., (2009)*

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Table 1 continued

B-14	Distance between project site and labour's place	*Thomas and Sudhakumar (2015); Jarkas and Bitar (2011)*
	C. Crew and Human-related factors (43% of all factors)	
C-1	Education, skill and experience of labour	*Thomas and Sudhakumar (2015); Jarkas and Bitar (2011)*
C-2	Crew size and composition	*Thomas and Sudhakumar (2015); Jarkas and Bitar (2011)*
C-3	Competency of supervisors and foreman	*Hughes & Thorpe (2014); Dai et al., (2009)*
C-4	Physical fatigue, injuries and accidents of human	*Hughes & Thorpe (2014); Jarkas and Bitar (2011)*
C-5	Absenteeism and turnover of labour	*Hughes & Thorpe (2014); Lim and Alum (1995)*
C-6	Communication difficulties between supervisor/foreman and worker	*Hughes & Thorpe (2014); Jarkas and Bitar (2011)*
C-7	Pulling people off a task before it is done	*Thomas and Sudhakumar (2015); Dai et al., (2009)*
C-8	Teamwork among workers and crews	*Naoum (2015); Thomas and Sudhakumar (2015)*
C-9	Motivation of labour	*Jarkas and Bitar (2011); Dai et al., (2009)*
C-10	Working culture	*Naoum (2015); Jarkas and Bitar (2011)*
C-11	Skill of equipment operatives	*Jarkas and Bitar (2011); Dai et al., (2009)*
C-12	Availability of proper work front	*Thomas and Sudhakumar (2015); Jarkas and Bitar (2011)*
C-13	Linguistic differences between workers, crews and supervisors	*Thomas and Sudhakumar (2015); Lim and Alum (1995)*
C-14	Basic facilities for workers	*Thomas and Sudhakumar (2015); Jarkas and Bitar (2011)*
C-15	Respect for workers and crews	*Dai et al., (2009); Thomas and Sudhakumar (2015)*
C-16	Stress and work-life balance of human	*Thomas and Sudhakumar (2015); Jarkas and Bitar (2011)*
C-17	Improper coordination & cooperation among workers and crews	*Naoum (2015); Dai et al., (2009)*
C-18	Respect and recognition for craft worker suggestions/ideas	*Jarkas and Bitar (2011); Dai et al., (2009)*

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Table 1 continued

C-19	Job satisfaction	*Naoum (2015); Dai et al., (2009)*
	D. External factors (5% of all factors)	
D-1	Inclement weather	*Jarkas and Bitar (2011); Lim and Alum (1995)*
D-2	Unforeseen events	*Thomas and Sudhakumar (2015); Dai et al., (2009)*

Looking closely at the crew and human-related factors, it can be inferred that several of them are particular relevance to this research. For instance, communication difficulties between supervisors/foreman and workers; improper coordination and cooperation among workers/crews; teamwork among workers/crews; pulling people off a task before it is done; working culture are strongly influenced by practices that crews follow when executing activities and tasks onsite. Hence the significance of understanding the nature of crew work practices is ubiquitous in the literature, although crews *per se*, are not directly acknowledged as the specific phenomena of interest. This research hence aims to uncover the influence of crew work practices on productivity.

On the other hand, the importance of work practices through the eyes of work teams/crews can be found in other related disciplines. Studies in other comparable disciplines such as aviation, military, health care indicate that practices of work teams within the project and organisation context significantly influence safety, quality and performance (Kozlowski and Bell, 2003; Salas et al., 2008). Furthermore, research into high reliability work teams/high reliability organisations investigated characteristics, operating principles and practices of organizations performing complex operations in extreme conditions, but achieving surprisingly low rates of serious incidents. Such organizations include nuclear power plants, aircraft carriers and firefighting crews (Roberts, 1993; Bigley and Roberts, 2001). They perform operations that have an overwhelming potential for error and disaster and have developed ways of acting that enable them to manage the unexpected better than most kinds of organizations (Weick and Sutcliffe, 2001). These proven benefits in comparable disciplines, further reinforce the need to study crew work practices and the related influence on onsite construction contexts.

Lean construction and broader construction management practices for improving productivity

Lean Construction practices have developed over the last few decades in many countries, bringing in continuous improvement, inclusive culture and improved levels of certainty in project delivery. Koskela (2000) presented the 'TFV' theory of production where the production was conceptualized in three complementary ways - Transformation (T) of inputs into outputs; Flow (F) of materials and information; Value (V) generation for the customers. Koskela (2000) noted that to improve productivity and optimise production, it is important to consider all aspects of production, i.e. transformation, flow and value. Within lean construction, a significant amount of research has been conducted on how to stabilise and improve workflow and the effects of flow variation in the production process (Howell and Ballard, 1994; Horman et al., 2002; Liu and Ballard, 2009). One of the essential features of these studies was how to ensure a reliable workflow as ill-planned work assignments are a major source of workflow variability in construction (Howell and Ballard, 1994; Liu and Ballard, 2009). Ballard and Howell (1994) introduced the Last Planner System (LPS), which helps to stabilise workflow. LPS aims to improve the formation and assignment of tasks to crews by ensuring that all resources are mobilised and ready for the task. With LPS, the percentage of planned tasks completed (PPC) is measured to show changes in planning reliability. While LPS, as a planning tool provides an introduction to the issue of onsite crew dynamics but it does not delve into the makeup and execution of productive crews onsite, especially if the dynamic behaviour and practices of crews impacts on productivity as distinct from measurements of individual workers.

Broader management practices have also focused on improving productivity in the wider construction productivity literature. In 1983, the USA Business Roundtable identified CLP improvement as a primary management issue (BRT, 1983). Following that, Sanvido (1988) categorized four ways to improve labour productivity through management practices which include planning, resource supply and control, information flow and feedback, and selection of the right people to control certain factors. Later, a study by Adrian (2004) emphasized other key management practices, including estimating and cost control, subcontractor management, and new technology. Subsequent studies by Bernold and AbouRizk (2010) and Gurmu and Aibinu (2017) enlightened the importance of management practices in construction and included categories of materials, preconstruction-phase, construction methods, construction equipment and tools management practices, human resources management practices, and safety and health practices.

The key point here is that even though construction is often a labour-centric management proposition, management structures, while broad spanning, rarely cover the main construct under which labour operates on-site, namely activity level crews and the practices they follow while executing tasks.

Methodology and approach

To explore the proposition that crew work practices considerably influence onsite construction productivity, an exploratory case study was conducted. Since the primary focus of the study was on crew work practices and in order to study them in real time, in a natural setting, a case study approach was found to be most appropriate (Yin, 2013). Also, as the nature of crew work practices are not well documented, the case study approach allows exploring this with a relatively in-depth understanding of the nature and complexity of the phenomenon (Yin, 2013). Within the case study approach, a mixed-method approach to data collection and analysis strategy was adopted.

Evidently, project based crews usually work together over time, perform similar operations from one project to another, and the major trades are independent of each other. The rebar trade activity was chosen because it not only enables the crew to be studied independently of other major trade activities, but also facilitates studying interdependent sub-crews by splitting the activity into different tasks of rebar cutting, rebar bending, stirrups fabrication and rebar tying.

In order to leverage potential differences between productivity of rebar crews, the project manager on the case study assisted in the sample selection. As the study was carried in the middle of the project, the manager could identify a high-performing and an average-performing crew, based on floor cycle time assessment and an evaluation made in consultation with relevant site managers. This pragmatic approach was useful, in the absence of a standard on-site productivity evaluation techniques. It also had the benefit of providing *face vadility*

(Gravetter and Forzano, 2003) in reflecting the perspectives of those directly involved in managing the components relevant to the research (i.e. work crews and CLP). Finally, the fact that the two crews were undertaking identical work processes on two separate buildings in the same project, provided a reasonably high degree of control to match case study circumstances, over potential variances in activity scope, material availability, work environment and site conditions etc.

The selected project was a residential complex involving seven 4-storey apartment buildings. The two buildings were managed by different site engineers/managers of the main contractor. The main contractor supplied materials, but the physical work was undertaken by sub-contract labour. Two different labour sub-contractors managed the two chosen crews – a high performing crew (HPC) and an average performing crew (APC). The HPC and APC consisted of 18 and 23 members respectively. While the APC had 23 crew members, the average crew strength maintained by them during the duration of the study activity was 20. The crew faced issues with regards to absenteeism and relocation of crew members to different work stations, which are discussed below. Therefore, it is reasonable to compare crews of sizes 18 and 20 given that it is very difficult to obtain an exact comparison in real world circumstances and given that other variables have been controlled for.

Data collection methods and process

Each crew was engaged on rebar placement of 112 columns, constituting a total work quantity of 8 metric tonnes (MT). The steel reinforcement was cut and bent onsite. The study was conducted when the crews were placing rebar on second-floor columns in their respective buildings. This meant the crews had acquired initial experience in this activity before the study. The mixed-methods data collection included field observations, individual/group interviews and time studies (using time lapse video recordings). Table 2 outlines how the different data collection methods were used appropriately for different purposes at various stages of the study to help overcome the challenges in reliability, validity and triangulation of data (Yin 2013).

Table 2 Purpose and description of various data collection methods

Method	Type of data collected	Purpose and description	When it was used
Time study	Quantitative	• Video recording of individual tasks carried out by sub-crews/ individual crew members to measure and analyse productivity	• Carried out from the start to completion of the activity • All tasks of the activity were recorded for 10 sample cycles

Table 2 continued

Field observations	Qualitative	• Focused on examining the crew work practices during planning, organisation & actual execution of work onsite	• Carried out periodically, for about 3-4 times a day, and each observation cycle lasted for 30-45min. • Observations carried out from start to completion of the activity, covering all task
Individual interviews/ Group interviews	Qualitative	• *Individual interviews/ group interview sessions with crew members & foreman* - to understand crew characteristics, how crews & foreman plan, organise & execute work, key concerns and strategies for managing work • *Interviews with managers*- the identified practices and findings from the study were presented and discussed	• Carried out three times (each approx. at the end of 30-35% activity completion) for about 30 minutes with either individual crew members or by small groups (i.e. as sub-crews) • Separate interviews were carried out with foreman • Carried out after compiling all the findings - as a mean of reinforcing "face" validity

The identification of work practices through field observations, and the reasons for following such practices were verified and validated through interviews with crew members and foreman. The productivity data collected through time studies was used to explain and evaluate the relationship between CLP and work practices. The findings from the study were presented and discussed with the senior site engineers and project managers, to help support the validity of findings. This also helped triangulate the study findings.

Data analysis methods and process

Analysis of the time study (quantitative) data was carried out to determine the time taken to complete one task unit (represented as task/min). Early work by Adrian and Boyle (1976) remains instructive in setting out the main issues involved in measuring at this level of detail. For instance, there is the need to identify a production unit which can be visually measured, a production cycle relating to the time between consecutive occurrences of the production unit, and a leading resource as required by the production method (Forsythe, 2014; Adrian and Boyle, 1976). A few studies adopt a similar approach in rebar placement activity in different contexts (Forsythe, 2014; Jarkas, 2010). However, overall activity productivity is measured as installed quantity/actual hours, i.e. Kgs of steel tied/total input hours.

Analysis of the qualitative data was carried out in three steps. First, the data reduction process was carried out to sharpen and organise observation and interview data. This was done by writing summaries of the observational data and transcribing the interview data. Second, coding (using Nvivo) was undertaken using the summarised and transcribed data to identify the emerging specific and broad themes of work practices. Third, using the matrix technique of data display, the themes and patterns of similarities and differences among the high and average performing crew were made (Miles and Huberman, 1994).

Productivity analysis of the study crews

The rebar activity involved four key, value-adding tasks including rebar cutting (KT1), rebar bending (KT2), stirrups fabrication (KT3), and rebar tieing (KT4). Interspersed through this, waiting, transportation and storage tasks occurred - which are commonly referred as *non-value adding/non-value adding but necessary* tasks (Thomas and Daily, 1983).

Table 3 presents productivity data of the HPC and APC for the four key tasks. Table 3 also presents more detailed sub-tasks for each of these key tasks, based on different rebar diameters and task categories. For example, KT1a-e represents rebar cutting tasks for four different bar diameters and categories. As part of this, Table 3 provides description of task units, crew size and number of task units produced per cycle, total number of time study cycles carried for each task (in each crew), total input time considering all cycles for each task, productivity achieved per cycle for each task: measured as task unit/minute, and percentage difference in productivity between crews. At least 10-15 sample cycles are generally needed for a statistically valid time study (Maynard et al., 2001). In this study, a sample of 10 cycles was gathered for each sub-task, and for each crew. The 10 cycles were considered adequate as there was no significant variation noticed between each cycle. Therefore, for a total of 35 task units which included measurement of 10 cycles, the resulting data gathering involved 350 cycles per crew and 700 cycles in total for the overall productivity study.

It can be inferred from Table 3 that the unit productivity of the HPC, considering all the key tasks, on average was 25% higher than the APC. In some cases, the unit productivity of the HPC was significantly higher than the APC which includes 12mm rebar bending (46% higher), rebar tieing (44% higher) and 20mm rebar bending (40% higher). In some cases, less difference in unit productivity between HPC and APC was noticed, which includes 20mm rebar cutting and type-B stirrups fabrication (both only 2% higher). However, the overall activity's productivity of the HPC was 7.94 Kg/hr (total quantity=8000 Kg; total input hours=1008 hours), and APC was 5.50 Kg/hr (total quantity=8000 Kg; total input hours=1454 hours). Hence, considering the overall activity completion, the HPC was 44% more productive than the APC. However, as mentioned earlier the two crews' undertook identical work processes on the same project and contextual factors such as activity scope, material availability, work environment and site conditions etc. were very similar. It was thus reasonable to conclude that work practices were the main differentiator influencing productivity differences between the crews. The next section therefore discusses the influence of the identified crew work practices on onsite crew productivity.

Table 3 Productivity study outputs of individual tasks for high performing crew (HPC) and average performing crew (APC)

Task code	Task category	Task name	Description of one task unit	Crew size per cycle		No. of task units produced per cycle in HPC&APC	No. on time study cycles carried in HPC&APC	Total no. of task units produced considering all cycles in HPC&APC	Total time taken considering all cycles (in min:sec)		Productivity obtained for each task (Total no. of tasks completed/total time taken)		Percentage differences in productivity between HPC&APC
				HPC	APC				HPC	APC	HPC	APC	
KT1a	Rebar cutting	8mm rebar cutting (Type-A)	One rod cut	3	2	8	10	80	64.3	80	1.24	1.00	24
KT1b		8mm rebar cutting (Type-B)	One rod cut	3	2	12	10	120	72	84.3	1.67	1.42	17
KT1c		12mm rebar cutting	One rod cut	3	2	3	10	30	28.18	34.48	1.06	0.87	22
KT1d		16mm rebar cutting	One rod cut	3	2	3	10	30	12.42	16.18	2.42	1.85	30
KT1e		20mm rebar cutting	One rod cut	3	2	3	10	30	9.3	9.48	3.23	3.16	2
KT2a	Rebar bending	12mm rebar bending	One bend rod	2	2	1	10	10	2.18	3.18	4.59	3.14	46
KT2b		16mm rebar bending	One bend rod	4	4	1	10	10	5.48	7.18	1.82	1.39	31
KT2c		20mm rebar bending	One bend rod	4	4	1	10	10	7.12	10	1.40	1.00	40
KT3a	Stirrups preparation	Type-A stirrups preparation	One stirrup fabrication	1	1	1	10	10	3.48	4.18	2.87	2.39	20
KT3b		Type-B stirrups preparation	One stirrup fabrication	1	1	1	10	10	3.12	3.18	3.21	3.14	2
KT4	On-site rebar tieing	Stirrups & bend rod placing and tieing	One column tieing	1	2	1	10	10	269.7	388.3	0.04	0.03	44

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Work practices of the high and average-performing crew: Discussion

As indicated in Table 2, the researcher made direct observations on-site and recorded the work practices at regular pre-defined intervals during each study day. These field observations were explained, verified and validated through interviews with crew members and each foreman. As mentioned, to triangulate the study findings, it was also presented and discussed with the senior site engineers and project managers.

In the HPC, the foreman/labour sub-contractor (LSC) had 15 years of experience in the trade and had been with the main contractor for 10 years. The HPC consisted of a 'leading hand' with 10 years of experience and managed the crew in the foreman's absence. Most of the HPC members had been working with the foreman for more than six years. The foreman treated the crew's skilled workers as his core workers and maintained good relationships with all the crew members.

The APC also included a foreman and a leading hand. Similar to the HPC, the foreman had 13 years of experience and had been with the main contractor for two years. However, the crew's foreman only occasionally visited the project, and the crew was mainly managed by the leading hand with nine years' experience. Many crew members had been working with the foreman for two-three years. This foreman also treated all his highly skilled workers as his crew's core workers.

Table 4 compares broad themes based upon specifically coded work practices that emerged from the analysis of the field observations and transcribed interview data. These included:

1. Work preparation and execution strategy
2. Group formation and stability (skills and experiences)
3. Avoiding duplication (of non-value adding tasks)
4. Crew social cohesion
5. Internal and external leadership

The above-mentioned themes are discussed in more detail, under dedicated sub-headings, with respect to the high and average-performing crews, below.

Work preparation and execution strategy

This involved review of job-related drawings, materials arrangement, and determining an overall job execution strategy. In the HPC, the foreman reviewed the column layout and detailed design drawings to check for any changes in the rebar details from the previous floor and paid particular attention to details that his crew were not familiar with. He simplified details regarding the number of rebar rods to be cut and bent, prepared his own notes, and communicated these to his crew. In this way, he tried to minimise material wastage during rebar cutting, rework and quality-related issues. This foreman also made sure his crew had all needed material for work the next day. He checked for sufficient stock of rebars onsite before executing the activity.

As in the HPC, the APC's foreman reviewed the detailed drawings with the leading hand and the crew, and discussed changes in rebar details. However, there were no simplified notes given to the crew on the rebars to be cut and bent. The leading hand along with the core crew members had to figure out these details on their own. There was some wastage of rebar because of the absence of the overall cutting details being provided to workers. The leading hand had to coordinate with the main contractor on material availability.

Table 4 Comparison of broad themes and coded practices between high and average performing crew

Broad Theme	Coded practice	High performing crew	Average performing crew
Work preparation and execution strategy	Review of detailed drawings	Head foreman reviewed and simplified the drawing details as short notes	Head foreman was not involved in drawing reviews - site foreman reviewed and verbally communicated the details
	Arrangement of materials before work execution	Foreman and core members checked the availability and quality of materials	Site foreman checked the availability and quality of materials
	Overall work execution strategy	Foreman developed an overall work execution plan and communicated to the crew	A meso-level plan was made by the foreman, and no communication was made to the crew
Group formation and stability	Formation of sub-crews	Meaningful formation of sub-crews by matching crew member's skills with tasks	Random allocation of work to crew members
	Relocation/ shuffling of crew members to different work locations	No relocation/shuffling of crew members to different work locations	Relocation/shuffling of crew members to different work location and also to other projects
Avoiding duplication of non-value adding tasks	Transportation of processed materials	Minor excess movements observed	Major excess movements observed
	Storage of processed materials	Less over production and less unwanted storage of processed materials	Less over production but unwanted stock of processed materials
Crew social cohesion	Teamwork processes and practices	Pre-task briefs, de-briefs and backing-up behaviours were noticed	Minimal interactions were noticed between the crew members and foreman about tasks
	Share knowledge about tasks and progress	Shared mental models facilitated crew members' interactions and work progress was discussed between crew members and foreman	Absence of shared mental model and less involvement of members to know about other crew members tasks and their progress
	Task and team cohesion	Overall, the crew was found to be cohesive, both task and interpersonal cohesion	The crew was found to be less cohesive
Internal and external leadership	Inspection and feedback	Foreman was regularly involved in quality checks to avoid rework	Less frequent quality checks, reworks observed
	Leadership style	Foreman generally followed a centralised crew management approach. Core members were also involved in decision making	Head foreman was occasionally present onsite. The crew was centrally managed by the site foreman
	Coordination with other trades	Head foreman was predominantly involved in coordination	Less experienced site foreman was predominantly involved in coordination

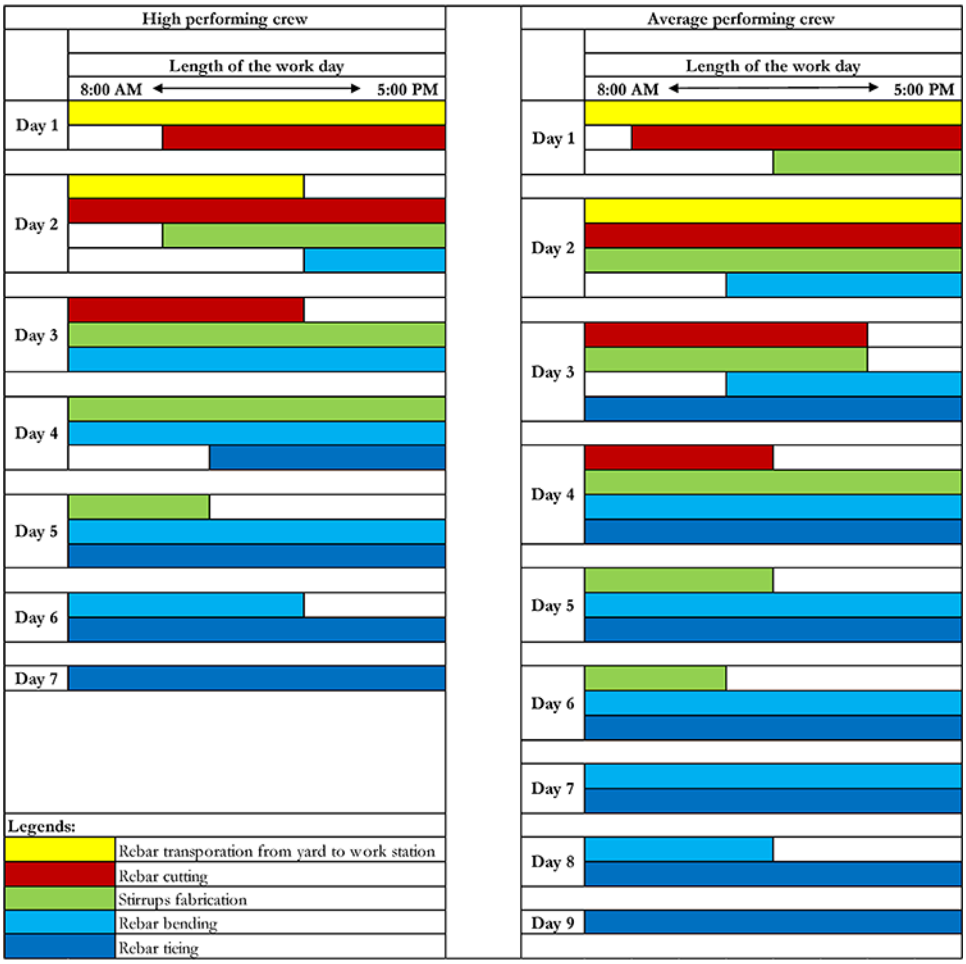

Figure 1 Actual work execution approach of the study crews

Figure 1 depicts the actual work execution approach adopted by both the crews from activity start to completion. As indicated, the HPC took seven days, while the APC took nine days to complete the activity. The horizontal bars indicate the various tasks within the activity. The bars move from left to right in a given day, i.e. from start of the day at 8 am to end of the day at 5 pm. As can be seen in Figure 1, the HPC executed the activity with minimal parallel tasks in a given day as compared to the APC. This can be seen by simply noting that the number of rows in the figure for HPC is much shorter than the APC. As a further example, on day-1, almost all the crew members of the HPC were engaged in the transporting rebars from yard to work station for cutting. After substantial transport of rebars, part of the crew was involved in rebar cutting. In the APC, after moving some initial stock of rebar, rebar cutting and stirrups fabrication was carried out on day-1. Similarly, for all other days, the APC engaged members to carry out parallel tasks within a day which was less the case for the HPC. This also caused additional difficulties to the APC, in terms of problems with coordinating inter-dependant yet parallel tasks in a way that provided smooth and overall continuity in executing the activity. In this context, Thomas et al., (2004) argued that symbiotically-related crews underperform when compared to sequentially-related crews. Here, clearly, the pace of installation involves this need where the likes of the rebar tieing sub-crew is dependent on the pace of bending sub-crew and stirrup fabrication. Further, the pace of bending sub-crew in turn depends on the pace of cutting sub-crew. The same study also indicated that symbiotic crews incurred a 25% increase in labour resource compared to sequential crews (Thomas et al., 2004). This study also indicates that the APC, which exhibited a greater emphasis on symbiotic relationships than the HPC, consumed 44% more labour resources. Hence work preparation and organisation significantly influenced crew productivity.

Group formation and stability (skills and experiences)

This involved forming well-structured and stable work groups from available workers for daily site processes and came about the differences between the HPC and APC. In the HPC, for each of the four key tasks, dedicated crew members/sub crews were formed except during the all-inclusive transporting of rebar materials. The foreman knew the skill-level of each worker, hence assembled appropriate sub-crews for the various key tasks. He utilised a *rule-of-thumb* for each of the sub-tasks, for example, during an interview, he mentioned "a skilled worker can fabricate 900-1000 stirrups per day". He benchmarked individual's skill levels against such heuristics and allocated tasks accordingly. The foreman also allowed the leading hand to take control of the tasks that he had less involvement with, from that point onwards. The foreman also assessed the risk-levels of certain tasks and allocated the most experienced crew members with the requisite skills and capabilities for the most demanding tasks. This aligns with findings in other studies that indicate preventing errors in high-risk tasks improves productivity and reduces the likelihood of accidents (Mitropolous et al., 2009; Mitropolous and Cupido, 2009).

The reliability of the less skilled HPC members contributed to better workload distribution, better support, and housekeeping. Also, the pairing of semi-skilled and unskilled workers with the skilled workers was carefully executed by the HPC foreman. For example, in case of a sub-crew with four workers (for 16 and 20mm rebar bending), two skilled workers, one semi-skilled and one unskilled worker were brought together. From safety perspective, studies have identified that this practice facilitates socialisation process and is also a systematic attempt to create shared accountability of less experienced workers (Mitropolous and Cupido 2009).

In the APC, the crew formation and stability lacked the same logic and technique in matching crew members' skills to tasks. Even though the foreman knew each member's skill level, he only visited the site occasionally and hence his involvement in day to day work organisation of the work was less direct. The leading hand was often more involved in the formation and allocation of tasks to sub-crews and specific crew members within. Even so, the foreman often shuffled crew members out of their existing crew into another, thus destabilising the original crew. With stable crews, the foreman could have estimated work duration more reliably and would better know crew capabilities including individual strengths and weaknesses. This can be related to other studies on turnover of crew members, where for instance, low levels of turnover were considered to be important in preventing errors and accidents onsite (Mitropolous and Cupido 2009). Further, crew stability and reliability have already been recognised as important factors affecting productivity (Dai et al., 2009; Thomas and Sudhakumar, 2015).

AVOIDING DUPLICATION OF NON-VALUE ADDING TASKS

Duplication of non-value adding tasks significantly impacted on productivity and mainly related to transportation and storage of processed materials. Figure 2 depicts the process undertaken by both crews including the transportation and storage of materials between key tasks. In Figure 2, steps 1 to 15 depict the main process followed by both the crews. However, within this structure it can be seen that the lower half of the figure shows additional non-value adding steps that only applied to the APC via additional transportation and storage of materials i.e. including the grey-boxed portion incorporating steps NV-1 to NV-7 and steps 13a and 13b.

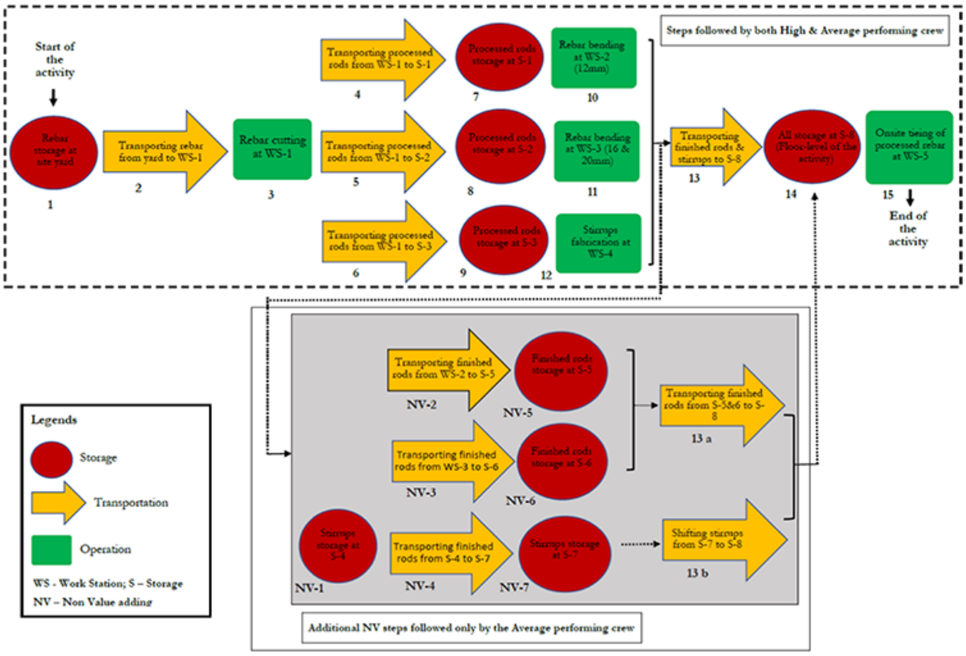

Figure 2 Process duplication of transportation and storage tasks

They could have avoided the steps NV-1 to NV-7, while steps 13a and 13b could have been carried out as a single step like in the HPC. With better material handling practices, they might have significantly reduced their labour hours, and in turn, increased crew productivity. During one of the interviews, the leading hand of the APC said: "it is difficult to manage the whole crew all alone...it is difficult to note what each person is doing". He further explains as "…some crew members may just spend time in transporting some materials from one end to another end, without coordinating with others and checking whether it is appropriate to store materials at this place..." This shows the influence of tasks duplication on crew productivity.

CREW SOCIAL COHESION

Crew social cohesion refers to the non-technical communication needed for affective coordination and assimilation of crew members. At the beginning of each day, the HPC foreman briefed his crew on what needed to be done that day - commonly referred to as team briefings. On a few occasions, informal team de-briefings at the end of the day conveyed what was achieved against what was planned that day. Team briefings contributed to team performance in several ways such as the development of a shared mental model, facilitating situational awareness and error management, and the ability to adapt to changing situations (Kozlowski and Bell, 2003). For example, in healthcare settings, the use of preoperative checklists and team briefings between surgeons and nurses has been found to reduce communication problems during surgery (Lingard et al., 2008).

Backing-up behaviour was also noticed among the HPC crew members. Backing-up behaviour occurs when crew members assist someone who is unable to complete his or her task on-time and/or help the person correct a mistake (Salas et al., 2008). Porter (2005) found that backing-up behaviour was positively related to performance in teams where some members had excessive workloads. Some practices relating to backing-up behaviours such as cleaning up the work area, organising the tools and materials for other team members were noticed in the HPC.

In the APC, some members followed similar practices such as backing-up behaviours and cross-monitoring of other members' performance. However, unlike the HPC, team briefings were not organised by the APC's foreman. This led to a lack of shared awareness about the various crew member tasks, for example, the additional material handling processes alluded to above. Also, the shuffling of crew members in the APC (mentioned previously) also caused lack of bonding between the crew members as different work habits and methods lead to disagreements and reduce cooperation. However, team cohesion was high in the HPC since there was greater crew stability due to consistent work roles.

INTERNAL AND EXTERNAL LEADERSHIP

In some ways, a construction work crew can be compared to sporting teams (soccer, basketball, etc.), where success depends on the coach's understanding of the situation, creating the right tactics, selecting the team according to those tactics and establishing strong teamwork so they offer more as unit, compared to a disparate group of indivdiuals.

Crew leadership involved work inspection, feedback, coordination with other crews and overall crew management. With regards to internal leadership, the HPC foreman was regularly involved in quality checks to avoid rework. Whilst he followed a centralised crew management approach, the core members were also involved in crew management and decision making. Here, autonomy represents the capacity of a system to make its own decisions about its actions. Researchers suggest that increased autonomy can enhance group performance as it gives a sense of pride in the crew, when managing tasks by themselves; thereby conferring 'ownership' of the task (Hinze, 1981; Salas et al., 2008). However, the generally top-down approach in construction only serves to reduce autonomy in given crews (Hinze, 1981; Dai et al., 2009). While the HPC foreman provided a degree of crew autonomy, this was not apparent in the APC.

With regards to external leadership, in coordinating with other trade crews, the HPC foreman directly coordinated with the foreman of other crews, such as formwork crews. He did not want the presence of the formwork crew to pressurise his crew and therefore negotiated around this position. Whereas in the APC, the foreman was not directly involved in coordination with other crews as this was delegated to the less experienced leading hand. Apart from lack of experience, this also carried with it a second problem, of the leading hand having limited time to negotiate with other crews, as he was already fully occupied in physically executing work as well as trying to concurrently manage it.

The themes of crew work practices identified in this research provides an alternative approach to manage onsite productivity. To link the themes identified from this study with the existing literature, mapping of the identified practices with critical factors affecting CLP was carried out. Table 5 achieves the comparison by cross referencing factor numbers used in Table 1, which are shown within parentheses in Table 5. Here, only crew/human-related factors and associated project-related factors from Table 1 are mapped with the identified practices, given the context in which the practices are emerged. This serves to show commonality between work practices identified in this study that impact on productivity, and the associated isolated productivity factors in the extant literature. What this means in practical terms, is that these isolated factors can be mediated through crew based work practices, thus providing a more practical and centralised means of managing onsite, relative to what would otherwise be an isolated and disaggregated set of factors. The identified practices, which bundle isolated factors together, can help to realistically improve onsite crew productivity. The validity of this perspective is also based on the previously mentioned finding that crew productivity can vary significantly, but is not necessarily explainable when looking purely at individual worker productivity measurement.

Table 5 Mapping broad themes of practices with critical factors affecting CLP

Broad themes of practices identified by this study	Related critical factors affecting CLP from the existing literature
Work preparation and execution strategy	Clarity of technical specifications (B-2), Availability of drawings onsite (B-4), Availability of tools and equipment (B-5), Availability of materials (B-6), Poor planning and scheduling of activities and tasks (B-11)
Group formation and stability	Unbalanced distribution of resources (B-9), Crew size and composition (C-2), Absenteeism and turnover of labour (C-5), Pulling people off a task before it is done (C-7),
Avoiding duplication of non-value adding tasks	Site layout (B-1), Methods of working (B-3)
Crew social cohesion	Communication difficulties between supervisor/ foreman and worker (C-6), Teamwork among workers and crews (C-8), Motivation of labour (C-9), Working culture (C-10), Linguistic differences between workers, crews and supervisors (C-13), Respect for workers and crews (C-15), Stress and work-life balance of human (C-16), Improper coordination & cooperation among workers and crews (C-17), Respect and recognition for craft worker suggestions/ideas (C-18)
Internal and external leadership	Inspection delay (B-8), Competency of supervisors and foreman (C-3), Availability of proper work front (C-12) Respect and recognition for craft worker suggestions/ideas (C-18)

Therefore, this indicates the need and relevance to conduct more in-depth studies on trade crew work practices. While the study is conducted in the context of labour-intensive building construction activities (where the degree of advancement in construction technology is less when compared to large infrastructure/mega projects) and only one trade activity is studied are considered as limitations of the study, it is focused on generic traits in crew practices and behaviour more so than the exact specifics around their actual work tasks. Hence, similar to the present study, studies in other contexts and other trade activities may help to verify and validate the practices identified by this study. In-depth understanding of crew based work practices will enable training of foremen and work crews in such practices to systematically develop high-performing crews. Lack of exploration in these fields also highlights a research landscape that is out of pace with mainstream organisational and management literature.

Conclusion

The exploratory case study on a residential project compared a high-performing with an average-performing crew, in unveiling the influence of crew work practices on productivity. The former exhibited 44% higher productivity than the latter. It was found that work practices considerably influenced the productivity of each crews, as most other project and activity-specific variables were relatively controlled by the virtue of the chosen research method. The high-performing crew was found to have adopted better work practices compared to the average-performing crew.

Drilling deeper, the study identified five broad themes influencing this difference including: work preparation and execution strategy; group formation and stability; avoiding duplication of non-value adding tasks; crew social cohesion and; internal and external leadership. Future work should focus on verifying, testing and validating these work practices which are henceforth proposed as dimensions that influence crew productivity. These dimensions suggest that crews - as distinct from individual workers - can be seen as important when evaluating CLP. Also, it makes conceptual and practical sense to focus on work crew practices as a central and mediating variable, instead of a long list of isolated and disaggregated factors impacting on productivity. In sum, a key benefit of the study is that crew work practices can be used as a means of mediating what was previously many separate CLP variables. It also offers a practical "one stop" means of implementing productivity improvement in a way that is inclusive of these factors but is also inclusive of a closer real world understanding of people management onsite.

While the chosen study activity, the case study approach and a specific location of any case study would pose inherent challenges in generalizing the findings. However, the systematic exploration of this little researched and less understood but evidently critical area, using this carefully developed methodology, helps provide direction for broader based research and targeted testing in other trade activities and locations. Furthermore, findings from this study also point to new avenues for future research in construction productivity theory and practice.

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