The Productivity of Steel Reinforcement Placement in Australian Construction

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ABSTRACT

Purpose of this paper
The purpose of the research is to more accurately understand steel fixing productivity for the purpose of benchmarking, process improvement, assessing competing construction methods and improving the underlying assumptions that contribute to cost management decisions.

Design/methodology/approach
A time and motion style approach was used to measure worker productivity for the on-site placement of steel reinforcing. Quantitative and observational data was gathered from three multi-storey residential buildings.

Findings and value
Productivity ratios were derived according to a variety of different repetitive work tasks and based on hours input against production output. Based on the data and subject to sampling limitations, it was found that productivity was highest where using rebar at regular open intervals with few step downs, few penetrations and few beams – as per flat plate floor slab construction. Productivity was lower where construction was floor construction was characterised by deep and complex transfer beam construction with limited room for dexterous tying work, complex setout and other contributing factors. The worst scenario involved stair construction where additional complexity was created by sloping planes, tread layout and landing set out; additional cogged bars; lapped bars at landings; and the existence of construction joints. The productivity of mesh fixing was not as high as expected, possibly due to the method of measurement and the influence of balcony construction involving significant cutting of sheets to fit.

Research limitations/implications
The research findings are not statistically valid but instead represent an introductory study identifying core tasks that influence the productivity of steel fixing. A relative series of productivity levels is proposed. Future research should focus on a larger sample to test the above findings and to facilitate statistically valid findings.

Practical implications
The findings can be used to target tasks within the steel fixing work package that would benefit from process improvement or the selective implementation of industrialised construction methods.

Originality/value of paper
The research provides a basis for detailing construction and designing work processes to improve labour productivity. It also provides for benchmarking and comparative measurement between competing methods.

Keywords: steel reinforcement, construction, labour productivity, process improvement.

1 INTRODUCTION

When people discuss productivity improvement in construction, they often use this expression as a euphemism for cost savings or as a means of driving down the price-to-client for building procurement. Though cost and productivity are intimately linked - for instance higher productivity can lead to lower production costs– the two constructs are not exactly the same thing. At the very least, theory on transaction cost economics (Coase 1960) indicates that many market driven aspects influence cost such as transaction frequency, specificity, uncertainty, limited rationality, and opportunistic behaviour as important factors (Williamson 1981). Therefore productivity in the context of this research, focuses on reducing resource usage onsite during trade based construction processes.

It is well known that construction projects have many different stakeholders brought together under a temporal arrangement and specified project outcomes, hence reducing the ability to control the productivity environment in the same way as manufacturing settings. Further, manufacturing typically has an orientation towards intra-organisational business processes, whilst construction projects have a greater inter-organisational focus which brings with it a degree of process incompatibility between participating organisations (Love & Li 1998). Complex supply chains are involved, process management becomes more critical, and there is an increasing need for risk allocation and contractually defined dependencies between the organisations involved. From a productivity point of view, a fundamental requirement is to understand the context in which it occurs as distinct from purely keeping workers busy (Ballard, Harper & Zabelle 2003).

Under these circumstances, productivity is important to anyone within an organisation that is responsible for supervising, estimating, accounting and paying for the resourcing of trade activities on construction projects. Over the years there has been constant pressure to improve productivity performance as driven by the likes of total quality management (Easton & Jarrell 1998), construction process reengineering (Love & Li 1998) and continuing efforts at converting lean production to suit the construction industry (Jørgensen & Emmitt 2008). Productivity is also important when comparing competing construction systems or in assessing the viability of industrialised or off-site construction methods. Finally, there is simply the practical need to confidently predict productivity levels when programming and planning construction, and in apportioning construction infrastructure (preliminary) costs to projects e.g. crane usage, scaffolding, worker accommodation.

Despite this need, the cost management profession appear to have relatively little information at hand when estimating and comparing the productivity of common methods of construction. What's more, there seems to be little understanding about the more detailed aspects of trade activities which can affect the productivity within a given trade work package. Consequently, a more measured approach to productivity could serve to design-in efficiency and reduce construction costs.

Given the above, this paper reports on an ongoing programme of research that aims to measure trade productivity (on site) for common construction activities. The paper specifically reports on the productivity of steel reinforcement placement (colloquially known in Australia as "Steel fixing"). Here, steel reinforced concrete construction globally represents a cost competitive and very popular method of construction, but one that is labour intensive and at times slow relative to more industrialised forms of construction. Steel fixing is especially laboursome and so it offers a targeted area for improvement within the context of reinforced concrete construction. Even so, it is an area where no data could be found in the extant literature concerning productivity measurement and so the research aims to help fill this apparent gap in knowledge. In a general sense, this research aims to help resource management practices change from being an art to a more scientific approach. Ultimately, the purpose of the research is to assist work planners and cost managers to more accurately understand and predict steel fixing productivity for benchmarking, process improvement, assessment of competing construction methods, and improving the underlying assumptions that contribute to construction management decision making.

2 BASIC PRINCIPLES SURROUNDING CONSTRUCTION PRODUCTIVITY MEASUREMENT

Productivity ostensibly concerns the conversion process of input resources to output quantities (Thomas et al 1990). Important variables that impact on this basic relationship typically include a focus on labour coupled with variables such as construction materials, consumables, engineering drawing management, tools and equipment (Dai, Goodrum & Maloney 2009). As alluded to previously, one could also include the impact of both off-site manufacture and the strategic use of information technologies such as Building Information Modelling as impacting on productivity – see for example Kaner et al. (2008) and Eastman and Sacks (2008).

It is apparent from the literature that there are macro, micro and case specific levels of studying productivity (Edkins & Winch 1999). The main differences between these options include the sources of data, the level of data aggregation, the boundaries defining production processes, and the completeness with which productivity processes are described (Chau & Walker 1988). For instance, given the stated aims of this research, there is a distinct need for detailed data in order to define trade based productivity relating to steel fixing. The natural focus of the study is therefore on case specific productivity and indeed, repetitive trade work tasks within the steel fixing work package.

Early work by Adrian and Boyle (1976) remains instructive in setting out the main issues involved in measuring work 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 (Adrian & Boyer 1976). Further, it is important to select an appropriately sized production unit in order to get the most out of the collected data: units that are too broad may be of limited use in explaining how to improve productivity; units that are too small (such as the time it takes to lay a single brick) may exclude too many aspects of the overall work process to be informative (Adrian & Boyer 1976).

In applying the above principles to this research, the chosen production unit and cycle time revolve around the steel reinforcing for floor construction including related reinforcing elements. Of note, such a unit can be broken down into tiered sub-units, thus enabling different levels of analysis. For example, steel fixing can be broken down to the placement of mesh and rebar in different scenarios such as slab panels, beams, columns and stair construction.

The lead resource in steel fixing is clearly labour, and this has led to the research adopting a partial (or single) factor approach to productivity as distinct from total factor approaches (Rakhra 1991). In adding to this, the Construction Industry Institute established the basic framework for labour performance metrics including cost, schedule, safety, changes, and rework variables (2001, 2002). Labour intensive endeavours are commonly measured in terms of input hours compared to output products (Hanna et al. 2008; Sonmez & Rowings 1998; Thomas & Yiakoumis 1987). Such an approach avoids external factors that influence more cost-based approaches to productivity (Yi & Chan 2013). Ultimately, this can be expressed as simple ratio and is commonly defined in the literature as - *Labour Productivity = actual hours worked/installed quantity (Thomas & Mathews 1986).* Even so, it is also evident that the order of such ratios change according to local methods and so in order to suit the intuitive approach used in Australia, productivity has been presented as *installed quantity/actual hours worked* e.g. *kgs of steel tied/hour*.

Extending understanding of the literaturefurther, Park et al (2005) developed an approach to labour measurement based on a standardised approach to gathering labour usage data from accounting information. For instance, they defined a framework for collecting direct and indirect accounts for labour usage on projects (including rework and other significant factors). Their approach to data gathering appears to be especially time efficient where drawing on a central database containing the above accounts information, as may be held by the likes of the head contractor on a project. However, this task becomes more difficult when many subcontracting organisations are involved in a project (as commonly occurs in Australia). Such subcontractors typically provide a fixed price for a given work package and this tends to mean that labour usage data remains private (to them). It is also evident that terminologies and therefore the categorisation of direct and indirect accounts differ between countries which further limit the application of such an approach to Australian circumstances. Further, whilst the likes of Park et al’s (2005) approach to data gathering provides global level productivity indicators (e.g. of steel fixing productivity for the entire project) it does not provide the ability to breakdown the overall production unit into sub-units and so lacks the ability to target and understand where within the work package process improvement would be most beneficial.

Studies focusing on productivity from the perspective of work processes onsite are said to have scarcely been reported in the literature (Yi & Chan 2013). Similarly not much attention has been paid to construction labour productivity metrics (Yi & Chan 2013). There is the concurrent need to provide context and detail concerning the multiple factors that can impact on productivity (Jarkas & Horner 2011; Rakhra 1991; Talhouni 1990). Consequently, the research reported in this paper is thought to add important detail to the relatively small amount of work reported on trade based construction productivity.

3 RESEARCH METHOD

Given the aims of the project and its emphasis on studying the placement of steel reinforcement at a detailed, micro level, the chosen approach has been to observe and measure such trade activities on site, using a time and motion approach. To this end, three case study projects have been used, all of which involved multi-story residential buildings. Further to this, a work sampling approach has been adopted within each case study project. Details concerning the sample are provided in Table 1 below.

Other principles of the work sampling involve construction being broken down into a series of stages, where each stage is composed of one or several operations; each operation is performed by a specific trade, typically defined in jurisdictional or subcontract terms (Buchholtz et al. 1996). Further, the focus on measuring defined work areas (such as construction of a specific floor level) has meant that there has been an inbuilt exclusion of unwanted intervening variables that sometimes impact on productivity measurement including the likes of sick leave, vacations and holidays. Further, as suggested by Yi and Chan (2013), efforts were made to focus on work days that were unaffected by significant rework, bad weather or disruptions.

In executing this and as consistent with Ellis et al's (2006) approach, the first step was to establish a database of standard and relatively homogenous tasks within targeted trade activities that are known to cause variance in work process and work productivity. Data gathering was supported by the standardised techniques used in the Singaporean Government's "Builder's Guide to Measuring Productivity" (Building and Construction Authority 2012) but were adapted to suit Australian conditions. The general approach is built around standard quantifiable parts of the work (as would commonly be used in Bills of Quantity and for the scheduled payment of work) which provide a natural structure for measurement.

Table 1: Sample details

Project location	Building size			Work sample (where productivity was measured)		
	Floor levels (above/below ground)	No. of apartments	Floor plate area (m^2)	Location	Area (m^2)	Production unit
Inner urban	60/3	261	1121	Level 6	875	Suspended floor slab and associated columns including large post tensioned transfer beams 3200 x 2400mm
Inner urban	5/1	26	745	Level 3	745	Suspended flat plate slab, associated columns and stairs
Outer urban	5/1	30	2000	Ground floor	2000	Suspended floor slab including post tensioned beams 300 x 600mm

4 FINDINGS AND OBSERVATIONS

It was apparent that the amount of steel reinforcing required on a project was proportional to concrete usage and the degree of structural design efficiency with which it was applied to the concrete. Whilst the work package consisted of a number of identifiable sub-activities, the central act of tying steel was by far the largest proportion of the work involved.

Quantitative and observational data from the study is shown in Tables 2 and 3. As an overview from Table 2, productivity for steel fixing at an overarching level fell between 177Kgs/hour and 60.5Kgs/hour. This covers a mix of slab and beam settings with lesser contribution from stair, column and wall construction.

Even though the sample is too small to create statistically valid findings, it serves to provide a framework for future data gathering and to provide a basis for productivity grading of (sub-unit) tasks within the steel fixing work package. The data in Table 3 is particularly interesting in showing how different sub-units of production vary in productivity relative to each other and relative to the overview data in Table 2. For instance, the data suggests that:

- Productivity is highest where re-bar is placed in open and simple flat floor plate slab situations - especially situations where there is limited need for step downs, cogs in bars and other aspects that create placement complexity.
- Surprisingly, the data indicates that the placement of mesh is not as productive as re-bar and this appears to be the case because mesh is restricted to low wire diameter (e.g. 8mm diameter) which means relatively low measured mass of steel placed per hour (e.g. Kgs/m2). Another suspected reason for the low productivity of mesh in this study is that a reasonable amount of the measured work related to balcony situations and in these instances there was significant cutting of mesh sheets in order to suit the irregularly shaped balconies (including staggered wall alignments, the existence of door reveals, floor level step down locations). Despite the above findings, it is expected that mesh placement productivity would be considerably different where used in simple ground level raft slab and pavement construction because in such instances, the structural design typically requires lower structural performance, there is less intricate cutting of individual sheets and there are typically large open laying areas involved.
- Productivity worsens as the amount of steel increase in complex, confined and cluttered formwork situations such as stairs and complex transfer beams. In undertaking work in these situations greater dexterity is required in tying the steel; greater mental attention to bar setout; greater care in checking for concrete cover; greater forethought in selecting the correct pieces from the stack; greater time in threading long or bent pieces into position; and greater likelihood of the need to cut, bend and modify steel due to clashes from cluttered steelwork.

Table 2: Over-arching productivity data i.e. overall steel fixing work package

Total Input	Total Output	Productivity ratio (from sample area)	Work process features
Man hours	Steel tied Kgs	Kgs/hour	
2,900	175,000	60.5	Single fixed crane usage; Congested reo and formwork space
154	14,500	94.0	Occasional mobile cranage; excessive manual handling; poor site programming.
678	12,000	177.0	

Table 3: Task specific productivity data within steel fixing work package

Breakdown of repetitive steel fixing sub-units	Input	Output	Productivity ratio Kgs/hour	
	Labour (man hours)	Quantity of tied steel (Kgs)		
Rebar fixing (at 200mm spacing for flat plate slab)	55	8500	155	Low complexity open deck work
Rebar fixing (for basic transfer slab and beams)	769	90,000	117	Open slab deck with well spaced beams of only 600m depth and small diameter bars (up to 16mm) resulting in low complexity work
Rebar and some mesh fixing (fabricated at site work stations prior to placement)	527	58,000	110.0	Well organised work setting
Mesh fixing (for simple balcony slabs)	20	2000	100	Open deck work, but cutting to suit balcony configuration
Mesh fixing for simple flat plate slab	15	1,000	67	Low weight steel matched with low complexity open deck work
Rebar for columns supporting suspended slab	64	3000	67	Delicate and some work complexity
Mesh for open slab	476	30,000	63	Open slab deck with low complexity work (but fabric is lightweight relative ti rebar
Rebar fixing (for columns, walls, slab and very large, complex transfer beams)	2373	117,000	50.0	large amount of steel involved including delicate, intensive and complex setout work;
Rebar and mesh fixing (for insitu stairs)	23	600	29.0	Delicate and complex work in cramped work area and difficult labour movement

An adjunct to the above, related productivity issues concerned the observed influence of site specific materials handling and work sequencing which impacted on the distance workers had to carry steel, the provision of clear working space, walkways for workers to quickly move about the site, the ability of the first layer of steel fixing to provide a source of reference for subsequent layers, the minimisation of rework, and the inherent simplicity of work processes. Further to this, labour productivity was observed to be slower where:

- Reinforcing steel was poorly scheduled offsite (including poor attention to bend and cog locations and poor attention to the number of pieces required). Though uncommon, this required ad hoc bending on-site, oxy acetylene cutting on-site and splicing bars on site.
- Re-sorting and re-organising reinforcing steel onsite before moving it to the required deck location e.g. bottom steel not placed on top of the stack, or steel for various areas of the site not being easily identifiable via colour coded paint spots or bands.
- Cranage problems where the lifting cycle time of the crane was not well synchronised with the cycle time and delivery needs of workers
- Requiring two or more workers rather than one to carry steel e.g. heavy steel lengths often needed two or more people to carry steel long distances across a floor level or manoeuvre the lengths into tight positions.

- Site cutting of bars (especially larger diameter bars) e.g. large bars must be taken to and from a saw cutting station; manual cutting becomes problematic and awkward especially on medium to large diameter bar sections or if trying to cut it insitu.

5 CONCLUSIONS ABOUT STEEL FIXING PRODUCTIVITY

The sample presented in this study is not large enough to create statistically valid predictors of steel fixing productivity that can be used predictably on other projects (work is ongoing). However, it does provide a number of case study examples which can act as an initial sample (and framework) for larger scale data gathering. The research goes some way to revealing the main sub-units that are worthwhile measuring to improve productivity within the steel fixing work package. Using this, a potential trend in the data – as drawn from the previously discussed findings - is hypothesised and is set out in the numbered list below. It aims to facilitate practical application in industry and will benefit from verification via larger scale data sampling. It is set in the context of a relative scale where each level down the scale offers incrementally lower productivity relative to the level above:

1. Best labour productivity - open flat plate slabs where using large amounts of bar at regular spacing and open intervals (e.g. 200mm), simple setout, few stepdowns, few penetrations and few beams
2. Fair to good labour productivity – More difficult than the above due to band beam or basic beam construction including limited clutter at beam/beam and beam/column intersections.
3. Fair to poor labour productivity – More difficult than the above due to deeper beams and more complex beam/beam and beam/column intersections i.e. where bars are closely spaced, clashes occur and hand tying space is somewhat limited.
4. Low labour productivity – More difficult than above due deep and complex transfer beams involving: closely spaced bar intervals, use of heavy bars, tying space is limited, difficulty in threading post-tension tendons through steel reinforcing cages, work sequence is critical to being able to thread/place bars into position, complex setout, complex bending schedule, clashes are likely due to steelwork clutter,
5. Low to very low labour productivity – More difficult than the above where additional complexity created by sloping stair planes; tread layout and landing set out; additional cogged bars; lapped bars at landings; the existence of construction joints where stairs meet slabs.

Subject to ongoing verification of the above findings, the information can be used to direct the detailing of steel fixing and associated work processes to be more efficient. Simplicity is clearly a key ingredient. Some specific options apparent from the research include:

- Consider targeted modularisation and prefabrication of selected complex reinforcing assemblies – mainly complex column and beam reinforcement cages or perhaps complex beam-beam intersections. Implementation should focus on improving the overall cycle time of floors. Provision for construction tolerances and work processes will be important.
- Consider the use of prefabricated steel stair formwork including stringers, risers, soffits and reinforcing steel cages included. In Australia (as with many other locations) standard proprietary options already exist in the market and this study tends to support the viability of such options.
- Consider trialling the use of temporary onsite work stations for the fabrication of complex reinforcing assemblies. Attention should be given to worker efficiency, ergonomic safety, and minimising worker movement onsite. Such stations could be expected to include use of fabrication work trestles, cutting benches, mechanised and/or hydraulic steel cutting equipment, mechanised tying equipment, temporary clamping tools, mobile tool racks/belts, holding jigs, setout templates, basic lifting equipment for spinning and turning cages around and consideration of materials delivery/landing ports. To optimise this approach, efforts need to be made in breaking down complex reinforcing structures into lesser assemblies suited to modularisation. Use of this approach must also consider attention to work flow on the deck

being constructed e.g. coordinating beam cage delivery to allow efficient work flow on the floor deck concerned.

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