"LEAN" AS AN ANTIDOTE TO LABOUR COST ESCALATION ON COMPLEX MECHANICAL AND ELECTRICAL PROJECTS"

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ABSTRACT

This paper represents "work-in-progress" as part of a collaborative research project being undertaken at the Centre for Innovative Construction Engineering for an Engineering Doctorate at Loughborough University, UK. The programme is funded by the EPSRC and is sponsored by a major UK mechanical and electrical contractor (the company). The project will have specific objectives, which will be capable of making a significant contribution to the performance of the company. That is, the tasks will benefit the company whether or not the Engineering Doctorate was being undertaken. It will not be a "student" project, which has only been selected to keep the research engineer busy, nor will the tasks be at the margin of the company's interest.

In the mechanical and electrical (M&E) sector in the UK, labour cost is one of the largest variables which can have a direct influence on the financial outcome of a project. Actual labour cost incurred has a dependency upon the productivity achieved on site, which in turn is dependant upon the conditions that prevail on that site. For a major UK M&E contractor, labour cost has escalated to such an extent that margin slippage has occurred. Margin slippage can be defined as the negative variation between the expected margin (gross profit) for a project when acquired, and the final margin when the project is finished. Consequentially, the company, as part of a performance improvement initiative, have the objective of developing lean techniques to overcome the causes of the cost escalation—poor productivity, and see this research project and implementing lean as a result of it, as a vehicle to deliver the improvement. This paper will propose that lean techniques, when imposed upon a project, can be an antidote to the causes of poor productivity, and therefore prevent labour cost escalation, along with its impact on the project's final profitability. These lean techniques, known as "interventions", are applied to a case study project with positive results in terms final labour cost and margin.

KEY WORDS

Margin slippage, Productivity, Labour, Mechanical sector, Electrical sector.

INTRODUCTION

This paper represents "work-in-progress" as part of a collaborative research project being undertaken at the Centre for Innovative Construction Engineering for an Engineering Doctorate at Loughborough University, UK. The programme is funded by the EPSRC and is sponsored by a major UK mechanical and electrical contractor (the company). The project will have specific objectives, which will be capable of making a significant contribution to the performance of the company. That is, the tasks will benefit the company whether or not the Engineering Doctorate was being undertaken. It will not be a "student" project, which has only been selected to keep the research engineer busy, nor will the tasks be at the margin of the company's interest.

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The themes of the research project are "Innovative Construction Technologies" driven by the desire to use leading edge research and learning to improve the business of the sponsoring organisation. The sponsor company is a major provider of advanced mechanical, electrical and communications solutions in the construction sector in the UK. It works for customers in banking, retail, leisure and commercial property development, as well as education, health, defence and government offices, secure establishments and airports.

RESEARCH PROJECT OBJECTIVE

A primary objective of the company is to develop a way of working that will contribute to reducing the costs of implementing its projects by a target of 10%. This is being delivered as a performance improvement initiative, and there are four primary business drivers behind this objective, and these are; 1) client driver; clients want more and more for less and less; 2) competitiveness; the company operate in a competitive environment; 3) efficiency improvement; poor productivity is a feature of UK M&E projects, and; 4) competing new alternatives; whole buildings can be manufactured off site, and assembled on site, making large sections of traditional site installation redundant.

It is not the intention to explore these drivers further here, but they are the reasons for the improvement initiative, however, Gibb and Isack (2003) explains more on client expectations and drivers. Of particular concern within the company are poor labour productivity and the resultant cost escalation it has experienced on its recent major projects. This has had serious consequences on the financial performance of the projects to the point where severe margin slippage has occurred. Margin slippage can be defined as the negative variation between the expected margin (gross profit) for a project when acquired, and the final margin when the project is finished.

On these particular projects, these being the worst case and having the most serious affect on the company, labour cost escalation has been vast. This is presented in table 1 below. The company reports that not all of the losses are entirely attributed to poor productivity, but it is the main contributing factor. Other cost variables are worthy of attention, but are not the focus of this paper. What the company intend to do is to develop new ways of working to overcome the causes of poor productivity, and see the research project, and implementing lean as a result of this, as a vehicle to deliver its improvement objectives. Productivity improvement interventions will be designed using "lean thinking" principles, and applied to a case study project, as will be shown. The company further intend to implement these, and further lean techniques into what will be called their "lean construction system", to be applied to all projects as they occur over time. So the interventions implemented as part of this research are only aspects of the "whole" system to be developed.

DOES LABOUR HOLD THE KEY?

According to Hawkins (1997), labour costs typically constitute 30% of the overall project M&E costs, so maximising the output on site is essential to increase a contractor's performance and the value for money investment of the customer. This statement was part of report of an investigative study, undertaken by the Building Services Research and Information Association (BSRIA), and sets a foundation for understanding the problems and issues that the UK M&E industry faces within the construction sector. BSRIA undertook this investigative study comparing 4 UK, 1 American, 1 German and 1 Swedish construction project to highlight productivity problems relating to M&E building services, to assist the UK M&E industry in promoting improvements in productivity, and to suggest remedies to solve these problems and improve performance. Remedies are indeed suggested in the form of best practice recommendations, but actual design and implementation of these remains at the discretion of the contractor.

Within the company, as previously mentioned, the increased cost of labour on recently completed major projects has had a direct impact on the financial outcome of those projects, and because of the scale of the cost overruns, the company itself. This is shown in table 1. These projects were run in a traditional manner, with no specific lean interventions being made.

It can be seen that each project saw an increase in labour costs of 263%, 89% and 334% respectively. Whilst other cost variables on the projects influenced the final margin, the losses on labour virtually equalled the margin slippage suffered.

SITE FIRST PRINCIPLE

In his book, Toyota Production System, Ohno (1988) describes his plant-first principle. He says that the production plant is manufacturing's major source of information, and that it provides the most direct, current, and stimulating information about management. This is the same for the construction site; the site is to construction what the plant is to manufacturing. It is the culmination of all the construction processes and what is given to the customer when it is finished. Also, are workers the only participants in the building process

Table 1: Labour cost escalation and margin slippage on recently completed major M&E projects with high complexity and high value (values are £000's).

Cost Element	Project 1	Project 2	Project 3
Project value	£19,096	£42,665	£38,500
Estimated labour cost (A)	£1,117	£6,408	£5,295
Final labour cost (B)	£4,052	£12,088	£22,962
Labour cost escalation (B-A)	£2,935	£5,680	£17,667
Estimated margin (C)	£2,334	£4,169	£1,381
Final margin at completion (D)	£319	-£4,773	-£16,255
Margin slippage (C-D)	£2,015	£8,942	£17,636

Project 1 was not a project of the company but has been included here as a comparator of performance.

directly generating value to the customer? Larsen, Odgaard and Buch (2003) argue this point, and these are the reasons for the principle themes of this project. It seeks to focus on the worker, the worker's environment, and what makes the worker do what they do and why they do it, and will only be concerned with M&E workers and those of key interfacing trades insofar as they apply. The overarching aim then is to implement "lean" in an action research project for the company with a particular focus on the worker and their activities and behaviour. This will be addressed through investigating three principal themes:

Practical: (sensible, useful, effective, involving, the simple basics) ***What*** *people "do" at the workplace*—Standardisation of work, process and products to create flow, pull and value delivery. This aspect of the research will seek to develop innovative methods and use of innovative components for installation by standardising the work. Standard work is an agreed-upon set of work procedures that establishes the best and most reliable methods and sequences for each process and each worker (Productivity Press, 2002).

Physical: (to do with the body as opposed to the mind or spirit) ***How*** *people do things in the workplace*—Ergonomics and workplace organisation to improve health, safety and productivity. This aspect of the research will seek to address how people do things in the workplace. Of particular interest is ergonomics, which in the industrial workplace is generally defined as a variation of the following:

"A science devoted to determining the range of anatomical, physiological and psychological human factors and designing work environments conducive to these ranges with the objective of maximising productivity and minimising injury" (McNamara, 1986).

Psychological: (of or affecting the mind) ***Why*** *people do what they do*—Understanding motivation of the worker and its influence on behaviour at the workplace. This aspect of the research will separately look at the psychological and motivational factors that cause the worker to behave in the way they do.

SO WHAT'S THIS ABOUT AN ANTIDOTE?

As Womack and Jones, 1996, states, Lean Thinking is a powerful antidote to muda. Muda is a Japanese term for waste, and specifically any human activity, which absorbs resources but creates no value. These are; "Mistakes which require rectification, production of items no one wants, processing steps which aren't needed, movement of employees and transport of goods, waiting for upstream activities, goods and services that the customer does not want".

Added to this is the eighth category of waste, making-do (Koskela 2004). Koskela contends that there is a very common, generic type of waste that should be added to the list, because it can be justified using the same conceptualisations as used by the seminal authors. Further, the principal problems described by Hawkins (1997), can each be categorised as one form of muda or another. He ultimately charges the UK M&E industry with very low productivity for a variety of reasons, as explained in his report. So herein lies the hypothesis of lean as an antidote to labour cost escalation. This should be tested with a case study.

TURNING THEORY AND RESEARCH INTO ACTION—A CASE STUDY

An action research approach was chosen to understand where to start and what to do first. Coghlan and Brannick (2003), define action research as

involving a cyclical process of diagnosing a change situation or problem, gathering data, taking action, and then fact finding about the results of that action in order to plan and take further action. Also, the key idea of action research is that it uses a scientific approach to study the resolution of important social and organisational issues together with those who experience these issues directly.

In order to commence the process of deciding where and how to start making changes to current practice, observational studies were undertaken on various sites of the company. A primary finding from this is that making-do, or improvisation[5], occurs naturally to a greater or lesser degree with regard to how physical work on site is carried out, and this seemed to have a direct influence on productivity itself. In order to formulate an understanding of this in the context of this case study, an ethnographic study was then undertaken. Ethnography is a style of research rather than a single method and uses a variety of techniques to collect data, Cassell et al (2004). They defined this style of research as:

> *"…the study of people in naturally occurring settings or 'fields' by means of methods which capture their social meanings and ordinary activities, involving the researcher participating directly in the setting, if not also in the activities, in order to collect data in a systematic manner but without meaning being imposed on them externally…"*

The purpose of this study was for the researcher to become a participant in the site process in order to be immersed in the day-to-day site activities and not just be an observer. This study did not set out to measure specific productivity performance of the activities undertaken; enough of this has been done already (Hawkins, 1997). Rather, the primary objective was to experience the conditions that exist on site and occur naturally, and how workers do their work, without intervention. This method will allow the researcher to understand people's actions and their experiences of the world in natural settings as they occur independently of experimental manipulation, Cassell et al (2004). One week was spent as a ductwork fitter's assistant (not a project for the company), and another week was spent as an electrician's assistant (this was a project of the company). This involved the researcher doing actual installation work with teams under the direction of the team leader. A diary was kept at the end of each day to record events and discussions and digital images were taken. A "rich picture" of the key words and phrases from the diary entries was created in order to reveal a rich moving pageant of relationships, which is a better means of recording relationships and connections than is linear prose (Checkland and Scholes, 1992). The main findings are summarised as follows:

- limited, unplanned or improvised workplace organisation, workbenches, and equipment;
- assembly work carried out on the floor or on whatever came to hand;
- materials stored randomly around the site in no particular order, and in unknown quantities;
- scaffold systems provided that had to be accessed, with no facilities to store materials or tools. If something was missing, the operative had to climb back down to replenish whatever was needed;
- tools only provided by the tradesmen—they had what they had irrespective of their suitability;
- various trades worked in the same area at the same time. Materials for one trade were left in the way of the other trade/trades.

Figures 1–6 (following page) represent a sample of the research findings.

The ethnographic studies revealed the amount of waste and improvisation that naturally occurs without attention being given to eliminating the causes of it. If lean interventions are designed to overcome the causes of this waste, and this prevents labour costs from escalating, then lean as an antidote can work. Given this data, the next phase was to design lean interventions to be able to overcome the causes of waste, and then to further test them in a live situation. A project was chosen as the "experiment", and a hypothesis, which is a statement about cause and effect that can be tested, was set as follows:

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Labour is the independent variable to be manipulated in the experiment, and the outturn cost of labour is the dependant variable, which is observed as the outcome of the experiment. In order to manipulate the independent variable, labour, lean interventions were designed and applied to the project. These were standardisation

5 Improvisation is proposed here as a form of making-do. Making-do, according to Koskela (2004), is the eighth category of waste adding to the 7 wastes defined by Womack and Jones (1996). To improvise: to make, invent, or arrange offhand; to fabricate out of what is conveniently on hand (Merriam-Webster online dictionary).

Figure 1: Improvised cable dispensing.

Figure 2: Working on the floor.

Figure 3: Conventional scaffolding and manual handling.

Figure 4: Improvised workbench and random storage of components.

Figure 5: Unplanned workplace, conventional scaffold.

Figure 6: Various trades in same workplace, materials in each trades way.

of components, standardised work sequencing, mobile work cell and ergonomic access equipment. Each of these was designed to overcome the common route causes of the waste experienced during the ethnographic study. So let's look at each one in turn:

STANDARDISATION OF COMPONENTS

The report, Innovative M&E Installation (Wilson, 2000), follows on from BSRIA's Improving M&E Site Productivity (Hawkins, 1997). The research underlying this report led to the recommendations that alternative systems, components, materials and innovative methods should be thoroughly evaluated to identify opportunities for productivity gains on M&E projects. It concludes that the UK construction industry must replace outdated components and processes if it is to remain competitive in a global marketplace. This research project has found that the UK construction industry can realise a significant gain in installation performance through the adoption of innovative components and systems. Also, according to Ballard and Matthews (2004), a lean ideal for the championship, prefabrication and assembly, is to "simplify site installation to final assembly and commissioning". These principles were considered in the context of this case study and the solutions were selected accordingly, and summarised in table 2.

The specific purpose of this intervention was to eliminate unnecessary site processing of materials and fittings.

STANDARDISED WORK SEQUENCING

A "week-beat" system of structuring the work was employed, where the building was divided into smaller work zones (approx 1,000m2) and sequenced a "parade of trades" through each zone. Each trade was provided a period of one week in each zone to complete their work. This is as described by Horman et al (2002) as short interval production scheduling (SIPS).

The specific purpose of this intervention was to eliminate the situation whereby materials and access equipment for one trade interferes with another, and tradesmen are fighting for the same workplace.

MOBILE WORK CELL

Santos et al (2002) described applying the concept of mobile cell manufacturing in construction. This paper presents the results of an exploratory study investigating the application of the "mobile cell manufacturing" concept within the construction environment using a case study research method. The paper defines the characteristics of a cell as creating a work flow where tasks and those who perform them are closely connected in terms of time, space and information.

These were the basic ingredients in the design of a simple mobile work cell appropriate to M&E workers. These were designed in conjunction with the operatives with the objective of having all that was needed at hand when it was needed, with the ability to be mobile and be able to move around the product (the installation). The following equipment was developed and provided:

- Mobile component trolley—see Figure 7.
- Mobile cable dispensing and component trolley—see Figure 8.
- Mobile workbench with vice, shelf and drawers.
- Mobile material trolley for pipes and electrical containment.

The specific purpose of this intervention was to eliminate unnecessary sorting, fetching, looking, bending, carrying etc of materials and fittings necessary to carry out the work uninterrupted.

Table 2: Solutions selected in accordance with installation activity and benefits derived from the solution (terminology for benefits is as used in Wilson (2000), Innovative M&E Installation).

Activity	Solution Selected	Benefit of solution
Connection to the structure	Shot fixing system	Increased productivity
Method of support / suspension	Pre-assembled, integrated supports	Integrated system; increased productivity
Means of connecting service to support	Lightweight, fast assembly channel system; quick fit support components, pipe-clips etc.	Increased productivity; material savings; ease of installation
System installation	Press-fit pipework and conduit systems	Increased productivity; ease of installation
Tools and equipment	Cordless power tools; mobile work cell and ergonomic scaffold system	Increased productivity; improved working practices

Figure 7: Mobile component trolley, with simple manual replenishment.

Figure 8: Mobile cable dispensing and component trolley with simple manual replenishment.

ERGONOMIC ACCESS EQUIPMENT

The majority of M&E equipment is installed at high level within buildings, and this requires the worker to gain access in order to install materials and components using access equipment. Normal scaffolding typically consists of standard sections assembled to provide the necessary working platform height with kickboards and handrails. Access to the platform is via an integral ladder normally accessed from the inside of the tower through a lift up hatch in the platform floor. Tools, materials, consumables etc. are placed on the platform floor and used from there. This is a time consuming process and involves the worker climbing, stooping, bending, twisting and reaching just to get to the place of work. In consideration of this, a more ergonomic scaffold was designed with the objective of minimising significant body motions when gaining access to and carrying out work at the point of installation (high level). This included getting from the floor, to the services installation point, and to the underside of the concrete slab for fixing supports, and the like. The tower is still assembled from standard sections but put together in a different way. It is readily accessible via a series of steps at one end to give access to the services working height, and a step-up "poop-deck" at the furthest end to provide higher access to the underside of the slab. On-board storage bins are provided which are refilled using a simple manual replenishment system.

The specific purpose of this intervention was to eliminate unnecessary motions for the tradesman getting to the place of work, and to have the necessary materials and fittings at hand to carry out the work uninterrupted.

RESULTS

This case study set out to measure the cost of labour used compared to the estimated labour cost, and consider its impact on the final margin of the project. To do this, actual labour used (not earned) was monitored on a weekly basis from the start of the project and compared to planned labour usage, and this is represented in Figure 11.

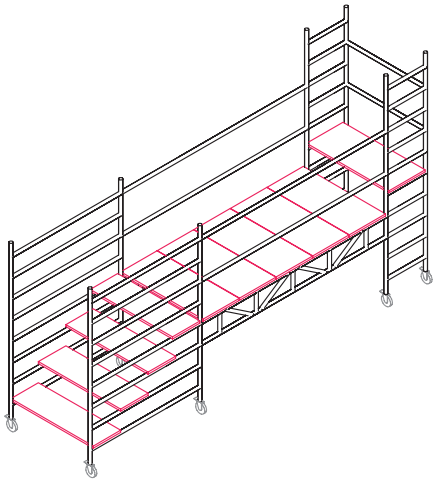

Figure 9: Tower as designed.

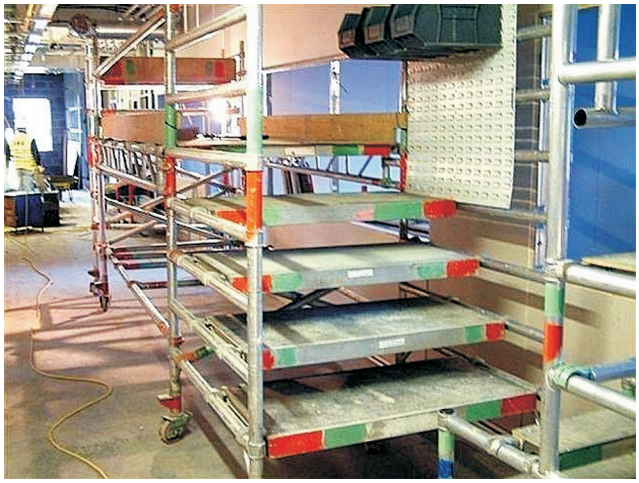

Figure 10: Actual tower.

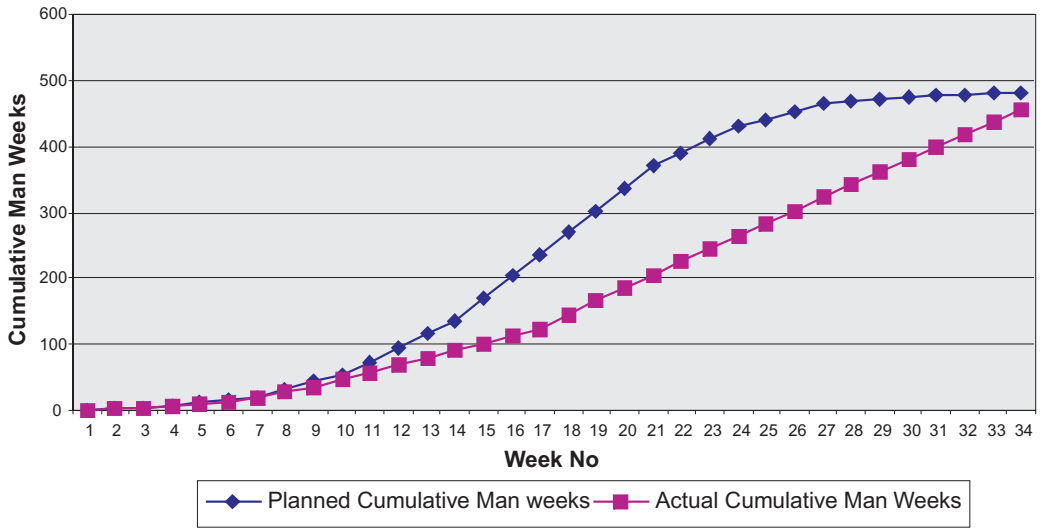

Figure 11: Planned cumulative man weeks versus actual cumulative man weeks

This study did not intend to measure specific enhancements to productivity such as metres of cable / pipe installed; rather, it sought in a fairly simple but scientific manner to test the effect that the lean intervention inputs had on the cost of labour, on a weekly basis, then cumulatively. The authors do recognise, however, that the former would be valuable for future research to test the actual effectiveness of each of the interventions.

As can be seen, actual man weeks were consistently below planned on a week-by-week basis, with actual cumulative man weeks being 8.5% below planned that planned. Table 3 below represents the estimated costs for the project, showing each element, and comparing this to the final cost per element.

A point to note is that the researcher did not influence the tradesmen by being present in the experiment, this did not occur. Once the interventions were made, progress was monitored by phone-calls and random site visits.

DISCUSSION

Table 3 shows that the project ended with a 7% saving in materials and plant, an 8% saving in labour, a 5% increase in sub-contract costs and a 24% saving in preliminaries. Overall the project had a cost saving of £91k, which resulted in a margin increase of £144k, contributed too also by an increase in value from the customer of £53K.

Under normal experimental conditions, it would have been desirable to compare these results with those of a control experiment, where the hypothesised cause was absent. In other words, to observe an exact same project that runs at exactly the same time but without the lean interventions being made. However, in the context of operating in a live business and with a live project it was not possible to do so. The historic projects shown in Table 1 represent the control group which did not have lean interventions imposed upon them, the cause, but had the result of substantially increased labour costs, the effect, contributing to severe margin slippage. What this experiment has shown is that the four interventions proved effective in enhancing productivity, and the outcome in terms of reduced labour costs seems to be a function of these inputs. Did, therefore, these interventions eliminate the route causes of waste that would have otherwise occurred naturally? It would appear so. Labour costs did not escalate and margin slippage did not occur, in fact the margin increased significantly on the case study project.

It could be argued that the project improved its financial outcome because of skilled project management, a good estimate, a better client, or better contractors in the other trades etc. This cannot be substantiated in the context of this study. But given that the company has experienced increased labour costs where interventions were not made, the results of this experiment are an encouraging step in its performance improvement initiative, by showing positive results in its first endeavours. So, is "lean" an antidote to labour cost escalation on complex M&E projects as hypothesised, and did this lead to preventing margin slippage? The authors would argue yes, it is, and yes, probably it did. They also recognise that other cost variables need to be controlled which deserve equal attention in the future. But the final reminder is that this research set out to focus on the labour element only, this being the company's biggest current concern. This research has investigated the practical and physical themes of the overall research project. The psychological theme, although partly experienced during the ethnographic study, was not investigated.

Table 3: Estimated costs per element compared to final costs per element (values are £000's).

Element	Estimated costs	Final costs	Variance	Variance %
Value	£1,672	£1,726	£54	3%
Costs:				
Materials and plant	£590	£550	-£40	-7%
Labour	£335	£309	-£26	-8%
Sub-Contract	£357	£375	£18	5%
Preliminaries	£181	£138	-£43	-24%
Contingency	£17	£17	Nil	Nil
Sub-Total Costs	£1,480	£1,389	-£91	-6%
Gross Margin Totals	£192	£337	£145	75%
Gross Margin / Revenue Ratio	11.5%	19.5%	8%	

FURTHER RESEARCH

These interventions were the first stage of designing and implementing a Lean Construction System for the company. The findings from this report will be used to inform and develop standardised operating procedures and routines for how work will be conducted in the future on new projects. This will be together with new lean features yet to be researched, developed, implemented and tested on these new projects, which will be reported on in the future. One aspect of this will be psychological factors that influence the worker. This was not considered as part of this case study, but is one of the main themes for the research project.

REFERENCES

Ballard, G. and Matthews, O., (2004). "Championship—Prefabrication and Assembly". *Proceedings of the 12th annual conference of the International Group for Lean Construction*, Elsinore, Denmark, August 3–5, 2004.

Cassell, C. and Symon, G., (2004). "Essential Guide to Qualitative Methods in Organisational Research". SAGE publications.

Checkland, P. and Scholes, J., 1992). "Soft Systems Methodology in Action". Wiley Publications.

Coghlan, D. and Brannick, T., (2003). "Doing Action Research in Your Own Organisation". SAGE publications.

Gibb, A.G.F. and Isack, F. (2003). "Re-engineering Through Pre-assembly: Client Expectations and Drivers". Building Research and Information, **31**(2), 146–160.

Hawkins, G (1997). "Improving M&E Site Productivity". BSRIA.

Horman, M.J., Messner, J.I., Riley, D.R., Pulaski, M.H., (2003). "Using Buffers to Manage Production: A Case Study of the Pentagon Renovation Project". *Proceedings of the 11th annual conference of the International Group for Lean Construction, Blacksburg*, Virginia, July 22–24, 2003.

Koskela, L., (2004). "Making-Do—the Eighth Category of Waste". *Proceedings of the 12th annual conference of the International Group for Lean Construction*, Elsinore, Denmark, August 3–5, 2004.

Larsen, J., Odgaard, G., and Buch, S., (2003). "A Trade Union's View of the Building Process". *Proceedings of the 11th annual conference of the International Group for Lean Construction*, Blacksburg, Virginia, July 22-24, 2003.

McNamara, Brian E (1986). "Ergonomics: Maximising the Human Resource". 1986 Logistex Forum, May 6–8, 1986.

Ohno, T., (1988). "Toyota Production System, Beyond Large Scale Production". Productivity Press.

Santos, A., Moser, L., Tookey, J., (2002). "Applying the concept of Mobile Cell Manufacturing on the Drywall Process". *Proceedings of the 10th annual conference of the International Group for Lean Construction,* Gramado, Brazil.

The Productivity Press Development team (2002). "Standard Work for the Shopfloor". Productivity Press.

Wilson, D., (2000). "Innovative M&E Installation". BSRIA.

Womack, J.P. and Jones, D.T., (1996). "Lean Thinking, Banish Waste and Create Wealth in your Organisation". Simon and Schuster.