

A lean and agile construction system as a set of countermeasures to improve health, safety and productivity in mechanical and electrical construction

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This paper presents certain aspects of the findings of a research project to develop and implement a Lean and agile mechanical and electrical (M&E) Construction System on a case study project. The objective of the research project for the sponsor company is to improve its projects site operations making them safer for the worker and improving efficiency and productivity by overcoming the problems and issues that it faces in the M&E industry within the UK construction sector.

The research finds that using the System on the case study project, and when compared to a traditional method, a 37% reduction in onsite labour was achieved; no time slippage occurred during onsite assembly to delay or disrupt other trades; less workers onsite were exposed to lower health and safety risks from site operations leading to zero reportable accidents; good ergonomics was achieved by focussing on workplace design thus improving workers wellbeing; an improved quality of work was achieved for those required on site carrying out simpler assembly tasks; productivity gains were achieved by eliminating process waste; a 7% direct labour reduction was achieved leading to no labour cost escalation that otherwise could have occurred further reducing the risk of labour cost escalation. Significantly, an overall productivity of 116% was achieved using the Construction System which compares favourably to the Building Services Research and Information Association (BSRIA) findings of an average overall productivity of only 37% when compared to observed best practice for the projects in that case study research. Also, no compression of the commissioning period occurred with the built facility being handed over to the customer on time.

KEY WORDS Construction System, countermeasures, Last Planner, health and safety, productivity.

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Introduction

This is a practical paper drawn from a collaborative research project (the research project) being undertaken at the Centre for Innovative Collaborative Engineering at Loughborough University, UK. The programme is funded by the Engineering and Physical Sciences Research Council (EPSRC) and is sponsored by a major UK mechanical and electrical contractor (the company). The research project has specific objectives, which will be capable of making a significant contribution to the performance of the sponsor company. The research problem that this project is designed to overcome is that of the poor health, safety and productivity performance that the company faces in UK construction. These problems are described in this paper.

The researcher is developing a Construction System for the company to overcome these problems and therefore to improve the performance of its projects. This paper is the sixth in a series of papers reporting on the design and implementation of the System and is a continuation of the already published findings and results of the same methodology and case study project. This paper presents the health, safety and productivity findings measured as the outcome of implementing the System on the case study project during the sample period. As a point of note, the researcher is the M&E Project Leader for the company on the case study project and is submitting these papers as part of the award for an Engineering Doctorate being studied at Loughborough University in the United Kingdom.

Research project objectives

As stated the objective of this project for the company is to design and implement a new way of working on site to improve site operations, making them safer for the worker and to improve productivity. Safety is at the core of the company and according to the Business Leaders “...it is an absolute right for people to return home safely at the end of a productive day’s work,” and “failure to do so renders the company valueless.” The key words here being *safely* and *productive*, these are therefore at the core of this research project, which is to design and implement a way of working on site that will satisfy these objectives by overcoming the problems and issues that it faces.

Underpinning purpose

The purpose of designing and implementing this Construction System is to specifically understand and to overcome the issues that face M&E construction in terms of historically poor health, safety and productivity outcomes on projects. The System is a specifically designed construction methodology to act as a set of countermeasures⁴ to what would otherwise occur had this not been done. The System accepts existing research into the issues faced in construction (specifically M&E construction) and therefore does not seek to replicate this. Consider it as designing and implementing a new production process for M&E construction using innovative techniques drawn from extensive research, observation, experience, lessons learned, continuous improvement, and new technology. The main issues that the System is designed to countermeasure have been discussed in previous research papers together with how the System works to overcome them. These primary

⁴ A countermeasure is defined by Oxford English Dictionary (2009) as an action taken to counteract a danger or threat. The threat to the company is the primary issues faced in UK construction, i.e. the research problem.

issues were identified as an outcome of a thorough literature review and the particular research process undertaken. These are now described.

The research process

The initial phase of the research process undertaken involved a literature review, observational studies, and ethnography to establish the current state; how things are done today which sets a foundation of understanding the research problem and what to do to overcome it. The key findings of this phase and the issues that the company faces revolve principally around health and safety factors (HSE 2000, 2007, 2007a, 2007b, Gibb 2006); space availability issues (Winch and North 2006, Akinci et al. 2002, 2002a, Guo 2002); productivity issues (Hawkins 1997, 2002, Wilson 2000); crew conflict issues (Howell et al. 1993, Thomas et al. 2005 and Horman et al. 2006) and worker skills issues (Goodier and Gibb 2005). The primary issues and their source are summarised in table 1.

Table 1 Summary of primary issues

| Primary issues | Source |
|--|---|
| Manual handling injuries caused by repetitive and heavy lifting; bending and twisting; repeating actions too frequently; uncomfortable working position; exerting too much force; working too long without breaks; adverse working environment and psychosocial factors. | Health and Safety executive (2007a, 2007b). |
| Slow accidents caused by health factors. The period over which the incident occurs may be longer but the result is the same, a worker gets injured but it takes longer. | Gibb (2006). |
| Site congestion generates hazards and reduces output. | Winch and North (2006); Akinci et al. (2002a, 2002b); Guo (2002); observational studies; ethnography. |
| Subcycle and symbiotic crew relationships delay each other. | Howell et al. (1993); Thomas et al. (2004). |
| Too much site cutting and elevation of parts into position. | Hawkins (1997); observational studies; ethnography. |
| Poorly conceived materials handling strategies. | Hawkins (1997); observational studies; ethnography. |
| Very poor levels of housekeeping. | Hawkins (1997); observational studies; ethnography. |
| Outdated components and processes. | Wilson (2000); Hawkins (2002); observational studies; ethnography. |
| Site workers in short supply or inappropriately skilled. | Goodier and Gibb (2005). |
| Limited, unplanned or improvised workplace organisation, workbenches, and equipment. | Observational studies; ethnography. |
| Assembly work carried out on the floor or on whatever came to hand. | Observational studies; ethnography. |
| Nowhere to hang drawings or other information. | Observational studies; ethnography. |
| Scaffold systems provided that had to be accessed by climbing a ladder and opening flaps, with no facilities to store materials or tools. | Observational studies; ethnography. |
| Tools only provided by the tradesmen - they had what they had irrespective of their suitability. | Observational studies; ethnography. |

These issues represent the basic underpinning reasons for the company to improve its site operations as it is indeed not immune from these. The next phase of research was conducted to be able to design a set of countermeasures to overcome the issues identified in table 1. This phase focussed on research and learning from manufacturing, and in particular Lean and agile methods in use today. The research and learning undertaken has been used to develop a theoretical Construction System that incorporates manufacturing

methods such as modular assembly; postponement; reflective manufacture; pulse-driven scheduling and ABC parts classification.

These manufacturing concepts are described, together with their applicability to the development of the Construction System, in court et al. (2006 and 2007). These methods are summarised in table 2.

Table 2 Summary of manufacturing methods used in the Construction System

| Method | Definition |
|----------------------------------|--|
| Modular assembly. | The ability to pre-combine a large number of components into modules and for these modules to be assembled off-line and then bought onto the main assembly line and incorporated through a small and simple series of tasks. |
| Postponement | An approach that helps deliver more responsive supply chains. Form postponement involves the delay of final manufacturing until a customer order is received. When distribution of the product is delayed to the last minute and only configured and distributed when the customer order is received then you have logistics postponement. |
| Reflective manufacture. | Evolved from Volvo's development of production systems which looked into quality of work as well as efficiency of production. It includes control over methods, time and quality plus the responsibility to plan ahead and the knowledge needed to reflect on work done. Quality of work also means good ergonomics, appropriate working tools and a good working environment. |
| Pulse-driven scheduling. | Means period batch control (also know as period flow control) which is a Just-In-Time, flow control, single cycle, production control method, based on a series of short standard periods generally of one week or less. |
| ABC parts classification. | Parts are classified into A Parts - the first 5 to 10 percent of the parts accounting for 75 to 80 percent of expenditure; B Parts - the next 10 to 15 percent of the parts accounting for 10 to 15 percent of expenditure; and C Parts - the bottom 80 percent or so of the parts accounting for only 10 percent or so of expenditure. |

These manufacturing methods form the underpinning design of the Construction System, which is now described.

The construction system

The Construction System is specifically designed as a set of countermeasures to overcome the primary issues that face the company and to deliver the objectives of the sponsor company and is represented in Figure 1. Its underpinning design incorporates manufacturing methods such as modular assembly, postponement, reflective manufacture, pulse-driven scheduling and ABC parts classification. These concepts from manufacturing are described in Court et al. (2006 and 2007). The System is designed with these Lean and agile concepts to specifically eliminate waste from M&E (and key interfacing trades) construction activities - the Lean dimension. The agile dimension is designed to provide each trade team exactly what they want, when they want it and where they want it. These Lean and agile attributes are designed to standardise the work, process and products to create flow, pull and value delivery. The ergonomic and workplace organisation attributes are designed to specifically improve workers health, safety and productive output (Court et al. 2005).

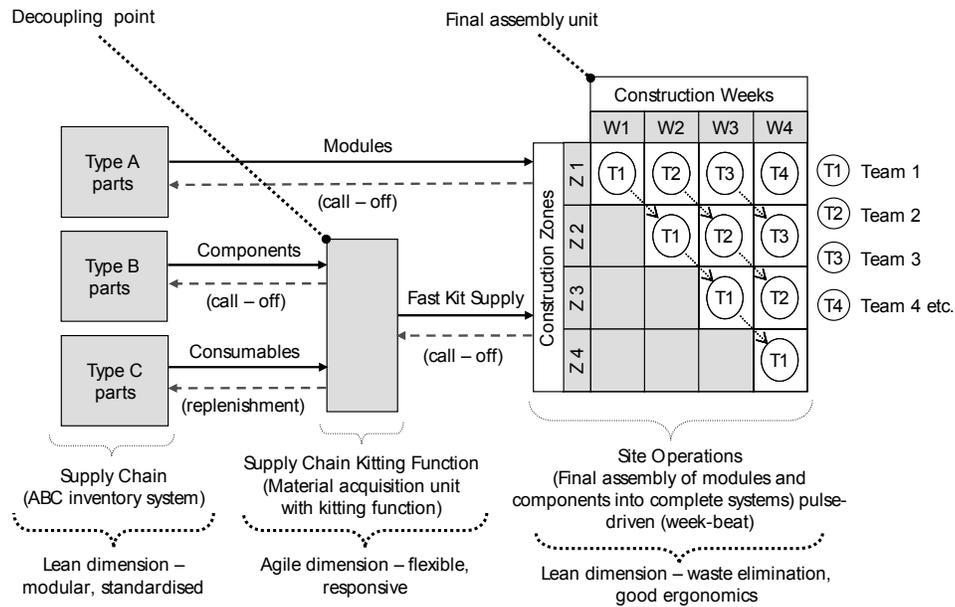


Figure 1 Model of the Construction System (adapted from Court et al. 2007)

Its key components are its supply chain with a postponement function and its site operations. The supply chain component has been categorised using ABC parts classification with modules (type A) being delivered directly to site on a call-off system. Components and consumables (type B and C) being parts kitted or replenished for delivery to site via the postponement function also on a call-off system and to the exact requirements for the site operations (Court et al. 2009). The kits are to be postponed until the moment they are needed. Site operations are conducted by trade teams (T1, T2 etc.) using mobile work cells and ergonomic access equipment (Court et al. 2005). Figures 2 and 3 show typical kit of parts on mobile stillages to be delivered directly to point of use by the logistics team, and mobile work cell in operation for drainage crews.



Figure 2 Kit of parts for vent system on mobile stillage



Figure 3 Mobile work cell - drainage crew

Another Lean component of the Construction System which is deployed is the Last Planner System (LPS) of production control (Ballard 2000). LPS is a production planning and control tool used to improve work flow reliability. It adds a production control component to the traditional project management system (Guilherme et al. 2005). LPS is deployed through each of the phases of the project with six week look ahead's and weekly

work plan meetings. LPS has complimentary properties with the Week-Beat method because the six week look ahead's and the weekly work plan meetings screen and shield each weeks planned operations in the Week-Beat using Construction Physics Seven Flows (Bertelsen et al. 2006). These are: information; materials; previous work; space; crews; equipment and external conditions. This drives the team to make ready all the areas of work and using this constraints analysis, only what *can* be done is placed in the weekly work plan. The look ahead is always into the projects strategic programme and measurement of progress is checked back against this which enables corrective actions as required.

As has been described, the Construction System has been designed as a set of specific countermeasures to overcome the issues that exist in construction, as discussed previously. These primary issues together with the Construction System components which act as the countermeasures to them are summarised in table 3.

Table 3 Issues and Countermeasures

| Primary issues | Construction System countermeasures |
|--|---|
| Manual handling injuries caused by repetitive and heavy lifting; bending and twisting; repeating actions too frequently; uncomfortable working position; exerting too much force; working too long without breaks; adverse working environment and psychosocial factors. | Modular assembly with mechanical lifting aids; trained manual handlers in logistics team; materials in purpose made stillages, trolleys and roll-cages. |
| Slow accidents caused by health factors. The period over which the incident occurs may be longer but the result is the same, a worker gets injured but it takes longer. | Modular assembly; ergonomic workplace design. |
| Site congestion generates hazards and reduces output. | Week-Beat (trade separation); mobile work cells; materials in mobile carriers. |
| Symbiotic crew relationships delay each other. These are tight and closely dependant trades and these are more common in mechanical, electrical, plumbing and finishing trades. | Week-Beat (trade separation). |
| Poorly conceived materials handling strategies. | ABC parts classification; modular assembly; Just-In-Time parts kitting. |
| Very poor levels of housekeeping. | Physical waste managed by trained logistics team. |
| Too much site cutting, drilling, assembly work and elevation of parts into position. | Modular assembly with mechanical lifting aids. |
| Outdated components and processes. | ABC parts classification; push-fit components; the Construction System; Last Planner System. |
| Site workers in short supply or inappropriately skilled. | Fewer workers required (modular offsite assembly); lower skill mix needed for simpler assembly tasks. |
| Limited, unplanned or improvised workplace organisation, workbenches, and equipment. | Workplace organisation; mobile work cells. |
| Assembly work carried out on the floor or on whatever came to hand. | Workplace organisation; mobile work cells. |
| Nowhere to hang drawings or other information. | Workplace organisation; mobile work cells; complete with mobile drawing boards. |
| Scaffold systems provided that had to be accessed by climbing a ladder and opening flaps, with no facilities to store materials or tools. | Ergonomic workplace design; walk-up scaffold systems; scissor lifts. |
| Tools only provided by the tradesmen - they had what they had irrespective of their suitability. | Appropriate working tools provided for all tradesmen. |

Having designed the Construction System, the next phase of the research project is its implementation on a case study project. This next phase is now described.

The case study project

The case study project is part of the development of a major acute hospital being procured using the UK Government's Private Finance Initiative (PFI). The project is to be developed in phases across two existing operational hospitals. The major new-build phases of the project are shown in figure 4 (excluding the community hospital phase which is in a remote location five miles away from the main site).

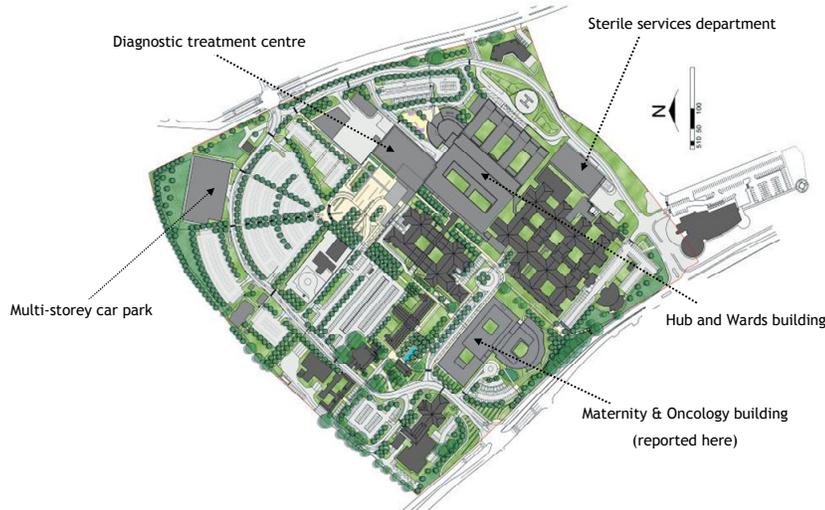


Figure 4 Site layout showing major new-build phases of the project

The phases are a new Maternity and Oncology Centre (20,000 m² gross internal floor area⁵); Sterile Services Department (2,000 m² gross internal floor area), Hub and Wards Unit (52,000 m² gross internal floor area); Diagnostic Treatment Centre (20,000 m² gross internal floor area); and a Community Hospital - remote location (12,000 m² gross internal floor area). The project commenced construction in December 2006 (M&E commenced August 2007) and is due for completion in 2012. The Construction System is being applied on each phase of the case study project the first being the new Maternity and Oncology Centre (reported here). This is a 20,000 m² building over four floors. It has electrical and water storage plantrooms in its basement with main ventilation plantrooms over the Oncology Centre at level two and on the roof at level five. Riser shafts are located around the building and distribute air, water, medical gas, electricity and the like throughout the building to the various departments. Corridor ceiling voids distribute the services from the riser shafts and then further into individual rooms and spaces, again in the ceiling voids. Finally, services distribute inside dry-lined walls to points of use such as electrical sockets, sinks, basins and bed-head units; everything you would expect to see in a new and modern healthcare facility. The work itself was sequenced using the Week-Beat method with close-scheduling as described in Court et al. (2007). This divided building fabric processes (BFP) into BFP1-6, and mechanical and electrical processes (MEP) into MEP1-5. This being everything required to start and complete all works in a construction zone from a concrete

⁵ Multiply m² by 10 for approximate area in square feet.

shell to a complete hospital department (in 1,000 m² zones), excluding testing and commissioning.

Findings from implementation

Assembly work commenced on the case study project in August 2007, with planned completion of the installation activities, using the Construction System, at the beginning of October 2008, a 63 week total cycle time including plantrooms (the sample period). This was a target period set and was calculated following a review of the original planned period using a traditional method, and applying this Lean and agile Construction System method to it. This allows a clean commissioning period of 12 weeks (after BFP6 for the final construction zone), with a five week buffer at the end of the programme period. All M&E processes (MEP1-5) and plantrooms were complete at the end of October 2008 (week 66), with the exception of the completion of major customer variations to the Oncology department and working backlog items⁶. These customer variations resulting in approximately 60% of this department (2 construction zones) having to be remodelled. Also, during the sample period (August 2007 to October 2008), 80% of electrical testing was complete; 80% of water systems pressure testing was complete; 50% of extra low voltage system testing was complete (building management systems, fire alarms etc.); 90% of voice and data system testing was complete; and clean commissioning commenced (air and water system balancing). High voltage power-on was achieved June 2008, and water-on to the building was achieved August 2008. Hand-over to the customer occurred in March 2009 for the Maternity facility and June 2009 for the Oncology facility, both on time. The findings are now reported for productivity and labour cost, followed by Health and Safety findings.

Productivity and Labour Costs Findings

The findings from the implementation have fallen into two sets. The first set was the results and analysis of the benefits from the use of corridor modules in lieu of a traditional installation method. This sub-process, the installation of corridor modules made offsite was evaluated (once the work was complete) and reported in Court et al. (2008). Here 1,568 actual onsite hours were used elevating and connecting together a total of 196 modules, compared to 22,320 hours estimated using traditional methods with various trade teams completing the required work all working at height; a 93% reduction. An 8.62% cost benefit is also reported. The second set combines this benefit with the results from the implementation of the Construction System through all M&E processes and a final analysis against overall expected benefits is now reported. Data collection to enable an assessment of the benefits of the System is presented in figure 5⁷. This presents a comparison of a traditional approach, the Construction System (target Lean and agile) approach, actual hours booked and actual hours booked minus unavoidable delays.

⁶ Working backlog is defined here as any minor incomplete works and rework items (such as snagging, missed items of work etc).

⁷ This analysis includes the onsite labour installing ATIF corridor modules described previously.

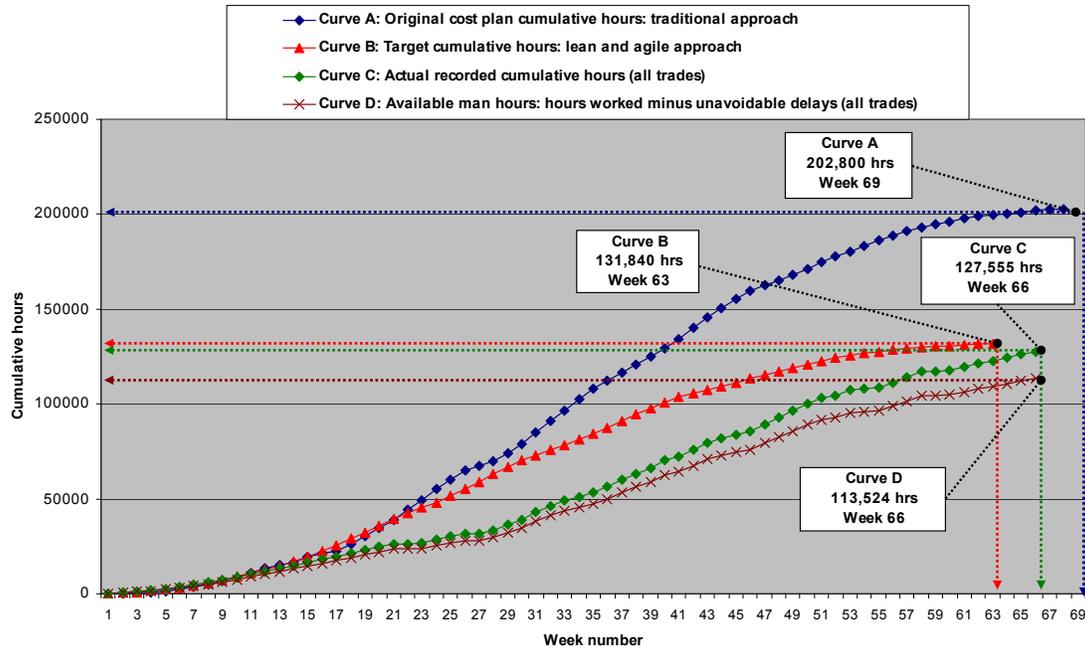


Figure 5 Comparison of traditional approach, target Lean and agile approach, and actual hours booked, with actual hours minus unavoidable delays shown

Curve A is the predicted cumulative labour hours and cycle time for a traditional installation method (for all work including sub-contractors originated from the project cost plan). **202,800 hours with a 69 week cycle time**. This curve is the benchmark against which the Construction System method is measured (planned - curve B, and actual - curves C and D). 202,800 hours is derived from 2,535 pair man weeks which is calculated as follows:

$$2,535 \text{ (pair man weeks)} \times 2 \text{ (men per pair)} \times 40 \text{ (hours per week)} = 202,800 \text{ hours.}$$

Curve B is the target predicted cumulative labour hours and cycle time after applying this Construction System method. **131,840⁸ hours with a 63 week cycle time**. This is the expected outcome. 131,840 hours is derived from 1,648 pair man weeks which is calculated as follows:

$$1,648 \text{ (pair man weeks)} \times 2 \text{ (men per pair)} \times 40 \text{ (hours per week)} = 131,840 \text{ hours.}$$

Curve C is the actual cumulative labour hours and cycle time recorded during the sample period. **127,555⁹ hours with a 66 week cycle time**. This is the actual outcome.

Curve D is the actual cumulative labour hours minus unavoidable breaks. 113,524 hours (unavoidable breaks equate to 11% of actual time) with a 66 week cycle time.

The onsite assembly finished at week 66 when all work was complete, this is shown as the final point of curve C in figure 4.42.

Following an analysis of the data, the measured benefits are presented in table 4.

⁸ These are paid working hours and therefore already adjusted for unavoidable delays. Workers are paid for a 45 hour week (excluding overtime if worked) and for their lunch break.

⁹ These are also paid working hours and therefore already adjusted for unavoidable delays.

Table 4 Table of Measured Benefits

| Curve comparison | Description | Data | Benefit |
|------------------|--|--------------------------------------|-----------------------|
| A to B | The expected benefit (target) | 202,800 hours minus 131,840 hours | 70,960 hours (35%) |
| | | 69 weeks minus 63 weeks | 6 weeks |
| A to C | The actual benefit | 202,800 hours minus 127,555 hours | 75,245 hours (37%) |
| | | 69 weeks minus 66 weeks | 3 weeks |
| B to C | Improvement to target | 131,840 hours minus 127,555 hours | 4,285 hours (3%) |
| | | 63 weeks minus 66 weeks | -3 weeks |
| B to D | Improvement to target after unavoidable breaks | 131,840 hours minus 113,524 hours | 18,316 hours (14%) |
| | | 63 weeks minus 66 weeks | -3 weeks |

The expected benefit using the Construction System was a 35% reduction in onsite hours and a six week cycle time reduction. The actual benefit achieved using the Construction System was a 37%¹⁰ reduction in onsite hours and a three week cycle time reduction. The actual onsite hours improved from target by 3% (before unavoidable delays) but the expected cycle time benefit of six weeks reduced to an actual of three weeks.

As described earlier this was due to the client changes to the Oncology department which could not be accommodated in the target cycle time period. However, the labour hours for this were absorbed within the actual hours recorded.

As described earlier, Hawkins (1997) reports that the UK projects monitored had an average overall productivity of only 37% when compared to observed best practice. Using the method presented by Hawkins, a similar overall productivity calculation was made. To achieve this, available hours, as defined by Hawkins, were calculated (curve D). This represents recorded actual man hours minus unavoidable delays such as lunch and tea breaks¹¹. This represents working hours available.

¹⁰ The 37% saving in onsite hours does not represent a saving in labour cost, as these hours contribute to the labour budget for offsite manufactured components.

¹¹ On average, this is one hour per day per worker: 30 minutes for lunch break; 15 minutes for morning break; and 15 minutes for afternoon break.

Overall productivity for the sample period was then calculated using the definition of overall productivity in Hawkins (1997):

$$\text{Overall Productivity} = \frac{\text{Output}}{\text{Available Time}}$$

Where:

- **OUTPUT** is a measured quantity of installed material to a defined requirement. The physical output is converted to units of time by employing an earned hour's concept based upon best practice installation times.
- **AVAILABLE TIME** is the total working day minus unavoidable delays such as lunch and tea breaks.

Using this definition and hours from figure 4.42:

$$\text{Overall Productivity} = \frac{131,840 \text{ hours}}{113,524 \text{ hours}} = 116\%$$

Where:

- 131,840 hours is the total earned hours from the target Lean and agile approach (using best practice installation times - the Construction System).
- 113,524 hours is the booked hours at completion (the sample period) minus unavoidable delays (lunch and tea breaks), tracked using the System.

Therefore, an overall productivity of 116% was achieved using the System, which compares favourably to the BSRIA findings of an average overall productivity of only 37% when compared to observed best practice for the projects in that case study research. This comparison needs to be viewed with a degree of caution, as the calculations shown reflects all of the M&E installations on the case study project compared with BSRIA's findings which represent an average overall productivity for only ductwork, hot and chilled water pipework, and cable management systems. This is treated by the author as a suitable benchmark from which to measure the performance of the Construction System against.

Figure 5 includes time for all labour on site, which is the company's own direct labour and that of its sub-contractors. Of concern to the company was the impact that direct labour cost escalation can have on the projects outturn profitability (Court et al. 2005). Therefore an analysis of the company's direct labour hours was also undertaken.

Table 5 presents a comparison between budgeted direct labour hours (excluding sub-contractor hours) and actual direct labour hours for the sample period (these being the workers actually employed by the company).

Table 5 Budget versus actual direct labour hours during sample period for the Maternity and Oncology case study project

| Budget direct labour hours | Hours |
|---|----------------|
| Budget hours | 121,646 |
| Variation hours agreed | 11,429 |
| Total budget hours | 133,075 |
| Actual direct labour hours | |
| Actual hours booked for the sample period (including supervision and non-productive overtime) | 107,973 |
| Further hours to complete (variations and working backlog) | 15,680 |
| Estimated final hours at completion | 123,653 |
| Forecast saving in hours | 9,422 |
| Forecast % hours saving | 7% |

It can be seen that a saving in direct labour hours of 7% is achieved using the System. After the sample period, a total of 15,680 hours is reserved to complete customer variations and working backlog items as described previously in this report.

Health and safety findings

In terms of safety findings, during the sample period, the case study project had zero reportable accidents, defined as injuries resulting in more than three days off work for the injured party. 19 minor injuries occurred during the sample period however and these were recorded in the company's accident recording system as they occurred. Each accident reported was categorised into accident type; date of accident; primary cause; summary details of accident; underlying causations; behaviours; injured body parts and injury type. An overview of the place of accident, behaviours and primary causes are as follows;

Place of accident: 8 were not at the place work itself; 11 occurred at the place of work.

Behaviours: 2 were non-compliance with procedures; 9 were human error; 7 were personal factors (carelessness, negligence etc.); 1 was a communication failure.

Primary cause: 3 were exposure to a harmful substance; 4 were slips/trips; 1 was contact with plant and machinery; 3 were moving/falling object, 4 were "other"; 4 were handling/lifting or carrying.

Whilst this is not an acceptable result given the interventions made with the Construction System, manual work itself is still at the core of the System and this factor will keep exposing the worker to the risk of minor injury. When studying these results, of particular note was the workers behaviour, all but one of the accidents could have been avoided if the worker complied with procedures, and paid more attention to avoid carelessness. This could be overcome with more routine training given into the

behavioural aspects of accident causation. Human error could be reduced with more attention to further error-proofing the installation work itself in the future.

From a health perspective, what benefits did the worker derive from good ergonomics and workplace organisation for their wellbeing? According to Gibb (2006) the often delayed onset of (health) conditions following exposure (to occupational health risks) should drive us to look for solutions and do something about the problems. The interventions made in the Construction System are about providing solutions to the health risks that would otherwise be faced by the workers had these not been made. They are about protecting workers from work related ailments such as MSD's through better management and reduction of their exposure to the causative factors (Gibb 2006). Occupational health is about risk management and in this sense the risk management applied is the workplace organisation implemented in the Construction System by undertaking the following:

Providing cast-in inserts to avoid the need to drill overhead into concrete for large fixings;

Providing walk-up scaffolds or scissor lifts to avoid the need to climb ladders inside traditional scaffold systems;

Providing handling equipment and workbenches to avoid the need to bend over and work or kneel on the floor. This decreases the physical workload of the worker (Sillanpaa et al. 1997);

Providing modular assemblies with mechanical aids to lift them. This avoids the need to cut and manually elevate components overhead and working at height. This enables employees to maintain an improved posture when connecting and testing the modules (HSE 2000);

Using mechanical lifting aids generally avoids the need for workers to manually elevate components into position at high level;

Providing mobile trolleys for tools, components and materials etc. This avoids the need to carry and move things around manually;

By having all materials stored in mobile trolleys at the workplace, exactly where they are needed. This avoids the need to walk around looking for and carrying things to where you need them;

By providing simpler assembly tasks with pre-assembled quick-fit components. This avoids workers being engaged in too much site cutting, drilling and assembly work and elevation of parts into final position (Hawkins 1997).

The Construction System was an attempt to reduce the occupational health risks that construction (M&E) workers face and to fit the work to the worker, as far as reasonably practicable. Due to the time lag between the cause and effect in occupational ill health, it was not possible to measure the benefit of these interventions in quantifiable terms within the scope of this research project. Also, without significant medical research and ethical compliance, there was no way of knowing a workers health condition prior to working on the case study project. As such the need would have been to measure over 100 workers physical condition prior to, and after their involvement, in the Construction System during the sample period, and then draw conclusions from the findings. Whilst this was not within the scope of this research project, testing the ergonomic interventions made is an area worthy of further future research. The ergonomic equipment provided

will, it is predicted, contribute to a significant reduction in the muscular load on the workers as found by Sillanpaa et al. (1999). What can be said, therefore, is that the Construction System will contribute in reducing the causative problems that lead to work related ailments, and in this sense has workers wellbeing and sending them home safely at the end of a productive days work at its core.

Conclusions

When compared to the benchmark traditional method 37% less onsite labour was achieved; a three week reduction in construction zone cycle time was achieved, but more significant than this is no time slippage occurring during construction to delay or disrupt other trades, and no compression of the commissioning programme occurred as reported in Dicks (2002), with the built facilities being handed over to the customer on time; 7% direct labour reduction was achieved leading to no labour cost escalation as reported in Court et al. (2005); fewer workers were exposed to lower health and safety risks from site operations leading to zero reportable accidents; good ergonomics was achieved by focussing on workplace design thus improving workers' wellbeing; an improved quality of work was achieved for those on site by carrying out simpler assembly tasks; productivity gains were achieved by eliminating process waste, further reducing the risk of labour cost escalation; a significant overall productivity of 116% is achieved using the Construction System which compares favourably to the BSRIA findings of an average overall productivity of only 37% when compared to observed best practice (Hawkins 1997) for the projects in that case study research (this being subject to the degree of caution mentioned above). Indeed, according to the company, the findings from the Construction System on this case study project, given its size and complexity, far exceed the company's expectations for performance improvement.

Further research

The next phase of research will be to continue the validation of the Construction System through implementation and measurement of the results emerging from the final phases of the case study project, this being the Hub, Wards and Diagnostic Treatment Centre, collectively being the largest buildings of the project. Also, a change management methodology is being devised to enable its implementation in these final phases, and further, into the sponsor company's wider organisation. This methodology uses Health and Safety performance as the change driver that the worker commits to through personal choice not just for the sake of it, or because senior management say so.

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