LEANER CONSTRUCTION THROUGH OFF-SITE MANUFACTURING

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ABSTRACT

This paper describes the improvements realised through the application of lean production methods in the off-site manufacturing of integrated mechanical services modules and proposes off-site manufacturing as a step forward in the integration of lean theory into construction. Using the manufacturing case study as a model the techniques implemented and the lessons learned are described and the significant components of process improvement identified. The paper highlights some of the principal failures in current construction practice and argues these form major constraints in the drive for lean project delivery. The final portion of the paper links lean enterprise with lean construction and argues that the definition and realisation of benefit is the only driver for change.

KEYWORDS:

Pre-assembly, off-site manufacturing, benefit, business improvement, kaizen, lean production.

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INTRODUCTION

Lean construction aims to extend the objectives of minimising waste and maximising value advocated within lean production management into the development of specific tools and techniques for lean construction project delivery (Lean Construction Institute[3]). Lean production has made significant improvements within the manufacturing sector and there is a simple argument that increasing the amount of factory based manufacturing of buildings, their components, sections and elements would form one logical method for incorporating lean production into construction project delivery. In principle, this should facilitate some of the year on year improvements in performance called for in the UK by the Egan report[4]. In reality though, the incorporation of off-site manufacturing (more usually called pre-assembly or prefabrication) into the construction process is meeting significant resistance from both Clients and many of their advisors. This resistance was revealed during research undertaken at Loughborough University (COMPREST & IMMPREST) into the use of standardisation and pre-assembly with factors such as inhibition of design creativity, increased capital cost, limited impact on critical path and increased waste through accidental damage/mishandling of units being cited as specific examples.

This research also revealed that although the benefits pre-assembly offered the construction industry had been clearly identified by CIRIA[5] and Gibb (1999) among others, methods for evaluating the benefits were lacking. Therefore it was difficult for consultants to make full evaluative comparisons of traditional versus pre-assembled design options. Current methods of evaluation relied on traditional cost comparisons based on direct resource costs. These evaluations were not able to incorporate issues affecting performance, health & safety (H&S), supervision, set up and logistics, teamwork and the effect of human resource issues, for example. The IMMPREST research project (www.immprest.com) undertaken at Loughborough University is producing an interactive tool to facilitate, firstly the identification of project specific benefits associated with standardisation and pre-assembly and then methods for their evaluation. The research is funded by the EPSRC[6] and DTI[7] under the Innovative Manufacturing Initiative with matching, formal industrial collaboration[8].

The aim of this paper is therefore twofold, firstly to examine the integration of lean production into the pre-assembly of building components and secondly, to demonstrate that the resultant benefit is lost to the wider project delivery as a result of inability to effectively evaluate innovation, using pre-assembly within the specialist Mechanical sector as an example.

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3 www.leanconstruction.org

4 Common name for the Construction Task Force Report 1998

5 Construction Industry Research Information Association, UK

6 EPSRC – Engineering and Physical Sciences Research Council, UK Government funding body.

7 DTI – Department of Trade and Industry, UK Government Department responsible for construction

8 Collaborators: Argent Group plc; Bovis Lend Lease; Britspace Relocatable Building Systems; Colledge Trundle & Hall; Crown House Engineering; Donald Smith Rooley and Seymour; Hotchkiss Ductwork; John Lewis Partnership; Lennox Industries; Schumann Smith; Stanhope plc and Turner & Townsend.

METHOD

The principal research method adopted for the IMMPREST research underpinning this paper is case study supported with multidisciplinary workshops managed by an industrial steering group and with the support of major UK construction companies, consultants, clients and manufacturers. The case studies followed an iterative process and have been undertaken over a twelve month period. Information regarding existing methods for comparative evaluation of options and decision making relating to the use of pre-assembly was collected by observation and interrogation of personnel and by the analysis of project information over many visits.

The specific lean production aspect to this paper has been split out of the wider IMMPREST research project and results from a separate (but related) case study within the manufacturing facility of a major UK specialist Mechanical and Electrical services contractor. This organisation is a major collaborator in the IMMPREST research project and it’s director a co-author of this paper.

GENERAL ADVANTAGES OF PRE-ASSEMBLY

These have been widely identified in the UK by CIRIA[9] and through the IMMPREST research project. These can be briefly summarised under the following headings as:

ON SITE BENEFITS:

- Reduced labour and consequent Health and Safety risk;
- Reduced waste in off-cuts, breakages and other losses;
- Reduced site co-ordination activity;
- Reduced plant, tools and materials storage requirement;
- Reduced installation time with Client control;
- Reduced need for welfare facilities; and
- Reduced complexity.

PROGRAMME BENEFITS:

- Increased up front commitment (from manufacturers and suppliers);
- Increased quality (due to factory quality control systems);
- Increased flexibility (especially if JIT delivery in place);
- Increased efficiency of installation (fewer installation processes);
- Increased reliability of installation (right first time); and
- Increased reliability of delivery (increases in line with proportion of off-site manufacturing)

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[9] CIRIA – Construction Industry Research information Association, UK .

MANUFACTURING BENEFITS:

- Improved working conditions;
- Improved productivity;
- Improved processes;
- Improved control;
- Improved performance;
- Improved cost;
- Improved quality;
- Improved safety records; and
- Improved delivery.

The manufacturing benefits relate to firstly the improvements in the factory environment resulting from lean production and secondly the difference between factory conditions and assembly on a construction site. Many of the benefits listed above will only be realised if construction clients and managers change their approach to project delivery including the way they collect data and measure performance. The challenge is to encourage the changes required and this will only be achieved if all these benefits can be expressly valued and/or scored on a comparative basis. The decision not to use pre-assembly should be based on a true comparative evaluation and not, as so often happens on habit/tradition or first cost criteria.

LEAN PRODUCTION IN PRE-ASSEMBLY – A CASE STUDY

The manufacturing centre at Crown House Engineering, UK principally produces integrated modules for heating, ventilating and air conditioning (HVAC). These include plant rooms and distribution systems and originally were designed as one-off project based items. Over the last ten years analysis of products and processes has lead to the streamlining of product design and production to give year on year improvements. This case study is the story behind that production path and the identification of the lessons learnt.

In the beginning, HVAC projects were pulled through from the traditional specialist contracting (and original) branch of the company. These projects were examined in the manufacturing centre and if they seemed feasible to manufacture (either fully or partially), modules were designed and manufactured. Today, the company uses what it calls "Kaizen, Formula One" (KF1) to achieve spectacular improvements in both processes and products.

IMPROVEMENT EXAMPLE

Over a timescale of 18 months the design and production of an integrated module changed to deliver the following value-adding improvement:

Table 1 : Multi-service Fan Coil Module (original product)

Application	**Labour Hrs**	**Materials £**	**Totals £**
Framework	9.62	91.84	234.22
CHW & LTHW Mechanical Services	35.00	317.60	836.49
Condensate	2.53	15.03	52.47
Electrical Containment	1.10	0.00	16.28
Ventilation Services	4.00	0.00	59.20
GRAND TOTALS	**52.25**	**424.47**	**1,198.66**

Table 2 : Multi-service Fan Coil Module (new product)

Application	**Labour Hrs**	**Materials £**	**Totals £**
Framework	2.92	31.20	74.42
CHW & LTHW Mechanical Services	10.64	313.34	470.81
Condensate	2.43	14.72	50.68
Electrical Containment	1.10	0.00	16.28
Ventilation Services	4.00	0.00	59.20
GRAND TOTALS	**21.09**	**359.26**	**671.39**

The biggest improvement is seen in the reduction of labour required. This is a result of the application of KF1 – observation of the pitstop operation in Formula One racing reveals an impressive application of "workplace organisation" (Suzaki 1987) and waste free process. When the driver arrives in the pit, fuel is supplied and tyres changed concurrently in the minimum time. The process is practiced over and over so that the real thing is flawless (mistake proofing). The equipment used is designed for the purpose and all resources to hand at the moment they are needed. This concept has been applied to good effect in the organisation of not only the assembly workspace at Crown House Engineering but also the assembly process itself to deliver the savings shown in Tables 1 and 2 above. The reduction of time in the process is not the only area of great improvement. Table 3 below reveals the full scope of cost savings which also include changes in product design.

Table 3 : Cost Comparison Savings:

Application	**Original Product**	**New Product**	**Cost Saving**	**%age Difference**
Framework	£234.22	£74.42	£159.80	
CHW & LTHW Mechanical Services	£836.49	£470.81	£365.68	
Condensate	£52.47	£50.68	£1.79	

Electrical Containment	£16.28	£16.28	£0.00	**0%**
Ventilation Services	£59.20	£59.20	£0.00	**0%**
GRAND TOTALS	**£1198.66**	**£671.39**	**£527.27**	**44%**

Brainstorming the module design using function analysis challenged the need for several aspects of the design. The most significant of these being the reduction in size, shape and dimensions of the steel framework as a result of changing the mounting brackets on the fan coil unit, using an innovative lightweight pipe work system and designing purpose made valves.

Whilst the savings made in first cost to the customer are easily seen here, the knock-on effects of this new product are much less obvious. There are benefits beyond first cost that need to be pulled through by the project delivery team. These include:

- The lighter module imposes less load on the building structure;
- The lighter module is easier to handle and transport;
- The module has a lower space requirement within the overall building space utilisation plan; and
- Installation of module requires lower skill level than insitu assembly and testing;

No benefit will be realised by the Client from factors 1 and 3 unless the manufacturer is involved early enough to influence the structural design and the space planning operations. Factors 2 and 4 can only be realised by the construction/project management team and site supervisors ensuring the appropriate workforce is in place.

The first step in the realisation of the benefits offered by pre-assembly is for the industry wide recognition of the success factors that permit off-site manufacturing to be implemented.

STRATEGIC FACTORS FOR THE SUCCESSFUL IMPLEMENTATION OF PRE-ASSEMBLY

Identified from the experiences of Crown House Engineering Manufacturing Centre during their trading in off-site manufacturing for construction projects, these factors have been identified as follows:

- The project must fit into the manufacturing company's strategic framework
- The project Client and delivery team must share a desire for high quality of
- operation, engineering and product
- The project design must be suitable for manufacturing.
- The site management must recognise and be committed to the installation requirements of manufactured modules
- An implementation protocol is required so that all project participants understand the changed processes and how to steer through constraints, avoiding the temptation to run back to "the good old ways" at the first difficulty.
- All project participants must be committed to continuous improvement.

- There must be repeat business to drive year on year improvements in a stable supply chain.
- The biggest opportunity for meeting Client need by pre-assembly is where there is a demand for speed of installation and high quality products.
- Pre-assembly should be a requirement of the specification.
- Pre-assembly works best if it is led by the clients.

These factors influence the success of project delivery but a manufacturing organisation can't afford to wait until they are all in place before driving improvements within their own business. The drive towards lean production, like charity, begins at home.

STEPS TAKEN TO IMPROVE MANUFACTURING PROCESS

Crown House Engineering (CHE) Manufacturing Centre has overhauled all their business processes during their drive for business excellence. In order to implement continuous improvement they have:

- Empowered their workforce advocating bottom-up change. In doing so the company has discarded rigid thinking and adopted a change is good philosophy. Specific actions include:
  - ♦ Suggestions schemes
  - ♦ Operator verification as opposed to supervisor control
  - ♦ Training to become multi-skilled – achieving more by working smarter rather than harder/longer
  - ♦ Visual control – performance measures displayed openly so workforce can judge their own performance and make their own decisions about where they are going. This is an important tool in the drive to get the product right first time and in mistake proofing the process (poka yoke).
- Just in time delivery pulled from the supply chain and made available to customers (though often not used to best advantage by them). This has:
  - ♦ Reduced waste in the process
  - ♦ Reduced inventory and provided inventory control
  - ♦ Facilitated year on year improvements through strategic alliances with preferred suppliers.
  - ♦ Increased trust in supplier relationships for example, specialist finishing equipment not being used is off-hired and re-hired when brought back into use. This is demonstrated to suppliers by moving the item to a specific location in the factory, at first checked in person by the supplier then by digital photograph on demand and now taken on trust. This is a big step in reducing waste in the movement of equipment between organisations and the administrative processes associated with this.
- Total quality control through statistical measures (Statistical Process Control SPC). The tools used include:
  - ♦ Number and percentage charts;
  - ♦ Pareto analysis;
  - ♦ Pie charts;

- Histograms; and
- Ishikawa (cause & effect/fishbone diagrams).

LESSONS LEARNED ALONG THE WAY

The most important lesson is the one that theory keeps on telling us - improvement is not a quick fix; it needs vision and leadership, training and commitment, time and resource. Anything else is lip service to a principle and probably only a shallow marketing ploy.

Significant components of process improvement include

- Kanban, without the communication of what is required and when no advancement is possible;
- Poka Yoke, without mistake proofing reversion to the earlier culture and behaviour is inevitable;
- Visual control, measurement is important but without displaying the performance indicators the workforce is operating in the dark and will consequently stumble about, achieving results more by luck than judgement.
- Operator verification, empower the workforce to **really** control their contribution to the team performance.
- Takt time, remove mutli-layered time contingencies to reduce process waste by using real time planning and drive JIT delivery.

These components must exist concurrently, if one is missing the others will fail.

FAILURE OF PRINCIPAL CONTRACTORS AND CONSTRUCTION CLIENTS TO PULL VALUE THROUGH FROM PRE-ASSEMBLY

There is little understanding within the UK construction industry of the process of putting parts of construction into manufacturing, the benefits that are available from doing so or the real meaning of lean terminology and theory. This is manifested in a number of ways. Firstly, pre-assembly of a part of a building may be quicker than assembly on-site but it still takes time. Whereas the components for insitu installation maybe readily available, pre-assembled items will have a lead in time and this must be built into the construction process from the beginning.

Design consultants have little understanding of the differences in designing for manufacture and assembly (DFMA) from designing for insitu assembly. It is not merely a matter of carving off a piece of the work and saying it can be pre-assembled. Thought needs to be given as to how factory assembly is best undertaken to realise the benefits available. The manufacturing process must not be undertaken as a mini construction project i.e. enclose a space then fit in out. Thought must also be given to the arrival of the pre-assembled item on site, its incorporation into the structure and the effect this has on the rest of the construction work.

To this end, the engineering design role should change significantly and be more focused on product and performance specification as even with the use of sophisticated 3D simulation packages, consultant designers have little or no understanding of DFMA. They should be advising Clients of the end user experiences of the finished products and appropriate product selection based on this end user requirement. In other words, concentrating more on fulfilment of function than design detail such as pipe sizes, bracket positions etc, etc. This detail has to be developed in the manufacturing centre and make greater use of the design expertise within the manufacturer.

Changes in the Client's administration of the payment process would also contribute to driving lean construction. Payment for materials on site encourages waste by providing incentive to stock inventory. Payment for partial completion focuses on starting items rather than competing them.

FAILURE IN PROJECT DELIVERY

There is no doubt there are many opportunities for improvement across the construction industry and this has been well documented. For the UK alone, there has been 10 major Parliamentary reports published in the last 60 years (Flanagan et al. 1998) all calling for similar improvements in construction performance. Frequently literature refers to the integration and co-ordination of specialist trades as a major influence on the success or otherwise of project delivery (Saad and Jones 1998). Miles and Ballard (2002) describe problems in interface and insufficient work structuring as a major failure in lean project delivery. That paper gives a US overview but the paradigm is similar in the UK, the Commonwealth and other countries using the UK construction procurement model. Miles and Ballard (2002) cite conflict in the relationship between the design engineer and the specialist contractor as pivotal in the resolution of integration difficulties. This applies equally for pre-assembled modules and components. It has long been recognised that design needs to be properly undertaken if subsequent production is to be efficient and effective, a theory strongly advocated by Taguchi, to the extent that flaws or errors should result in a shut down of work (offline/online management). That construction permits and even expects flaws and errors and continues production regardless accounts for much of the "firefighting" that is common in construction project management. It is difficult to convince construction participants of the possibility of mistake proofing, indeed it seems the skill of the project manager is judged by their ability to manage problems as they occur rather than by managing them out in advance. This is often blamed on the fragmented nature of the industry preventing early communication and discussion of organisational alignment to the project objectives.

Traditional risk management techniques contribute to the "firefighting" approach by relying almost exclusively on the use of time, money and materials contingency buffers. This demonstrates the acceptance of errors … "it's going to happen anyway so build in enough fat to let it" … building in "fat" in this way is, of course, the exact opposite of lean philosophy.

CHE Manufacturing Centre found empowerment a powerful tool in the move to lean production and improvement. But lack trust in construction is a big barrier identified by many authors (Latham 1994, Miller et al.). The "firefighting" approach to project management fosters a perception that the "lesser" parties (sub-contractors and labour only operators) are not capable of being entrusted with operator verification and consequent responsibility for quality control. Substantial changes across the industry are needed to begin to address these problems and following the CHE experience, visual control would be a significant step forward in aligning the attitudes of the parties involved. In the main, construction sites only display safety records e.g. number of days since last accident (and not always that) - is it any wonder then that operatives do not think beyond that? Why not display others to communicate what the project delivery goals are, what the "team" is working towards? The human contribution is an often overlooked aspect in business improvement (Green 2000, 2002) and a lack of concern for people is a major barrier to successful change.

INTEGRATION OF LEAN ENTERPRISE AND LEAN CONSTRUCTION

CHE Manufacturing Centre is a lean enterprise encompassing all the elements of lean manufacturing within their operating strategy including JIT delivery from their suppliers. As an individual organisation, the manufacturing centre has defined and realised benefit for itself and is able to pass this on to its customers. However, few construction clients are able to pull these benefits through because substantial changes in construction management processes are required in order to embed the lean project delivery advocated by Lean Construction.

Individual organisations across the construction supply chain can all implement lean business processes through tools and techniques such as Kaizen, Kanban, PokaYoke; they can map their value stream and derive individual benefit from doing so. Indeed, if construction project delivery is to become lean, the supply chain organisations must align themselves to lean thinking principles. It is only through this that they can begin to deliver year on year improvements that form a significant part of Total Quality and advocated in the UK by the Egan report. There is general belief that the construction client should drive the move towards an improved industry in the UK. This is at odds with lean theory and the Toyota experience (Womack et al. 1990). In this instance, the lead organisation in the supply side drove the change to lean production. It was not driven by the ultimate customer (the car owner) but by the need to increase competitiveness and market share by meeting value from the customer's perspective. However, construction delivers far fewer final products and may require a greater customer capital investment, therefore the construction client is a much more significant individual than one of several million car buyers. This is a powerful argument for the construction client to drive the move towards lean project delivery but it should not prevent organisations in the supply side from implementing lean processes and continuous improvement. There is a certain inevitability to this change as construction companies already face the need to change quicker and learn faster if they are to remain competitive (Flanagan et al 1998) in other words, it is commercially sensible to become lean and agile.

BENEFIT AS A DRIVER FOR CHANGE

It is difficult to measure the effect of the problems outlined although we intuitively feel the problems are costly e.g. case studies cited by Miles and Ballard (2002), but may be less than this where work is pre-assembled as more time needs to be spent earlier in process – but how much? Construction is a dynamic process and whilst direct effects may be measurable, there are knock-on impacts that also need to be accounted for. If the impact of existing problems is hard to assess, it stands to reason that the value of solving these problems and improving the construction industry across the board will be even more difficult to measure. And yet, without some measure of these factors, there is no real driver to change. Construction does differ from other industries in one respect, it is not exposed to destructive technologies e.g. the impact of IT on the printing industry. Although variances in demand do exist, the basic building model is unvaried – back even to the first caves. This provides great security on the one hand, but is a double edged sword as it is probably also the greatest barrier to change (IMMPREST 2001). If change is not to be driven by crisis, then it must be driven by the realisation of benefit and a market demand for improvement.

Proper evaluation is essential but requires much deeper knowledge of processes and subsequent changes in construction management methods. Unfortunately, competitive tendering often means that tenderers brought into the scheme early (and consequently pricing with full knowledge) are often under cut by competitors who do not have full appreciation of the project. That Clients still appoint on this basis is of great concern as it means a project delivered by organisations who really don't know what they are delivering! They continue to use first cost as the sole measure of benefit and are frequently criticised for doing so. However, all theory states that "value must be specified by the client" – so the industry must come to terms with the need to meet this criterion. The incidence of inventory turns is advocated by Womack and Jones (2001) as a measure of leanness. This is a measure that could be directly applied to off-site manufacturing and warrants investigation as a tool for measuring lean project delivery. However, in the absence of authoritative work in this area, the principal measurable benefits to be achieved from increased off-site manufacturing can be identified as:

- The impact on time
  - reduction of on-site labour, welfare cost, health & safety risk, co-ordination interfaces
  - JIT delivery of components
  - removal of activities from the on-site process
  - reduced opportunities for waste
- The impact on cost
  - improved cost certainty
  - difficult to compare off-site assembly cost with insitu.
- The impact on quality
  - zero defects
  - improved commissioning (factory tested components)
  - increased certainty of quality

Some of these factors are readily measured in numerical terms and some can be given a cost allocation. But the benefits offered are manifested by improved processes and project delivery and influence the performance on the construction industry in a varied and diverse way. As such, these benefits can't be accurately measured individually but can be linked to broader performance indicators such as those advocated by the UK Construction Best Practice Programme[10], following the recommendations of Egan. Other work is being undertaken to investigate the measurement of value and added-value (e.g. Kim and Ballard 2002) but the industry persists in defining value as least cost.

Knowledge is the ultimate outcome of performance measurement and knowledge is the key to improvement. There is resistance to this however as knowledge is seen as the enemy of competition, illustrated by the failure to secure a winning tender if involved in the early design stages. Proper evaluation of drivers and constraints will contribute to changing this paradigm and this is especially relevant for the specialist contractor (Gil et al 2000, Pasquire 1994).

[10] Construction Best Practice Programme, www.cbpp.org.uk

CONCLUSIONS

There are three principal conclusions to this paper:

- That lean manufacturing has a direct application in construction through the pre-assembly of building components and considerable benefits are available as a result of off-site manufacturing;
- That there is a relationship between lean construction and the development of lean enterprise within construction suppliers and sub-contractors; and
- That innovative project delivery systems such as lean construction, lean enterprise and off-site manufacturing will fail to be incorporated if the advantages they offer aren't or can't be properly evaluated.

In the absence of crisis as a driver for change, improvement has to come from a desire to do better. This desire is not generated by criticism of the industry (illustrated by the number of critical reports in the UK) but can be motivated by improved profits and working conditions, reduced risk exposure, empowerment and by the desire to work in a successful and fulfilled industry that operates in a market place that values better service. These factors must be clearly identified as being achievable and the methods for realising them proven. The experience of Crown House Engineering Manufacturing Centre as gone a long way to demonstrating the existence of benefits and some of the methods for achieving them, however there is some way to go before the knowledge and expertise gained is fully transferred into project delivery.

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