APPLICATION OF THE PRINCIPLE OF BATCH SIZE REDUCTION IN CONSTRUCTION

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ABSTRACT

One of the fundamental principles of lean thinking is single piece flow, however mass production remains the prevalent modus operandi in the United Kingdom construction sector that is dominated by sub-contracting. This paper explores how the concept of batch sizing can be used in a construction setting and the effects that reduced batch sizes have on construction programmes. It also examines the practical and cultural issues that arise in reducing batch sizes both at a master planning level and in the tradesman's approach to the work.

The paper explores the direct observations of four construction case studies in which the effect of batch size reduction has been quantified. These observations are then compared with a computer model developed by the authors, founded on the theory of lean and batch sizing. The model assesses the programmed completion time for projects using multiple trades, operating with differing batch sizes and cycle times. The theoretical background to the findings are developed as a result of the observations and compared with the computer model to provide a mathematical expression to identify the relationship between batch size reduction and overall out-turn programme length.

The paper concludes with the implications for the UK construction sector in developing a small batch approach, and provides a methodology for calculating the effects of such an approach on overall project duration.

KEY WORDS

Batch size, lean construction, work in progress (W.I.P.), Single Minute Exchange of Dies (SMED), Line of balance,

Inventory, overproduction, waiting, mass production.

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INTRODUCTION

So far no definition exists for lean production (Dauber, V.F. 2003), however we can agree that the concept of waste elimination as codified by Taiichi Ohnos' seven kinds of waste is fundamental in any discussion of lean production. For this reason we first seek to clarify the relationship between the seven wastes and batch size. We then look at how this relates to the construction industry. The case studies were all carried out in the UK but the principles formed would apply to the industry worldwide.

HOW BATCH SIZE RELATES TO OHNOS' SEVEN WASTES

Overproduction was regarded by Ohno to be the most serious of all wastes. Overproduction is here defined as making more than the "next process" requires and is not limited to creation of excessive finished goods inventory. So if a batch is made that is larger than that which the next process needs to start work and continue steadily, overproduction can be said to be present. If **defects** are discovered in the production of a small batch, say ten pieces, then the economic loss may be minimised. Conversely if a larger batch is made, say a hundred pieces, and there is a quality problem, the potential loss due to rework or scrap will be ten times greater in this example. The waste of **waiting** will occur as a result of overproduction, i.e. if we make more than the next process needs to start, the next process will have to "wait", or the work will have to wait for the next process. This problem may be compounded if we discover a defect in our large batch. Then we will have to wait at least twice as long as before. **Inventory** waste can occur in three phases of production. Raw materials, work in progress and finished goods. Large batch sizes have a negative impact on all three. Also large amounts of inventory at any stage will lead to transport and storage problems and at the work in progress stage particularly will be capable of making any defective work less visible. Can **transport** waste be caused by large batch sizes? The answer is definitely yes if the batch is defective in any way. It could also be argued that large batches in fact reduce the waste of transport when we are just looking at moving inventory of one form or another. However, if we also consider the amount of walking by operatives we can create a strong link between transport waste and batch sizes.

Above we have shown how 5 of Ohnos' 7 wastes are either caused or exacerbated by using large batch sizes. Here "large" is defined as making more than the next process needs to proceed.

'MASS PRODUCTION' BATCH SIZING UK CONSTRUCTION

Single piece flow is a widely accepted concept within many industry sectors however it is virtually unheard of in the UK construction market. Generally the sector works to large batch sizes in an attempt to ensure continuity of the same activity for as long as possible. The following two scenarios demonstrate the existence o f the commonly held belief that working to batch sizes of entire floors or even sites will provide the shortest programme. The scenarios were directly observed by the authors between the period 2003 to 2007.

CASE STUDY 1. A 40 BEDROOM TIMBER FRAME HOTEL

In 2003, direct observation of work was carried out on the fit out of a new build timber framed hotel in South West England. Direct observation was undertaken of the internal fit out stage of the project. Data was collected for all processes from the beginning of fixing plasterboard to the final cleaning of a sample room. The actual clock time in days, hours and minutes was recorded so that a good estimate of the amount of "waiting" could be established.

The purpose of the study was to explore the potential to deploy lean construction methodologies to future projects. Whilst many practical ideas were captured and later deployed, it became apparent that the biggest opportunity for improvement would be gained by the reduction of batch sizes that would vastly reduce the waste of "waiting". The batch size that was naturally worked to by the trades was 20 rooms at a time, which constituted 1 floor of the building. This adoption of a floor as a batch size is common and has been experienced on a number of projects outside of those examined in this paper.

The direct observation of the recorded room identified that the whole of the recorded process took 50 working days, with the observed value adding time being 5.2 days. For the purpose of this study value was said to take place if an operative was actually working in the room unless the purpose of the work was to remedy defects and a day constituted 8 hours. It is accepted here that it is probable that only a small proportion of this work would meet the classic definition of value in a lean thinking context. In total there were almost 45 working days where work was available in the sample room but none took place.

The obvious prime cause of the nearly 45 days "waiting" was the fact that all trades were working to a 20 room batch size or a whole floor. The key or "critical path" trades of plasterboard, dry lining, carpentry and painting would not start any work until the whole floor was completed by the preceding trade. They then proceeded to work through the rooms one by one on each of their own sub-processes. For example the carpenter would first hang every door on the whole floor, then all the architrave, then all the skirting, then all the ironmongery and finally fit the doorstops. The painter would not begin until all the doorstops were fitted and then proceeded to apply 1st coat emulsion to every room.

BARRIERS TO SMALL BATCH SIZING WITHIN THE UK CONSTRUCTION SECTOR

One of the fundamental concepts of lean thinking is "Flow". This is explained by Prof. Dan Jones of the Lean Enterprise Academy, *"The Key Building Block is the end-to-end process for making and delivering families of products that share comparable demand characteristics and follow a similar process routing. The Objective is to optimise the end-to end product flow, not to optimise the utilisation of each of the assets involved."*

In a construction context, the "assets involved" are in many cases, sub contractors, or indeed individual operatives within sub contract companies. It has been highlighted in the case study scenarios that there is a natural tendency for tradesmen to work to much larger than optimal batch sizes. Some of the underlying causes are discussed and challenged below.

To start to understand this situation we must look back at the evolution of the UK construction industry as a whole. A number of significant trends have occurred over time that have contributed to the current culture of the industry. Some, but not all, are here mentioned and will expose some of the barriers to improvement. A useful overview can be found in Ralph Morton's book "Construction UK".

- *The emergence of specialist trades*; Increased complexity and piecework have led to more and more specialist trades, which has in turn increased the likelihood of focus on local optimisation.
- *Piece work*; Local optimisation of assets is encouraged by piece work. For example, if we pay x pounds per square metre for plasterboard it will motivate the tradesman to fix as many full sheets as possible. The actions required to finish the process such as window and door reveals will be left until the end and in many cases not done at all until driven by the main contractor. This results in subsequent delay to follow on trades. (A simple remedy to this problem is to pay by finished area rather than by piece.)
- *Competitive Tendering*; Competitive tendering is not necessarily good or bad, however from a lean thinking perspective it is detrimental if it focuses on local optimisation of assets. In one observation a quantity surveyor refused to pay an extra £1000 to a particular trade to enable them to slow down as individuals but facilitate flow for the project as a whole, even though this action was necessary in order to reduce overall project lead time by four weeks equivalent to 25% of the overall programme duration.
- *Variation in demand and taxation*; Variation in demand for construction and taxation policy encouraged a mass exodus from direct employment in the UK in the 1970s'. Boom & bust economy does not support a stable labour force and how can a main contractor employ tradesmen when this month he needs a hundred men and next month none? Loopholes in the taxation system at the time meant that a typical tradesman could earn significantly more if self-employed. The UK construction industry has experienced a period of relative stability in the last decade and there is a growing popularity of longer term "Framework Agreements". These factors may reverse the trend away from direct labour however we are not currently seeing a mass return. It is the authors' opinion that many contractors spend more time and effort on managing "risk" and contractual issues than in the execution of the work itself and a return to direct labour may reduce this expense.
- *Self employment*; It can be assumed that in most cases there will be less motivation to consider the overall successful outcome of a project as a whole if the tradesman or consultant is self employed. As long as "their part" is delivered according to the contract little thought may be given to follow on trades or tasks.

It is contended that sub contracting, self-employment, piecework and specialisation encourage multi-tasking (multi-tasking is here defined as doing the same thing in more than one physical location), encourage large batch sizes and exacerbate planning and production control problems. We need to more seriously consider the benefits of direct employment and multi-skilling if we are to achieve "flow" in the construction industry.

The reason for the adoption of large batch sizes is exactly the same as witnessed in a manufacturing environment. i.e. a reluctance to "change over" from one process to another because of fear of working inefficiently. It is of course counter intuitive to accept that it is more efficient to work on one item at a time rather than a big batch. Our carpenter above knows the most efficient way to hang doors is by assembling the correct tools and materials and then doing all that can possibly be done with these before moving to the next process, in this case, architraves. In this way he will minimise the downtime experienced by a change of tools.

In manufacturing the answer came in the form of Shingo's Single Minute Exchange of Dies (SMED). Compared with manufacturing most changeovers in construction can be accomplished relatively quickly. A change of tool set for a carpenter may only take minutes, in some manufacturing processes a changeover can take days or even weeks. A bigger barrier is overcoming the mindset and mass production "common sense" that exists in many industry sectors, not least of which construction.

ABOUT CUSTOMER SATISFACTION AND THE "NEXT" CUSTOMER.

In the "Common Approach" to continuous improvement, as taught by The Construction Lean Improvement Programme (CLIP), a basic philosophy of achieving customer satisfaction is stressed. In addition, awareness is sought that in any process there exist different kinds of customer and that ALL must be satisfied in order to achieve success.

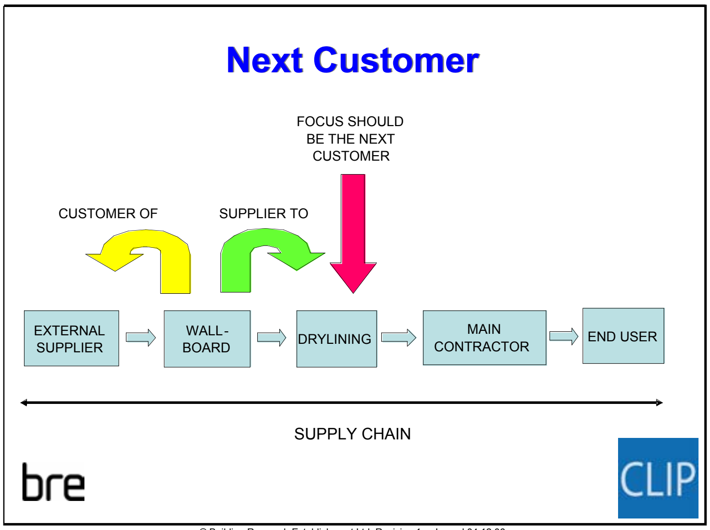

Fig.2: The Principle of the Next Customer

In any process it can be said that there are at least four kinds of customer. In the above example if we are the wall-boarder then the other customers would be the **"Supplier"** (immediately preceding process step or supplier of materials), the **"Next Customer".** (next step in the process- in this case dry-lining), the **"Cash Customer"** (Whoever is paying for the work- in this case the main contractor) and the **"End User".**

Whilst the concept of lean thinking correctly insists that we must begin by understanding value through the eyes of the end user, in order for the production process to actually achieve this pre-determined value we must focus on the "NEXT" customer or step in the process. This is also the essence of systems thinking according to Deming, but first noted in the early 1900's when Thomas Bata ran his extremely successful business on the principle, "the next man in line is the customer" (Tribus, M. 2004).

PREDICTING AND QUANTIFYING THE BENEFITS OF BATCH SIZE REDUCTION BY COMPUTER MODELLING.

One of the significant barriers to implementing batch size reduction is the inability of main and subcontractors to immediately see the impact of changes in programme and ultimately financial terms. There exists a significant cultural problem in construction whereby the focus of any given subcontractor is firmly fixed on the "Cash" Customer. In order to succeed in this environment a new level of awareness is needed, where individuals cease to regard themselves as painters, engineers, electricians, plumbers or carpenters but as hotel builders, school builders, hospital builders etc.

Successful application of lean principles will actually benefit all concerned financially. By reducing batch sizes and so improving flow sub-contractors will actually need to spend less time on site and so reduce costs and improve their utilisation rate. Companies that employ direct labour will have in the future more opportunity to secure competitive advantage by moving away from specialist tasks and utilising multi skilled tradesmen to deploy lean construction practices with less co-ordination problems than their fully sub-contracting competitors. Given that we have this proved principle to work from, the authors set out to produce a tool that could quickly quantify the benefits in time reduction and hence financial benefit, as a result of reducing batch size. The authors wanted to visually indicate waiting time within the construction programme.

It is possible to produce a hand calculation to identify the programme duration for any number of rooms, activities an batch sizes however it is time consuming with any subsequent changes requiring a the reworking of the calculations. The use of a computer model significantly speeds the process and allows the user to experiment with batch sizing to affect programme duration. The model developed by the authors requires the batch size, cycle time for each activity and the available resource (number of gangs) working concurrently to be inputted for each of the critical activities. Once inputted, the programme duration is calculated and a graphical representation of the programme produced. This graphical representation allows the user to identify when rooms are 'waiting' for following trades and those activities that are under-resourced.

OBSERVED AND MODELLED OUTCOMES RESULTING FROM BATCH SIZE REDUCTION

CASE STUDY 1. A 40 BEDROOM TIMBER FRAME HOTEL - RESULTS

The original programme of works showed that the proposed 'standard method of working' produced a completion time for the fit out trades of 12 weeks working days. The original cycle time and batch size of 20 was inputted into the author's computer model, and this calculated a completion at the end of day 58, comparable with the 60 days in the actual scenario.

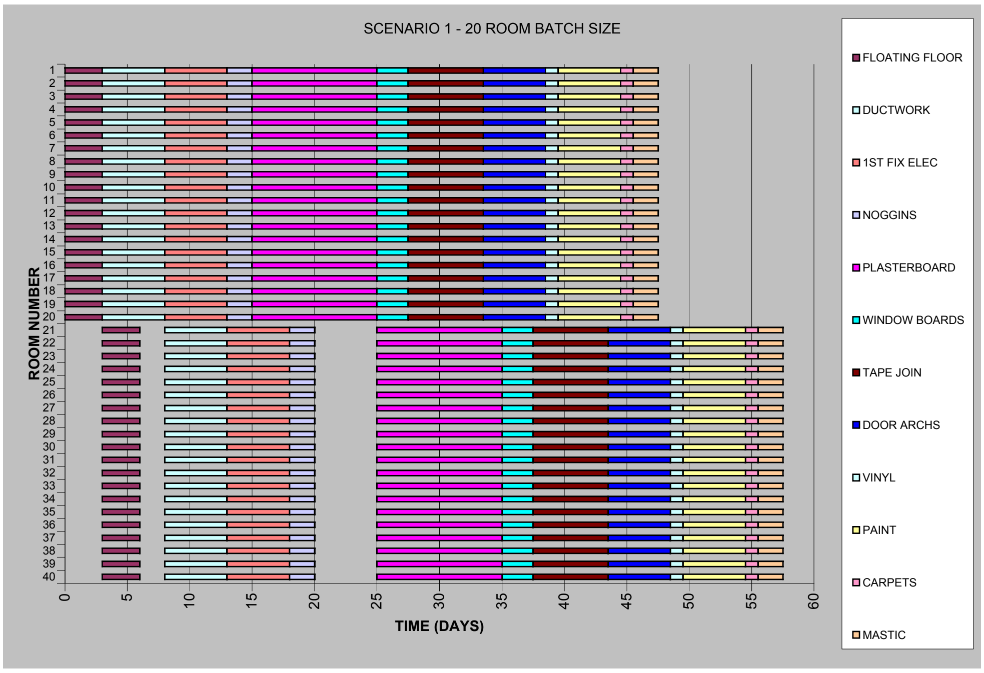

Fig.3: 20-room batch size model output showing completion after 58 days

Large batch Size and its links to the 7 wastes.

We can easily perceive in the case study the "**waste of waiting**" caused by working to a large batch size. We can also assume that "**overproduction**" is present if it can be proved that the trades did in fact not really need all 20 rooms available before starting work on the first room. It is noted that in this case study all the architraves had to be replaced to a whole floor because the wrong type was used. During, and at the end of the finishes process it was recorded that almost identical defects occurred in all rooms. If a smaller batch had been completed early and then checked it is likely that the repeat defects would have been avoided or significantly reduced. Therefore we can argue that the large batch size contributed significantly to the "**waste of defects**".

It is suggested here that the observed large batch size also fits the description of "work in progress **inventory**". The "**waste of excessive transport"** can be attributed to this example of batch sizes in the form of operatives walking from room to room numerous times. In the most severe case (dry-lining), the operative walked repeatedly from room to room carrying out eight operations totalling approximately 80m for each operation.

Proposed batch size reduction

An assessment of overall loss of productivity was made by taking the sum of operative man hours involved in the observed sample room from site diaries and subtracting the "value added time" recorded and a conservative adjustment for communal areas was made based on floor area. A workshop was held with the sub-contractors and, with the benefit of the above data, it was possible to convince the main contractor and key suppliers to trial using small batches. The majority of the trades agreed to a reduction to a 4-room batch size with the exception the plasterboard and associated tape and joint activities who would only work to a batch size of 5 and 10 respectively. The two short cycle time activities of carpeting and vinyl were kept to the original batch size as all 20 rooms as they could each be completed in a day.

An analysis of the data and trade sequence revealed if the batch size could be reduced to those agreed at the workshop, then the overall programme fit out time of 12 weeks would be reduced to 6 weeks with no increase in resource. Again the agreed cycle times and batch sizes were inputted into the model which calculated completion at the end of day 28.

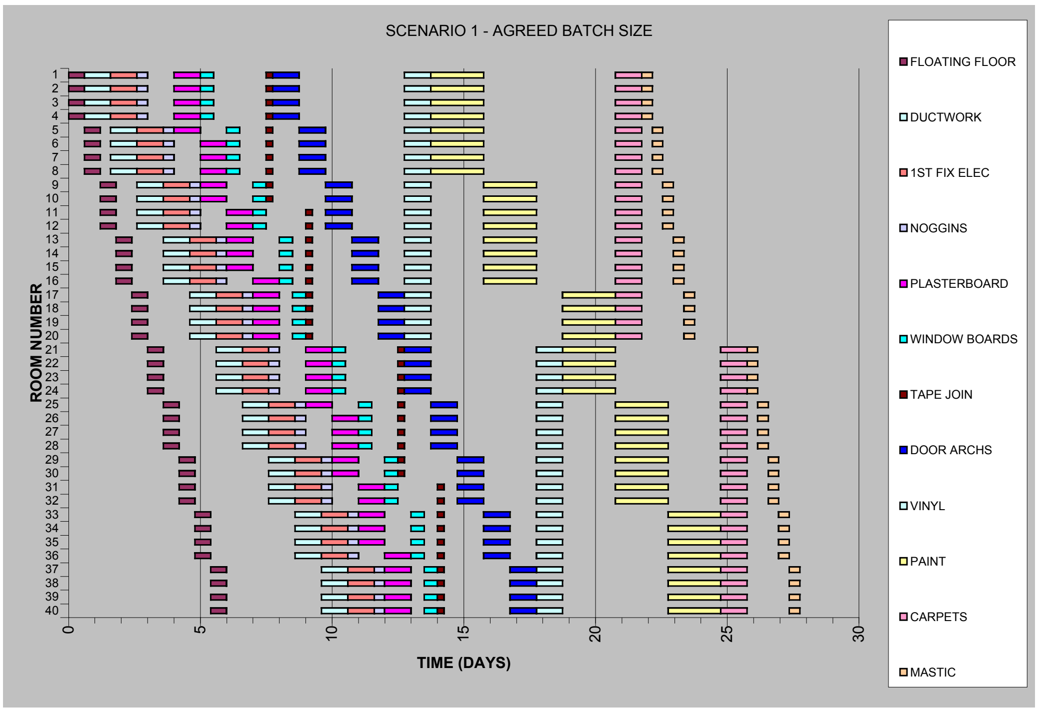

Fig.4: Agreed room batch size model output showing completion after 28 days

The model output identifies further inefficiencies in the agreed scenario primarily in the latter half of the programme due to the large 20-room batch size of the vinyl trade. Gaps between trades in any one room are indicative of that room 'standing idle'. The vinyl flooring occurring on days 13 and 18 clearly are disrupting the flow of work despite the short cycle time of 1 day for all 20 rooms. In each 20-room batch, 15 rooms could have been progressed earlier, some as much as 7 days sooner, had the vinyl layer been able to reduce his batch size in line with the other trades.

The second area of inefficiency is due to the mis-match in batch sizing, what we have called poor 'batch synchronization'. Batch synchronization is the concept of matching batch sizes to multiples of the smallest trade batch e.g. if the smallest batch size is 4 rooms the other trades should be 'synchronized' with allowable batch sizes of 4, 8, 12 etc. The effects of this synchronization allow the project to progress with a regular drumbeat providing better continuity between the trades. In our scenario had the minimum batch size been reduced to 5 rooms instead of 4, and maintaining the same batch sizes for plasterboard, vinyl and carpets we actually would have seen a further 2 days reduction in programme time to 26 days as demonstrated in the figure below.

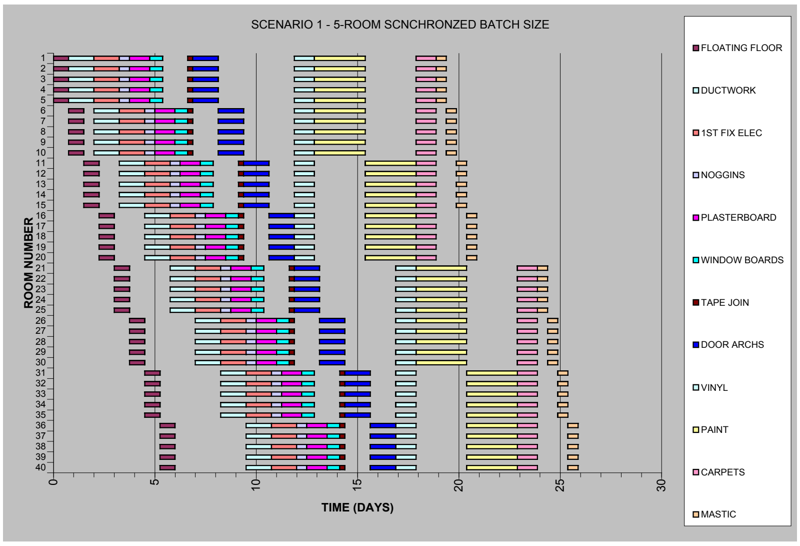

Fig.5: Synchronized 5-room batch size model output showing completion after 26 days

The model calculates an overall programme duration of 18 days is achievable, a reduction from the original duration of over 70%, with a synchronized and agreed maximum batch size of 5 rooms.

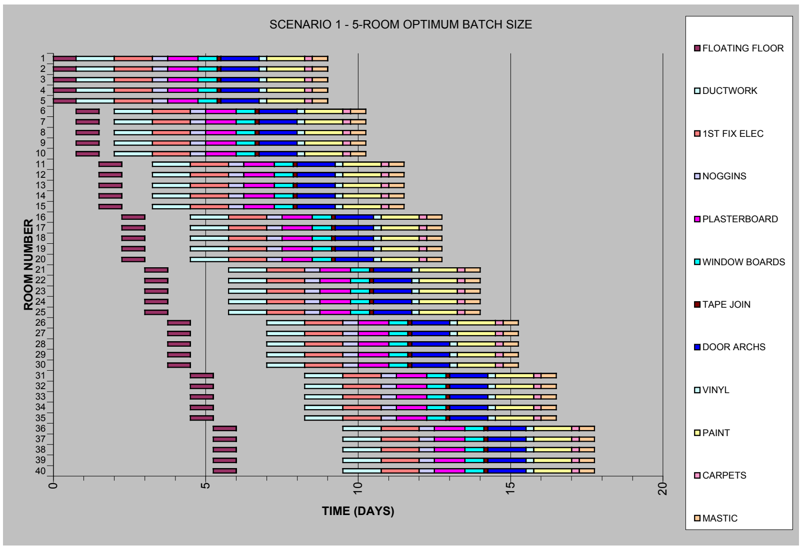

Fig.6: Synchronized 5-room batch size model output showing completion after 18 days

Observed Results and suggested approach to batch reduction

In summary, a 6-week programme reduction was targeted, equating to an overall project programme reduction of 30% (equating to a 50% reduction of the fit-out programme). Due to a number of unforeseen circumstances outside of the control of the construction team and difficulties in implementation due to the level of maturity of the supply chain an overall programme reduction 15% was achieved. Subsequent experience empirically gained on many other projects and companies during interventions undertaken have shown that it can be folly to attempt the optimum batch size at the first attempt.

As stated previously we can regard large batches as work in progress (WIP) inventory, however we saw in the case study above overambitious reductions in batch sizing often do not yield the predicted savings. High inventory levels, often known as the "sea of inventory" act as a buffer against and hide many other problems. Thus when we lower the "sea" or reduce WIP inventory we can expect to run into problems related to planning, co-ordination, lack of training, quality etc. We believe, therefore, that it is folly to immediately try to work to an optimum batch size with an inexperienced supply chain, indeed the "sea" must be lowered gradually if we are not to fall foul of the "rocks". The target programme reduction of 30% was not achieved due in part to the rocks of planning, training and communication. For this reason it is our recommendation that anyone attempting to employ this principle should, as proved heuristically, start by ascertaining what batch size would naturally be worked to with no intervention, and then half it. This will stand a reasonable chance of success. If the benefit of a stable supply chain exists it will then be possible to make further gains by incremental reduction until the optimum can be reached.

A MATHEMATICAL EXPRESSION FOR PREDICTING THE EFFECTS OF HALVING BATCH SIZE

Given the authors assertion that halving the natural batch size is a sensible approach to achievable programme reduction we have produced a simple savings curve that can be used for estimating this saving.

The methodology is based on calculating a "Batch Ratio" which when applied to a saving curve yields the estimated percentage reduction to the programme where;

Batch Ratio = Number of critical activities x (current batch size / max batch size)

In our scenario there were 13 critical trade activities and our batch ratios were as follows:

Batch ratio 20 rooms = 13 activities x (20 room / 40 room) = 6.5

Batch ratio 10 rooms = 13 activities x (10 room / 40 room) = 3.3

It should be noted that the savings profile reduces in accuracy as the batch ratio tends towards zero however, as the majority of sites will never reach this level of single piece flow the profile is deemed sufficiently accurate for an initial estimation. A more detailed analysis would always be recommended via the computer model.

Once the batch ration has been calculated this is used to identify the percentage saving from the graph below.

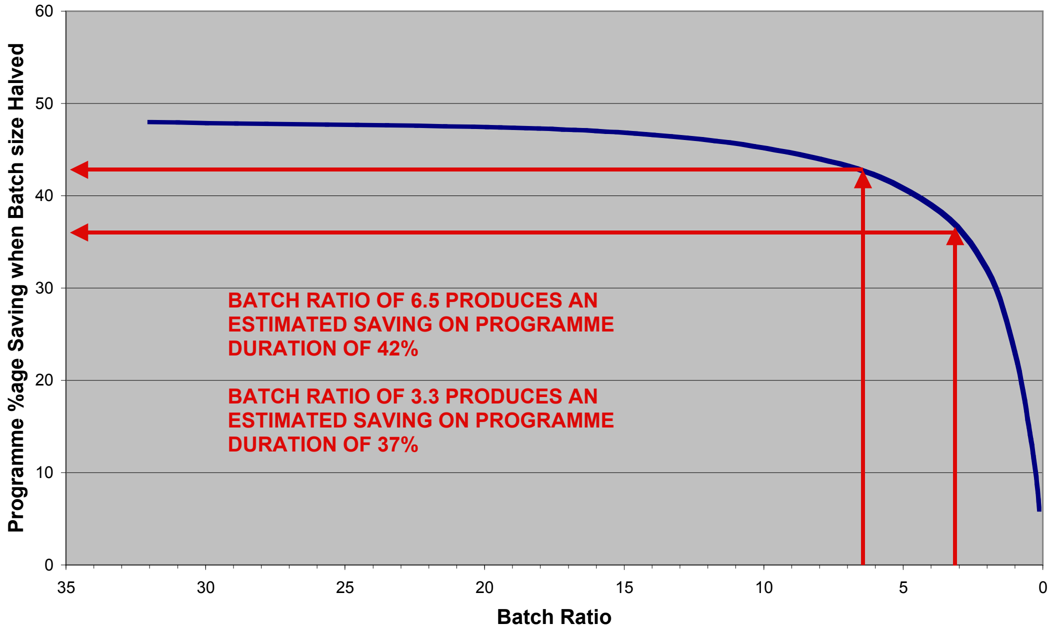

Figure 7: Savings profile for Halving Batch Size

Returning to case study 1 the savings profile graph identifies a saving of 42% (25 days) when the batch size is reduced from 20 rooms to 10 rooms followed by a further 37% (13 days) when reduced to a 5-room batch size. The result is a predicted programme duration of 22 days for a 5-room batch, a reasonable estimate against the agreed reduced batch size programme of 28 days and the synchronized programme indicating a duration of 26 days.

CASE STUDY 2. A NON- REPEATABLE NEW BUILD SUPERMARKET

A common negative response to the suggestion that we should reduce batch size in construction comes when the building in question does not consist of a number of similar small spaces such as offices, hotel bedrooms, school classrooms or hospital wards. The suggestion is therefore felt by many to be non-applicable. In this example the principle of batch size reduction was required to re-programme the erection and fit out of a supermarket in order to recover a 9 week delay that been caused by the discovery of antiquities on the site.

In order to minimise the impact of the 9 week delay caused by the discovery of antiquities two workshops were held for the whole supply chain, including consultants and designers, one each for shell and fit-out. The subcontractors were introduced to the concept of lean thinking with a specific emphasis on batch size reduction. The programme was then revisited and a new sequence formed collaboratively based on working to the smallest possible batch for each trade. (note: in practice in a sub contract environment this means the smallest batch that any supplier will actually agree to).

Because of large internal spaces (sales floor), a zoning approach was taken, the large space (batch), was cut into four virtual spaces or zones. In this way, the trades could complete a smaller amount of work and hand over to the next trade sooner than possible with the old programme. The same principle was employed for piling, ground beams, steel superstructure and roofing.

The overall impact of the batch size reduction produced a saving of 9 weeks, equivalent to overall reduction of 16% on the original programme. This short case study demonstrates that although it is easier to demonstrate the benefits of batch reduction where the project has a large element of repeatability, as in case study one, it is possible to achieve substantial savings on single large space projects.

CONCLUSIONS

The concept of batch reduction is not well understood within the UK construction sector and many sites run on very large batch sizes of building floors or even whole sites. The fragmentation of the labour force in the UK in the 1970's lead to large number of small sub-contractors working often to their own agenda with limited control by the main contractor. The case studies in this paper has shown that, where an enlightened supply chain exists, significant savings can be made to the overall programme duration by reducing batch sizes.

One of the difficulties in achieving reduced programme durations through batch size reduction is in demonstrating the potential at the start of any particular project. It is for this reason that the authors have produced a computer model that calculates accurately and quickly the effects of any alterations to batch sizes. The batch reduction savings profile can also be used as a first estimate to calculate the effects of halving batch sizes.

In order to achieve the savings indicated by the computer models other aspects of lean thinking must be introduced including the principles of the next customer, flow and value. If these can be successfully implemented there are significant advantages to be gained by both main contractor and sub-contracting organizations. In order to succeed a new level of awareness is needed, where individuals cease to regard themselves individual tradesmen but part of the project delivery team. It is also noted here that some of the aforementioned barriers are now slowly rescinding and the market is ready for those companies that adopt the approach of batch size reduction.

In concluding, the authors would also like to thank The Construction Lean Improvement Programme and Construct Wales for input into this paper and opportunity for research.

REFERENCES

Tribus, M. (2004) Section II p.5. "Quality Management according to the Teachings of W. Edwards Deming" NAE Pensacola Florida

Dauber, V.F. (2003). "Measuring and Minimising Waste in Construction by Applying Lean Thinking" Ph.D. Thesis Univ. of Dundee.

Morton, R. (2002). "Construction UK - Introduction to the Industry" Blackwell Publishing.