APPLICATION OF THE PRINCIPLE OF BATCH SIZE REDUCTION IN CONSTRUCTION

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ABSTRACT

Dominated by sub-contracting, mass production remains the prevalent modus operandi in the UK construction sector; this is contrary to single piece flow, a fundamental principle of lean thinking. The concept of batch sizing in a construction setting is explored together with the effects that reduced batch sizes have on construction programmes. Also examined are the practical and cultural issues that arise in reducing batch sizes both at master planning level and in the tradesman's approach to the work.

The effect of batch size reduction is quantified in two construction case studies. The observations of case study one are 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 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 implications for the construction sector in developing a small batch approach are discussed, and a methodology provided for calculating the effects of such an approach on overall project duration.

KEY WORDS

Batch size, lean, construction.

INTRODUCTION

Single piece flow is an accepted lean concept; however it is uncommon in UK construction. Generally the sector works to large batch sizes in an attempt to ensure continuity of the same activity for as long as possible. Two case studies are used to demonstrate the existence of and refute the belief that working to batch sizes of entire floors or even sites will provide the shortest programme. The case studies were directly observed by the authors from 2003 to 2005. It is established how computer modelling can assist in visualising the benefits of batch size reduction as well as indicating potential optimisation techniques. As a conclusion, a methodology is suggested for halving batch size and estimating the impact this would have on programme duration.

The case studies were all carried out in the UK but the principles formed are likely to apply to the industry worldwide.

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WHY IS BATCH SIZING CRITICAL FOR CONSTRUCTORS?

Application of the principle and understanding of the practical deployment considerations of batch size reduction will allow constructors to deliver projects faster, cheaper and with less rework and defects than possible with large batch construction, thereby providing a means of competitive advantage.

Batch size and waste

So far no definition exists for lean production (Dauber, 2003). However it is accepted that the concept of waste elimination as codified by Taiichi Ohno as seven kinds of waste is fundamental in any discussion of lean production. The relationship between these wastes and batch size are clarified as follows:

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 larger than the next process needs to start work and continue steadily, overproduction is said to be present. If **defects** are discovered in a small batch, say ten pieces, then the economic loss may be minimised. Conversely if a larger batch is made, say a hundred pieces, 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 more product than the next process needs to start is made, the next process will have to "wait". This problem may be compounded if a defect in a large batch is discovered. **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. Large amounts of inventory at any stage will lead to transport and storage problems and at the work in progress stage particularly will make any defective work less visible. Can **transport** waste be caused by large batch sizes? The answer is definitely yes if the batch is defective. It could also be argued that large batches in fact reduce the waste of transport when just looking at moving inventory. However, if the amount of walking by operatives is also considered, a strong link between transport waste and batch sizes can be confirmed.

Above it is shown how 5 of the classic 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.

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 Objective is to optimise the end-to end product flow,* ***not to optimise the utilisation of each of the assets involved****."*(Jones, 2001)

In construction, the "assets involved" are in many cases, sub contractors, or indeed individual self-employed operatives within sub contract companies. It has been highlighted in the case studies that there is a natural tendency for tradesmen to work to much larger than optimal batch sizes.

To understand this situation it is helpful to consider the evolution of the UK construction industry. A number of significant trends have occurred over time that have contributed to the current culture of the industry and encourage large batch working. Space does not permit a discussion here but a useful overview can be found in Ralph Morton's book "Construction UK". (Morton, 2002)

One reason for the use 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 for fear of working inefficiently. (McIntosh et al 2001) It is of course counterintuitive to accept that it is more efficient to work on one item at a time rather than a big batch. A carpenter 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, architraves. In this way he will minimise the downtime experienced by a change of tools. This behaviour was observed repeatedly in case study one. (Below)

In manufacturing the answer came in the form of Shingo's Single Minute Exchange of Dies (Shingo, 1985). Compared with manufacturing most changeovers in construction can be achieved 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. It would appear that a bigger barrier is in overcoming the mindset and mass production "common sense" that exists in many industry sectors, not least of which construction.

Another barrier to implementing batch size reduction is the inability of main contractors to immediately see the impact of changes in programme and ultimately financial terms. There also exists a cultural problem whereby the focus of any given subcontractor is naturally fixed on the "Cash" Customer. The authors opinion is that 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. and so begin to focus on "the NEXT customer".

CUSTOMERS AND BATCH SIZES

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. (CLIP 2003).

Whilst the concept of lean thinking insists that the starting point is understanding value through the eyes of the end user, in order for the production process to effectively achieve this pre-determined value the focus must be on the "NEXT" customer or step in the process. This is also the essence of systems thinking according to Deming, (Deming, 1994) but first noted in the early 1900's when Thomas Bata ran his business on the principle, "the next man in line is the customer" (Tribus, 2004), as it is shown in Figure 1.

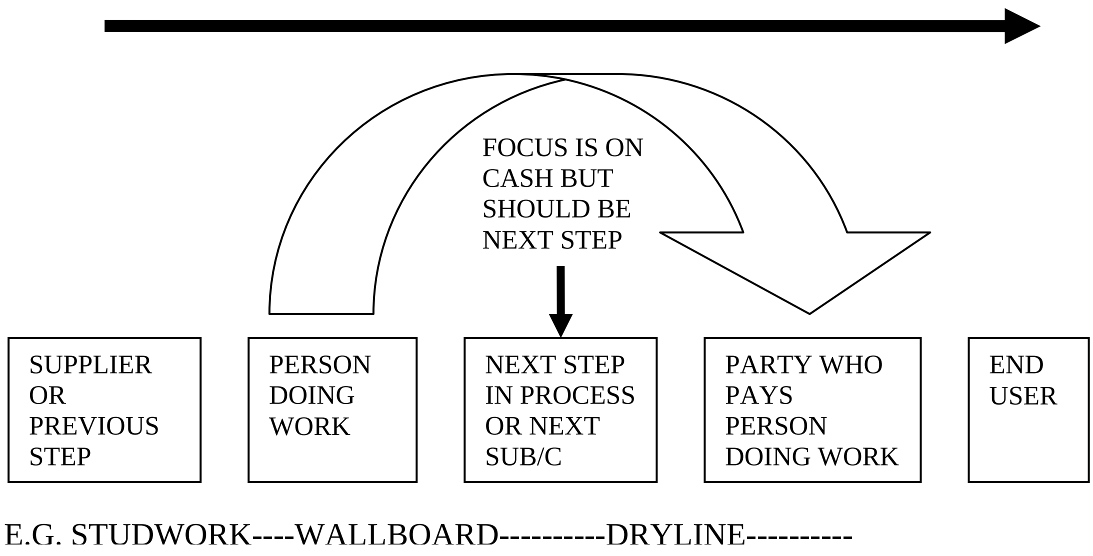

Fig.1: The Principle of the Next Customer

WHO IS THE CUSTOMER?

In any process it can be said that there are at least four kinds of customer from the perspective of the party or person carrying out the work. (Considered above as wall-board.) The customers would be the **"Supplier"** (who in process terms is the "customer" of the wall-boarder's information), 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"** (in this case the client).

Focussing on the "next" customer instead of the "cash customer" encourages reduced batch sizes and improves flow, sub-contractors will need to spend less time on site and hence reduce costs. Given this 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, wishing to visually indicate waiting time within a construction programme.

CASE STUDIES

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 Bridgewater England. Data were 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 objective of the study was to explore the potential to deploy lean construction methods to future projects. Whilst many practical ideas were captured, it became apparent that the biggest opportunity for improvement would be gained by the reduction of batch sizes that would reduce the waste of "waiting". The batch size that the trades expected 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 here.

The observation 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 the 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 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. 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.

Case Study 1. A 40 Bedroom Timber Frame Hotel Bridgewater - Results

The original programme of works showed that the proposed 'standard method of working' produced a completion time for the fit out trades of 60 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 that in the actual scenario and shown in figure 2.

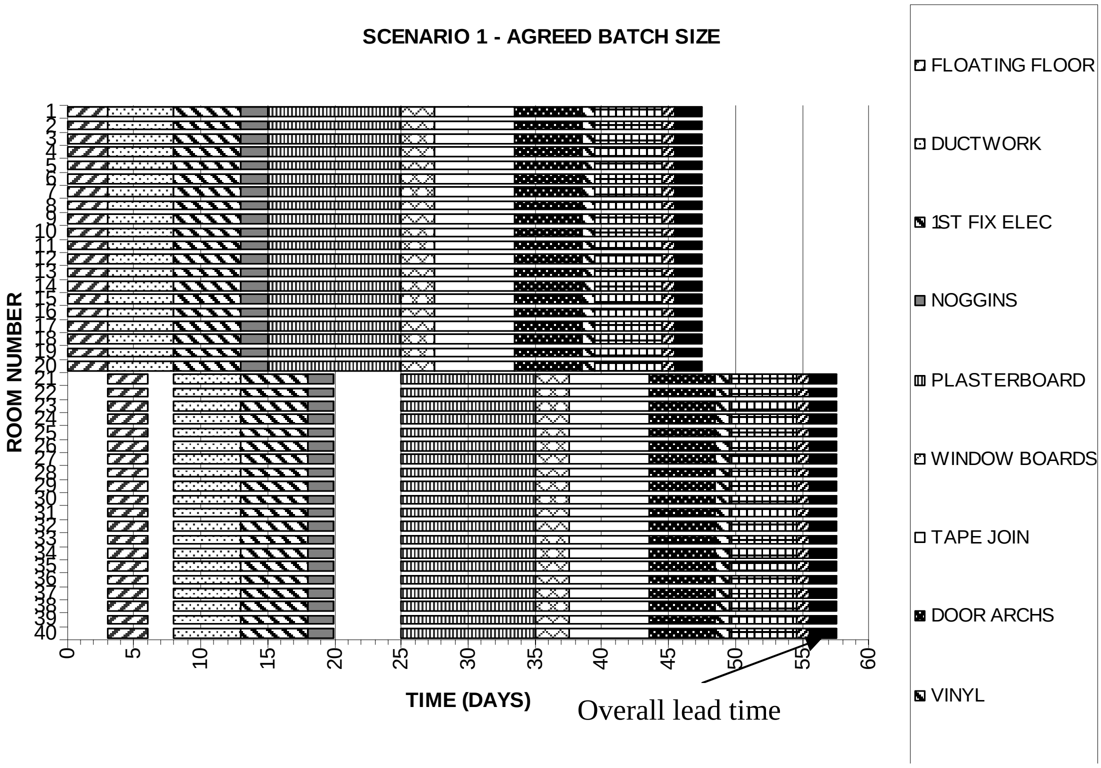

Fig.2: 20-room batch size model output showing completion after 58 days

Proposed batch size reduction

An assessment of 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. A conservative adjustment for communal areas was then 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 them to trial using small batches. The majority of the trades agreed to a reduced 4-room batch with the exception of 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 of 20 rooms as they could each be completed in a day.

Analysis of the data and trade sequence revealed that if the batch size could be reduced to those agreed at the workshop, the fit out time of 60 days would reduce to 30 days with no increase in resource. The agreed cycle times and batch sizes were inputted into the model which calculated completion at the end of day 28, as shown in figure 3.

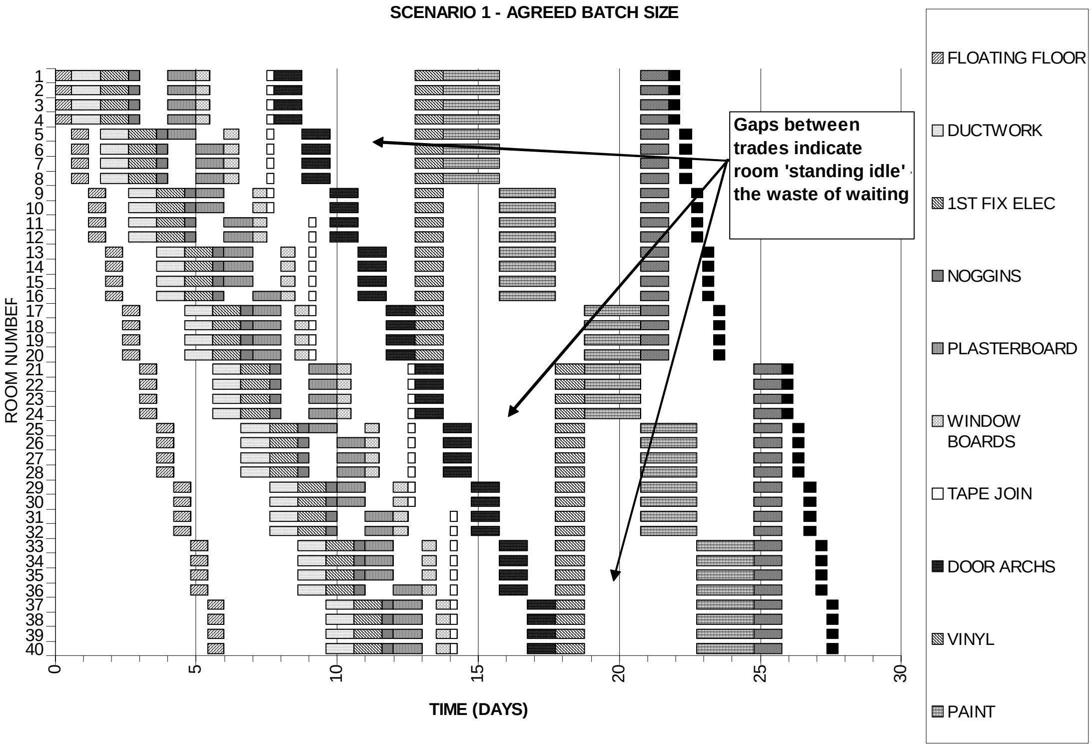

Fig.3: Agreed room batch size model output showing completion after 28 days

DISCUSSION: LARGE BATCH SIZE AND ITS LINKS TO THE 7 WASTES.

The case study identifies the "**waste of waiting**" caused by working to a large batch size, and, through its reduction compressed the programme from 60 days to 30 days. Figure 3 identifies further inefficiencies in the agreed scenario primarily in the latter half of the programme due to the 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 align batch size with the other trades. In effect this is the waste of "**overproduction**" as the vinyl trade released 20 rooms, only 8 of which were required immediately by the following painting trade.

During the case study all the architraves had to be replaced to a whole floor because the wrong type of profile 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 it can be argued that the large batch size contributed significantly to the "**waste of defects**".

It is suggested here that the observed large batch also fits the description of "work in progress **inventory**". The "**waste of excessive transport"** can be attributed to 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.

BATCH SYNCHRONIZATION

The second area of inefficiency that is only visible from the computer output is due to miss-matched batch sizing, which can be considered poor 'batch synchronization'. This 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 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, with the same batch sizes maintained for plasterboard, vinyl and carpets, a further 2 days reduction in time to 26 days would be realized as shown in the figure below.

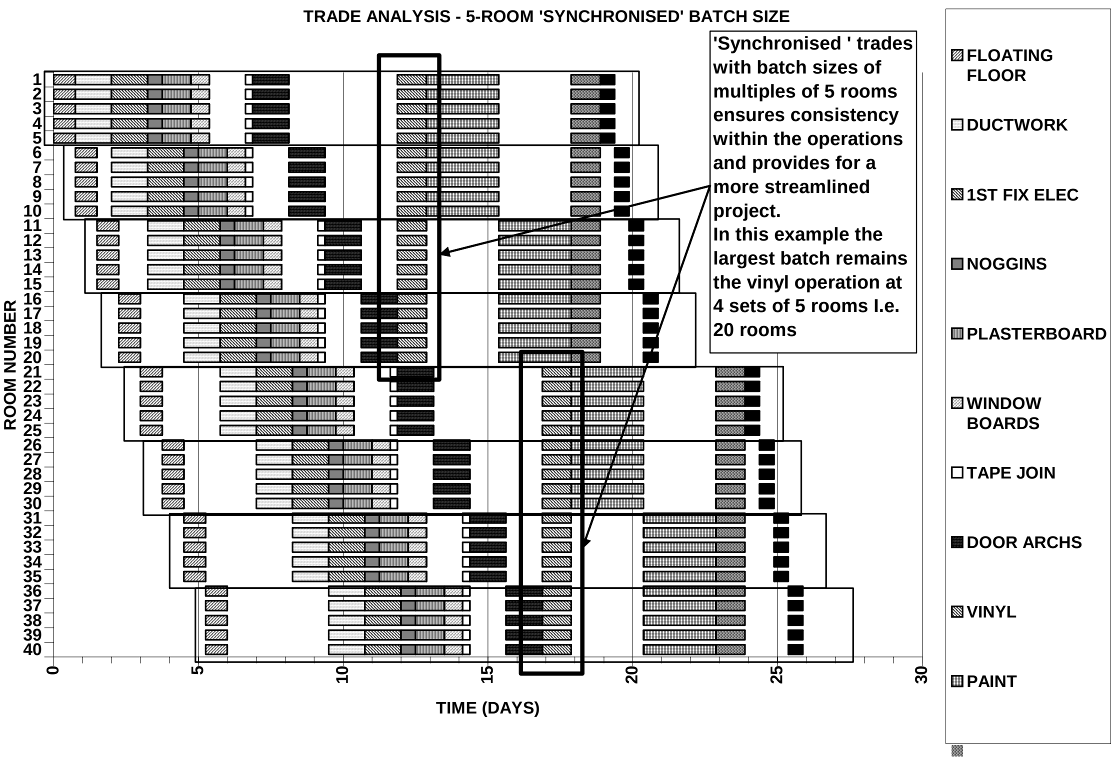

Fig.4: Synchronized 5-room batch size model output showing completion after 26 days

This concept of synchronisation produces an interesting counter to a commonly held view that all batch size reduction is beneficial. In this case study it is shown that by actually increasing the batch sizes for the majority of trades from 4 to 5 produces a reduction in programme duration, contrary to what would normally be anticipated. This phenomenon is due to the trades becoming more aligned with each other.

Observed Results and suggested approach to batch reduction

In summary, a 30 day programme reduction was targeted, equating to an overall programme reduction of 30% (or 50% reduction of the fit-out programme). Due to a number of changes 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 of 15% was achieved. Experience gained on many other projects has shown that it can be folly to attempt the optimum batch size at the first attempt.

Large batches represent WIP inventory waste, which acts as a “buffer” against causes of variation and delivery failure such as poor planning, logistics, and communication which become more critical as a result of smaller batch sizes. In the study above ambitious reductions in batch size did not yield the predicted savings. The target reduction of 30% was not achieved because the inventory “buffer” was reduced too fast for the production system as a whole to adequately cope. It is noted here that the Last Planner System (Ballard 2000) was used on site to help improve short term planning. For reasons above the authors recommend anyone attempting this principle should aim to reduce batch size slowly. An approach found to be consistently successful by the authors is to half the batch size that would naturally be worked to with no intervention. This stands a good chance of success. If the benefit of a stable and collaborative supply chain exists it is possible to make gains by further reduction.

A mathematical expression for predicting the effects of halving batch size

Given that halving the natural batch size is a workable approach to programme reduction the authors 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 the scenario there were 13 critical trade activities for a total of 40 rooms and the batch ratios were as follows:

Batch ratio 20 (to10 rooms) = 13 activities x (20 room / 40 room) = 6.5
Batch ratio 10 (to 5 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 to zero, however the profile is deemed sufficiently accurate for initial estimation. More detailed analysis would be recommended via the computer model. Once the batch ratio has been calculated this is used to identify the percentage saving from the graph below.

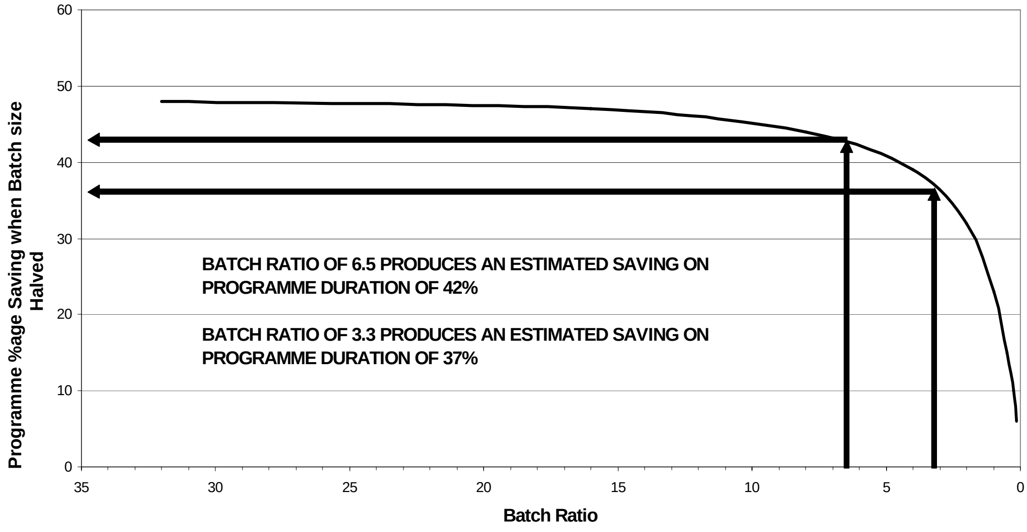

Figure 5: Savings profile for Halving Batch Size

Returning to case study 1 the savings profile graph identifies a saving of 42% (25 days) when the batch 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 response to the suggestion of reduced batch size in construction arises when the building in question does not consist of a number of similar small spaces such as offices, hotel bedrooms etc. The suggestion is felt by many to be non-applicable. In this example the principle of batch reduction was used to re-programme the build of a supermarket to recover a 9 week delay on an original 52 week programme caused by the discovery of antiquities on the site.

To recover the delay, two workshops were held for the supply chain, including consultants and designers, one each for shell and fit-out. The team were introduced to the concept of lean construction with a specific emphasis on batch size reduction. A new programme was then 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, (see Fig.6), 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 Last Planner System was again employed to help with short term planning on site.

The overall impact of the batch size reduction produced the desired saving of 9 weeks, equivalent to an overall reduction of 16% on the original plus delayed programme of 52 + 9 = 61 weeks. 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, it is possible to achieve substantial savings on large space projects.

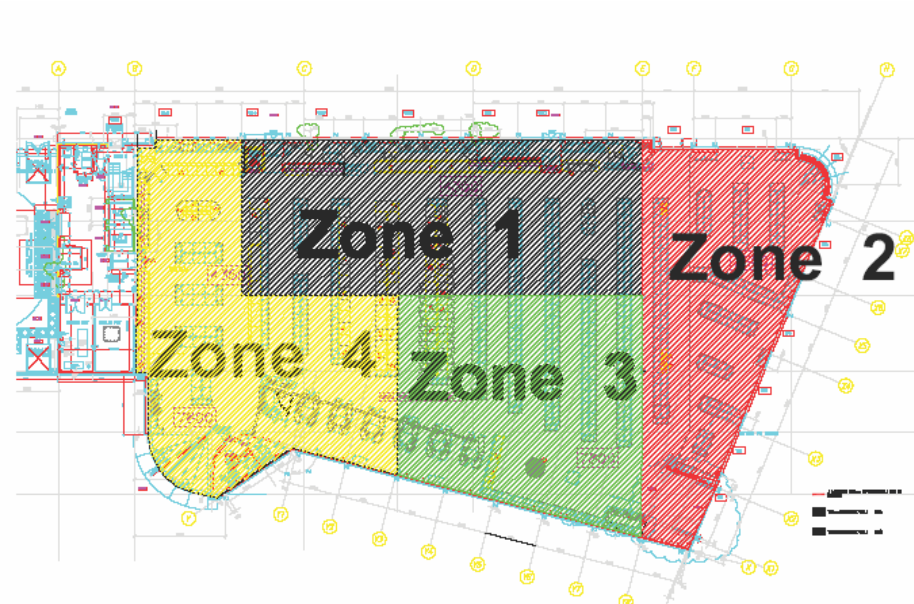

Figure 6. Example of zone plan used in case study 2.

CONCLUSIONS

The concept of batch reduction is not understood in construction and sites run on large batch sizes of whole floors or worse. Significant savings can be made to the overall programme duration by reducing batch size.

A difficulty in programme compression via reduced batch size is demonstrating the potential to stakeholders. A computer model that calculates the benefit has been produced as a response. A batch ratio can be used as a first estimate to calculate the effects of halving batch size.

In order to achieve the savings indicated other aspects of lean construction must be used, including the principle of the next customer and the Last Planner System. In order to succeed a new level of awareness is needed, where focus shifts from the "Cash Customer", to the "Next Customer".

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