HOW TO REDUCE BATCH-SIZE

Anni Schmidt Nielsen[1], Mikkel Andreas Thomassen[2]

ABSTRACT

One of the key elements of lean is the elimination of internal inventories along the production line. However, even though the benefits from reducing inventories theoretically are well described (increased learning, visible bottlenecks and reduced capital costs and production time etc.), the concept is not easily introduced at the construction site. Thus, this mainly empirical paper aims at investigating the question: *"How can significant reduction in batch-sizes be achieved at the construction site"*. More precisely it is investigated if reduced building time is a way of forcing a reduction in batch-size at the construction site.

In order to answer this question, two projects carried out by MT Højgaard are used as case studies. Both projects have been subject to considerable reduction in the building period, although for different reasons.

The paper at one hand illustrates, partly due to reduced batch-size, that it is possible to make significant reductions in construction durations and at the same time maintain and perhaps improve quality, cost and work environment on site. At the same time the case studies show that it is dangerous to reduce building time if the right contingencies are not in place. In particular, the way project management handles time pressure is of essence in this respect. The involvement of the construction crews working on site in the decision making and ongoing planning seem to be far a more efficient way of handling time pressure than by centralizing decisions at the project management level and as part of this increase the amount and richness of time schedules. Hence, this study supports the idea that The Last Planner System has an important role to play in reducing batch-size in construction.

The possibility of designing activities in ways where fewer hand-overs are needed is an important way of gaining time. Experience from previous projects is also of vital importance as it allows subcontractors to be honest about their real time consumption. In this way, the case studies suggest that there is a positive interaction between reductions in building time and batch-size on one side and The Last Planner System together with the concepts of partnering and supply chain management on the other.

KEY WORDS

Buffer management, work structuring, implementation, lean construction, fast track projects, last planner system.

---

1 Civil Engineer, MSc. MT Højgaard a/s, Knud Højgaards Vej 9, DK-2860 Søborg Phone +45 3954 4000, nil@mthojgaard.dk

2 Project Manager. MT Højgaard a/s, Knud Højgaards Vej 9, DK-2860 Søborg Phone +45 3954 4000, mlt@mthojgaard.dk

INTRODUCTION

Lean construction has gained momentum in the construction industry since the ideas, thoughts, methods and tools were introduced more than a decade ago (Koskela 1992). Koskela (1992) identified the need for replacing the dominance of conversion thinking in construction with a conversion/flow model in order to reduce waste. The ideal of Lean Construction is to produce and deliver to the customer only what is needed within a rapid timeframe thereby increasing value to the customer and at the same time reduce waste in the construction process. When looking at the construction process from a conversion/flow perspective it becomes evident that a way to reduce waste in construction (e.g. materials and information are defective or idle) is by rapidly reducing uncertainty in the incoming flows and thereby improving project performance. Shingo and Ohno also suggest that the processes (the course of events through which material is changed into a product) have to be addressed and balanced before trying to improve the operations (the course of events through which man and machine work on the product) (Ohno 1988). The implementation strategy proposed by Ballard and Howell (1994 a, b, c) is to stabilize work flow by shielding production at the construction site, reducing inflow variation and then trying to improve the operations within the shield by better matching labor to available work and improving downstream performance.

Variation and uncertainty in construction is common but on complex fast track projects, the need to manage and reduce inflow variation becomes even more evident and difficult e.g. due to long and complicated supply chains, many players, pressure to maintain some production or use of the existing buildings while construction is taking place etc. Responding to variation in production is a key element in Lean Construction and in this regard *buffering* and *batching* are means by which stability in operations can be achieved.

At the same time, buffers following from large batch-sizes induce costs. Hence, it would be expected that the firms that are best able to manage complex uncertain and quick projects with limited batch-size will gain a competitive advantage. Thus this paper aims at investigating *"How can significant reduction in batch-sizes be achieved at the construction site"* based on the proposition that reduced building time (as is the case of fast track projects) consequently reduces batch-sizes in construction.

To explore this proposition this paper investigates two fast track case studies both carried out by MT Højgaard (the largest building contractor in Denmark). For several years MT Højgaard has been a key player in Denmark with regards to implementing Lean Construction and thus are already accustomed to The Last Planner System.

The outline of the paper will be to first clarify the basic concepts used in the paper. Secondly, the likely outcome of reduced building time and (in turn perhaps batch-size) is discussed ("Propositions"). These propositions are investigated by reviewing two case studies where building time has been reduced substantially. Finally, a conclusion is offered.

This paper is written as part our daily work as project managers in MT Højgaard and therefore we have had limited time at our disposal for writing this paper. The purpose of it is not to elaborate on a theory for buffering or batching. Rather, the paper aims at collecting practical experience in our company with the consequences of reducing building time as well as batch-size. And in turn induct managerial consequences from this experience. We are well aware of the amount of literature on the topic of batching and buffering e.g. (Sakamoto 2002), (Alves 2003), (Tommelein 1998) and that more literature can be reviewed in order to support this paper. Also we recognize that the case studies could be expanded. We hope that this will be feasible in subsequent papers.

BUFFER MANAGEMENT IN CONSTRUCTION

In the manufacturing industry the concepts of buffers and batch-sizes are easily understood but in the terms of construction they might need further defining. In manufacturing batching means processing the product in lots rather than by the piece and buffering is usually used as a mean to maximize the utilization rate of workstations by accumulating several batches of input to the process being done by the workstations.

To explain the concepts of buffers and batch-sizes in construction terms as they are interpreted in this paper an example of a work process from an ongoing housing project, Gefionparken, in MT Højgaard is used as an illustration. The process describes the indoor work needed to finish an apartment consisting of 8 subsequent operations (prefab bathroom units are used). Each operation is scheduled to 1 day. In the present work structure - worked out very early in the process and therefore perhaps not the final one - only 5 apartments are worked on at a time by the concrete finishers, 1 per day, which takes 5 days in total. A buffer of one week is inserted by the project management in order to allow for some startup difficulties after which the plumbers work on the 5 apartments, 1 per day etc. The work process is illustrated in figure 1 below. In this example the apartments are passed to the next trade in batches of 5. Or in other words the product buffer is 5 while the time buffer for each operation is 1 week. The cycle time for each trade to finish an apartment is 1 day and with a batch-size of 5 this makes a total cycle time for 1 apartment for 9 weeks and 3 days.

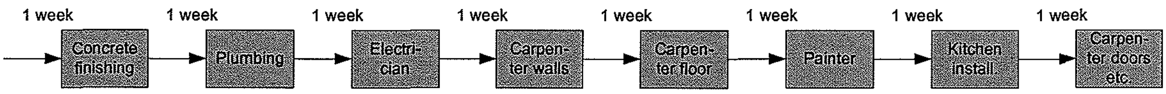

Figure 1: Present work structure for finishing indoor work on apartments at Gefionparken (batch-size = 5)

The present work structure - 8 subsequent trades, one week buffering between each trade and a batch-size of 5 apartments (each department taking a day) – implies that the first (five) apartment(s) will be finished after 16 weeks. The first wing of the building (with 21 apartments) including another wing is at present scheduled to finish after 24 weeks. If the first wing was the only one to finish the hand-over could take place after approximately 19 weeks (5 apartments after week 16, then another 5 in week 17, 5 in week 18, 5 in week 19 and 1 in week 20).

If the batch-size is reduced to 1 apartment and the start-up activities for each trade are completed before getting a hand-over from the previous trade, the first apartment could be ready for delivery within 6 weeks. This is taking into account that time is needed for drying concrete, wooden floors and painting. As it will take approximately another 4 weeks to complete 21 apartments, it would be possible to hand over the first wing of the building after approximately 10 weeks. The revised work process is illustrated in figure 2 below.

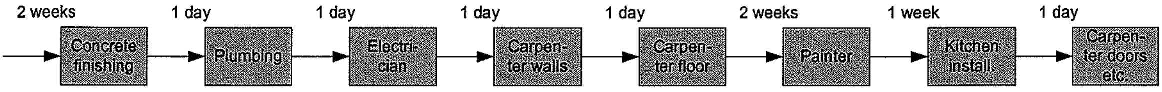

Figure 2: Revised work structure for finishing indoor work on apartments at Gefionparken (batch-size = 1)

The modified work structure and process approach involves two changes: a reduction in batch-size from 5 to 1 and a reduction of the time buffer. By implementing this modification in work structuring it appears to be possible to reduce the building time for the first wing at Gefionparken by nearly 50%. A reduction in the building time could also be achieved by keeping a batch-size of 5 and only reducing the time buffer.

Buffers in construction are commonly used to absorb variability and unreliable workflow between trades and can take different forms as to where in the process buffers are applied. Schmenner (1993) and Hopp and Spearman (2000) suggest that different types of buffers are needed to absorb different forms of variability. Alves et al. (2003) distinguish between two main categories of buffers. Passive buffers are related to the flow of process i.e. materials, documents, work in progress, time and space while active buffers are related to the operations where resources (either workers or machines) perform work on the product i.e. excess capacity of labor and equipment capacity.

One of the key elements in Lean Construction in order to create a steady and reliable workflow are the ability for downstream workstations to pull work from upstream workstations only when the work is needed. Some of the benefits of pulling work only when ready is reducing work-in-process inventory and production cycle times (in construction this will mean that e.g. rooms spends less time standing idle waiting to be worked on and thus a reduction in batch-size). By achieving a more reliable workflow between workstations then enables the pulling of materials to the construction site Just-In-Time (JIT). One mean to achieve implementation of JIT in construction and thus gain the benefits, suggested by Ballard and Howell (1995), is to involve the use of buffers. They distinguish between two types of inventories to serve the function of buffering downstream construction processes from flow variation; plan buffers (inventories of workable assignments) and schedule buffers (materials, tools, equipment, manpower, time etc.).

One way to reduce buffers in construction (inventories) and thereby reducing cost is to appropriately size batches. The choice of batch-sizes influences cycle times, frequency of hand-offs between trades and thus place and size of buffers in the construction process (Hopp 2000).

PROPOSITIONS

Supposedly, reductions in batch-size are likely to create a number of positive effects. However, when we (the authors) – as part of our job as internal Lean Construction Consultants in MT Højgaard - visit construction sites, it is our impression that this idea is not very well adopted. To some degree this probably has to do with the fact that some project managers are not acquainted with lean concepts. But even on projects where project management as well as subcontractors are accustomed to lean concepts like The Last Planner System, batch-size do not appear to be significantly reduced.

Perhaps this has to with that in the perception of most project managers the way to be able to manage the construction process is by decreasing interdependencies. In this perception it would seem counterintuitive to try to increase interdependencies.

What we are suggesting is firstly that project management do not necessarily reduce batch-size when they use the last planner system. Hence, some motivation, or pressure, may be necessary. And secondly, that reduction in overall building time may be one way to create such a pressure. Thus, in the following part we try to pursue the following question: ***what happens when building time is reduced?*** The overall proposition is as follows.

Proposition 1: *Reduced building time reduces batch-size.*

The degree to which reduction in batch-size and building time is planned or not is likely to impact consequences caused by this. An unexpected acceleration (or slowing down) of the building pace is more likely to create an uneven workflow than if the acceleration was expected and planned. In this sense, it is not only the absolute building pace that matters but also how often it changes and how anticipated it is.

Proposition 2: *Reduction in batch-size and building time will cause fewer disruptions on the construction site if these reductions are known in advance as opposed to being detected and introduced later on in the process.*

When batch-size is reduced, disruptions in production are more likely to disturb subsequent trades. This in turn makes it even more important to coordinate activities on site.

Proposition 3: *Reduced building time increase the need for coordination.*

As outlined in Grandori (1997, 2000), two principal ways of handling coordination is by *authority* and by *teams*. Authority at one hand makes it clear who is responsible in case of a delay. Thus, it might be expected that time-pressure enforce the use of authority. On the other hand and unlike teaming, authority is not very good at handling complex situations due to potential informational overload of superiors. Thus it might also be expected that time pressure increase the use (and need) of team based decisions.

Proposition 3a: *Reduced building time increase the use of authority based decisions; that is more decisions are made by the project management (that in turn becomes an informational bottleneck).*

Proposition 3b: *Reduced building time increase the use of team based decisions; that is more decisions are transferred from the project management to the construction team.*

Another expected outcome of reduced batch-size relates to the use of pull and push. It could be expected that when buffers dry out, contractors will start demanding work from up-stream contractors (they start pulling assignments).

Proposition 4: *Reduced building time makes pull of deliveries more dominant (and push less dominant).*

But what happens if the pull for work and improved coordination is not fully capable of handling the challenges imposed by a reduced batch-size? In order to utilize their production facilities subcontractors may start on activities at other parts of the site (they stay on site) or at other construction sites (they leave the site completely). In this way, batch-size might be improved on a single project (or part of the building), but as the subcontractors now engage in more projects, the overall batch-size is not reduced.

Proposition 5: *Unless strong countermeasures are established, subcontractors will engage themselves in more ongoing building projects in order to minimize the impact of reduced batch-size. This in turn ruins the anticipated benefits from reducing batch-size.*

CASE STUDIES

In order to investigate the propositions two case studies have been performed.

- **Three Schools in Skelskør .** Refurbishment and new build of three schools in Skelskør (a medium-sized town on Zealand, Denmark): Skelskør Skole, Eggerslevmagle Skole and Kirkeskovskolen. Design and building period: 1.6.2001-1.11.2003. Total budget for all three schools: 8.5 million euro. The three schools where carried out as subsequent projects with MT Højgaard as the Design and Build Contractor and with a few exceptions the same and mainly local subcontractors were used.
- **The University of Aalborg, Esbjerg.** Expansion of the university with a new building for educational purposes (approx. 21500 sq feet) separated from the existing buildings. Design and building period: 2.1.2003-1.11.2003. Total budget: 2.5 million euro. The project was carried out as a design-bid-build fast track project with MT Højgaard as the general contractor. 14 and mainly well known subcontractors were used.

In both case studies the project has been exposed to significant time pressure although for different reasons. Skelskør Skoler due to internal and external delays, The University of Aalborg, Esbjerg due to the fact that it was chosen as a fast track project from the very beginning.

The case studies are based on two in-depth interviews with the project managers on the two projects. Michael Southcott worked as a project manager for Skelskør Skole and Kirkeskovskolen (but not for Eggerslevmagle Skole) and consequently the first case study will in particular focus on these two projects. The project manager at the University of Aalborg, Esbjerg was Ole Bjørn Nielsen. The following empirical findings represent the interpretation of these two project managers. Due to time constrains, it has not been possible to triangulate the findings of the project managers with additional data.

EMPIRICAL FINDINGS AND ANALYSIS

CASE STUDY 1: THREE SCHOOLS IN SKELSKØR

Skelskør Skole was the first of the two projects managed by Michael Southcout. Even though it was only a 3 million euro project, it was carried out in 5 phases with, in principle, a tender for each phase. However, the first phase was used to examine the subcontractors, and after this phase two of the most important subcontractors (Plumbing and Electrician) were awarded the contract for all three schools. It later showed that also other major trades were used not only for all 5 phases on the Skelskør Skoler but also on the remaining two projects (schools). The only replacement from Skelskør Skole to Kirkeskovskolen was the carpenter doing the floor.

The first two phases of Skelskør Skole progressed as planned. Michael Southcott made a time schedule in a mainly bilateral collaboration with the various subcontractors. At the weekly site meeting he used the 5 week look-ahead plan and this was supplemented with a Last Planner meeting with the foremen in order to produce a weekly work plan. In this period the time schedule was revised once a week.

However, major problems appeared at the third phase which consisted of the demolition of an old building and erection of a $300m^2$ new school building. Delays of 4-5 weeks occurred the reason being that the teachers did not move out of the old building in due time. Furthermore the design was not ready implying that they could not order the planned prefab roof cassettes but had to make the roof on site. A very narrow and complicated building site did not make it any easier.

In order to gain the lost time, Michael Southcott made some changes in the way he managed the building site. He stopped the weekly meetings with the foremen. In stead he walked around the building site and came with very specific solutions to each of the trades not only on exactly when to start activities but also on how to carry out their assignments. As part of this he provided new and very specific time schedules on a daily basis.

He also introduced the notion of "First priority activities" and "second priority activities". "First priority activities" are the ones that are critical in order to meet the due date of the client whereas "second priority activities" can be performed when "first priority activities" are not available.

In the end the construction team managed to complete this phase on time. However, there were several disadvantages. It was an "adrenaline project" where everyone was pushed to the limit. Michael Southcott himself worked 60 very hectic hours a week and still he did not have time to do much of the paperwork (that was done later on). The atmosphere on site was not very pleasant, for instance when subsequent trades required previous trade to complete their work in time. And it was not very efficient. Michael Southcott estimated that the crews had worked 150% to improve outcome from 70% to 90% of the maximum). Quality also suffered from the stress.

Phase four and five was completed as planned and Michael Southcott began immediately hereafter to work on Kirkeskovskolen. However, due to late design specifications and the fact that Michael Southcott refused to commence before having proper time to get into the project, the start was delayed by 1-1½ month out of a total building time of 6 months. Michael Southcott tried to work out revised timetables but soon realized that it was not possible to make a realistic time schedule for the remaining time – there was simply not enough time.

With the experience of Skelskør Skole in mind, he chose a different strategy on how to meet the deadlines. He announced to the carpenters: "I think we can make it in due time, but I don't know how!" He then initiated a process where he and the subcontractors went through all the planned work in order to find a different way of structuring the work in order to execute it in ways that were less time consuming. For instance a brick wall were replaced with a light gypsum wall erected by the carpenter who worked on this part of the building anyway. These alterations were made easier by a partnering arrangement that – especially at the later projects – gave the contractors flexibility with respect to the specific technical solutions.

Michael Southcott also decided to get rid of the time schedules except the one specified by the specific needs of the client. In stead he discussed in collaboration with the subcontractors how to arrange and rearrange activities in order to avoid bottlenecks and fully utilize their resources (total resources were however not increased as most of the firms were small and local and hence working at their maximum). This was done on the weekly site meeting that now encountered the foremen as they were given full responsibility from the clerk of work within the different trades. Part of the effort was to identify the smallest unit that was possible to hand over and at the same time create a continuous workflow for each trade. As part of this Michael Southcott's own job changed. Rather than seeing himself as being in charge, he perceived himself as a mediator combining the different needs of each trade and ensuring that the focus on the final deadlines was kept.

Due to time pressure there was really no time for rework. Things had to be done right the first time and no work operations or rooms could be left half finished. In order to ensure this, they used a Quality Assurance system where each trade has to make his own Quality Assurance before proceeding to the next operation.

And again a buffer zone was established by distinguishing between "first" and "second priority activities".

As in the first project, deadlines were kept. At the same time the quality did not suffer and it was Michal Southcott's impression that the atmosphere on site was improved and he himself was not nearly as exposed of work overload.

Michael Southcott has no doubts that the way of handling time pressure used on the second project was far more successful than the one used on the first project.

But at the same time, he is convinced that the experience from the first project was a prerequisite for how they handled the second project. First of all, they (the construction team) learned from the first project that they all possessed extra resources but also that these were not very efficiently used. This gave them confidence and motivation to try out something new. It was also important that they knew each other and that the subcontractors had learned that the project management would do anything in their power to help them meet the goals – even expanding final deadlines if that turned out to be necessary. Otherwise Michael Southcott don't think they would have dared to remove the slack (on the activities) when estimating the time needed for each assignment.

CASE STUDY 2: THE UNIVERSITY OF AALBORG, ESBJERG

Due to the urgent need of offices and classrooms at the university in Esbjerg the client (The Danish government of research and educational buildings) wanted the building finished as quickly as possible and ready for use in time for the new semester. The project was carried out as a design-bid-build contract with MT Højgaard as general contractor.

The bid from MT Højgaard was 250.000 euro over budget and savings had to be found before the project could start. These savings resulted in changed work descriptions for some operations due to new materials and changed work methods.

From the beginning the construction period was 6 months but due to client changes in lock systems for the building and computer networks the period was extended to 7 months. 3 months were used for concrete erection and to close the building and 4 months where used to finish the work inside. In the experience of the project manager the normal building period would be 1 year with 6 months spend to close the house and another 6 months spend to finish the work inside.

The building is in 3 levels and with a cellar under the northern part of the building also containing offices and classrooms (level 0). Normally the building would be raised in whole storages due to the stabilization of the house. The strategy applied by Ole Bjørn Nielsen (the project manager) to finish the project on time was to erect the building in half storages and then switch to whole storages when the building was closed. Working on half storages offered the opportunity to close the building as quickly as possible in order to get the inside work started and thus get the subcontractors started on site as quickly as possible. The strategy of erecting the house is shown in the figure below. The strategy of working in half storages where discussed prior to the construction phase and had been accepted by the subcontractors who all had been working together with Ole Bjørn Nielsen on previous projects.

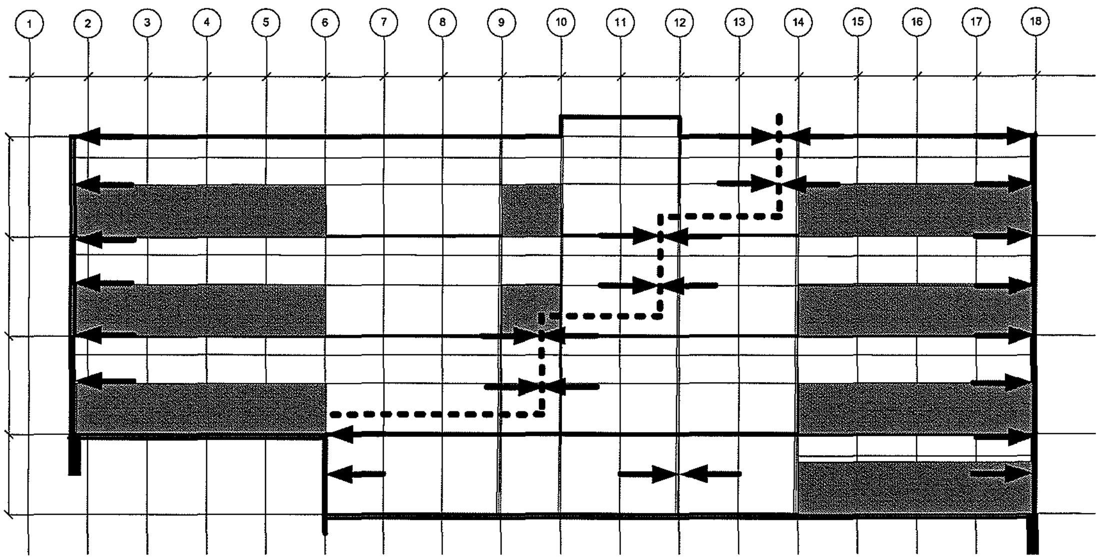

Figure 3: The erection of concrete elements at the Aalborg University, Esbjerg was constructed gradually.

Another strategy of Ole Bjørn Nielsen was to remove all scheduled time buffers between the crews working on site. This increased the need for involvement from the project management in the work processes. One of the concrete workers were also kept on site for the duration of the building period to help the other crews.

The project management was using The Last Planner System to create a lookahead planning that focused on removing constraints from production and in order to make ready work for the crews on site. One of the conditions for removing the time buffers between the trades were that there always had to be some work for the crews to do. The weekly work plan meetings between the project management and the crews on site served to coordinate work places and to pull work from one crew till the next.

An external evaluation of the project showed that - according to the client, the design team and the main contractor – the planned reduction in building time was kept without affecting costs or quality (Bertelsen 2003). .

ANALYSIS

The two case studies offer an interesting story on the different strategies projects managers follow when building time for one reason or another is reduced.

One way is to take a firmer grip of the planning process: provide more (and more detailed) time schedules and centralize decisions at the project management. This strategy was pursued on the first project in case study 1 (Skelskør Skole). Another strategy is to loosen the planning process in the sense that detailed time schedules are replaced with the ongoing planning made possible by transferring decisions from the project management to the different crews working on site. This strategy was followed on the last project in case study 1 (Kirkeskovskolen) and on the second case study (The University of Aalborg, Esbjerg).

Apparently, the two different strategies pose very different results. According to the project managers from the two case studies, both strategies make it possible to finish the project on time but at very different costs. When planning is tightened, productivity is lowered, quality reduced and the working atmosphere becomes unpleasant. The effects from "loosening the grip" is positive or at worst neutral.

In this way, the two case studies illustrates that it is perhaps possible to reduce building time significantly without making it more expensive or compromising on the quality. But it also illustrates that in order to achieve these benefits, a specific way / strategy of handling time pressure is probably required. And this strategy is again dependent upon a set of contingencies as illustrated in both case studies.

- An ongoing planning process is required in order to constantly locate and eliminate bottlenecks and unused resources. Both project managers stressed the importance of The Last Planner System in this respect.
- The contractors are allowed some degree of flexibility in meeting the needs of the client. Alternative technical solutions is an important way of solving the problem of long delivery times or a slow process due to many hand-overs. As pointed out by one of the project managers, the use of partnering enabled this process.

- Experience from previous projects making all parties confident that they could remove time slacks without being punished if something unexpected happened. Thus long term collaboration seems to enable a positive outcome of a reduced building time.
- The establishment of buffer-zones where subcontractors could work if the previous trade was not finished as anticipated. Different means were used to create bufferzones. In the first case study there was an explicit use of a workable backlog ("Second priority activities"). In the second case study this strategy was less explicit, although it was used to some degree. Also here an extra person to help the different trades when a bottleneck appeared constituted a buffer.
- The client or top-management of the construction company did not insist on detailed time-tables even when it was clear that the time-pressure was substantial.

The latter point potentially hold some very important managerial implications for the client as well as top-management of the construction company: "Do not always insist on detailed time tables when a project is delayed – you may delay the project by doing so!"

Our suspicion is that this way of thinking appear strange to most people in construction, and consequently that many delays could be avoided by different managerial practices and not necessarily by removing the original cause for the delay (that might be difficult to effect).

With respect to the proposition the case studies seems to suggest the following.

Batch-size is reduced when building time is reduced (proposition 1). However reduced batch-size is not the only mean for reducing building time. Different planning techniques and revised design of activities are also used in order to gain time.

Yet reduced building time and reduced batch-size do not always create the anticipated benefits as seen in the first project in the first case study. The second project in the first case study and the second case study created these benefits. This seems to support the view that a reduction in building time that is known and planned in advance results in fewer disruptions than if it is introduced during the project (proposition 2). However as observed, the successful handling of reduced time and batches depend on many other contingencies, for instance learning effects or the use of different coordination modes as discussed in the section that follows. .

It seems that reduced building time increase the need for coordination (proposition 3). In the first project in the first case study this was dealt with by increased use of authority (exercised by the project management) and on the second project and in the second case study it was dealt with by increased use of team decisions. Although it seems that in the latter cases both extended use of authority and teaming came into play. It also appears, especially for the first project on case study 1 that increased use of authority created bottlenecks (perhaps this problem was smaller for the second case study because (a) the short building time was anticipated in advance and could be considered when allocating managerial manpower to the site and (b) this new buildi project was simpler than the combined new building and refurbishment in the first case study).

Especially in case study 1 reduced building time appear to make pull of deliveries more dominant (proposition 4). This was not reported by the project manager on the second case study. This might be due to methodological reasons. We (the authors) have only interviewed the project managers, and consequently do not know exactly what happened on the building site or for instance at the weekly meetings with the foremen. A demand for work could have been raised here without our knowledge.

None of the case studies reported that the reduced batch-size made the subcontractors leave their assignments on this project to go work elsewhere (proposition 5). At the same time different initiatives had been taken on both projects to ensure that the subcontractors always had something to do. In this way, the case studies might indirectly support proposition 5.

CONCLUSION

Based on the findings from the two case studies, reduction in building time appears to be a possible way of reducing batch-size in construction. It also seems that this can create the associated benefits of focus on bottlenecks, better employment of resources and improved communication and cooperation.

However intentionally reducing building time as a mean to reduce batch-size can be a dangerous strategy to follow if the conditions are not right.

This was illustrated on the first project in the first case study ("Skelskør Skole") where the same team of project management and subcontractors were exposed to reduced building time on two subsequent projects. On the first project, reduced building time caused a reduction in batch-size but the way it was handled also reduced productivity on site, resulted in purely quality and created a hostile work environment. On the second project in the first case study and in the second case study reduced building time had the exact opposite effect: high productivity and quality and a friendly work environment on site.

The strategy applied by project management in order to cope with reduced building time and time pressure was crucial with respect to achieving the positive benefits. On the first project in the first case study the strategy for coping with the delays was to (a) centralise decisions, (b) increase the number and details of time schedules, and (c) increase manpower. On the second, and far more successful, project in the first case study and in the second case study the strategy was to (a) decentralise decisions, (b) replace time-schedules (except the one specified by the client) with ongoing planning, and (c) eliminating bottlenecks rather than increasing manpower.

Thus in general this paper suggests that reduction in building time can be a way of enforcing (as well as is dependent on) not only reduced batch-size but also The Last Planner System.

A number of conditions emerge as critical in order to ensure a positive impact from reducing batch-size: (a) the client or top-management of the construction company did not insist on detailed time-tables even when it was clear that the time-pressure was substantial, (b) a partnering contract allowed project management to come up with novel and time-consuming solutions as long as these solutions met the overall needs of the client, (c) previous experience had showed to all parties that at one hand they had unused production capacity but at the other hand, that the traditional way of handling time pressure was not very efficient, (d) previous experience also made all parties confident that they could be honest about assignment durations, (e) "buffer zones" allowed the subcontractors to work if delays occurred on one of the critical activities, (f) the limited size of the subcontractors prevented an increase in manpower on the construction site.

This in turn suggest that reduction in building time (and batch-size) should not only go hand in hand with The Last Planner System but also with partnering between client, designers and the main contractor and long term collaboration relationships between the main contractor and the subcontractors.

If these conditions are not in place, the case studies suggest that decreased batch-size has serious negative consequences. Firstly, quality can be reduced if the only way of coping with reduced building time is to carry out the same activities faster (rather than for instance changing the work structuring and work sequence and removing bottlenecks). Secondly, if a reduction in batch-size is not anticipated or planned it causes frustration among the trades working on site and can thereby harm the work environment.

AKNOWLEDGEMENT

The authors would like to thank Michael Southcott, Project Manager at MT Højgaard and Ole Bjørn Nielsen, Project Manager at MT Højgaard for their help with the case studies. Also thanks to the project management at Gefionparken for offering information on the work structuring used on this project.

REFERENCES

Alves, T. C. L. and Tommelein, I. D. (2003): "Buffering and batching practices in the HVAC industry". *Proceedings of the 11th Annual Conference of the International Group for Lean Construction, Blacksburg, Virginia.*

Ballard, G. and Howell, G. (1994 a) "Implementing lean construction: Reducing inflow variation". *Proceedings of the 2nd Annual Conference of the International Group for Lean Construction*, Santiago, Chile.

Ballard, G. and Howell, G. (1994 b) "Implementing lean construction: Stabilizing work flow". *Proceedings of the 2nd Annual Conference of the International Group for Lean Construction*, Santiago, Chile.

Ballard, G. and Howell, G. (1994 c) "Implementing lean construction: Improving downstream performance". *Proceedings of the 2nd Annual Conference of the International Group for Lean Construction*, Santiago, Chile.

Ballard, G. and Howell, G. (1994 d) "Lean production theory: Moving beyond can do". *Proceedings of the 2nd Annual Conference of the International Group for Lean Construction*, Santiago, Chile.

Ballard, G. and Howell, G. (1995) "Towards Construction JIT". *Proc. 1995 ARCOM Conference,* Association of Researchers in Construction Management, Sheffield, England

Bertelsen, N.H. (2003) "Turbobygning af undervisningslokaler på Aalborg Universitet i Esbjerg", By og Byg, Hørsholm.

Grandori, A. (1997): "Governance Structure, Coordination Mechanisms and Cognitive Models", *The Journal of Management and Governance, 1, pp. 29-47*

Grandori, A, (2000): "Organization and economic behaviour", *London, Routledge. Draft Copy. Final publication 2002.*

Hopp, W.J. and Spearman, M.L. (2000) *"Factory Physics". Scond Edition. McGraw-Hill International Editions, Boston, 698 pp. (First Edition 1996)*

Koskela, L. (1992) *"Application of a new production theory in construction". Technical Report No. 72 CIFE, Stanford University*

Ohno, T. (1988) *"Toyota production system: beyond large-scale production". Portland, Productivity Press*

Sakamoto, M., Horman, M. J. and Thomas, H. R. (2002): *"A study of the relationship between buffers and performance in construction". Proc. 10th Annual Conference of The International Group for Lean Construction, Gramado, Brazil.*

Schmenner, R. W. (1993): "Production/Operations Management". *Englewood Cliffs, N. J.: Prentice Hall.*

Thompson, J.D. (1967): *"Organizations in action", MacGraw-Hill, New York.*

Tommelein, I. D., Riley, D. and Howell, G. (1998): "Parade game: Impact of work flow variability on succeeding trade performance". *Proceedings of the 6th Annual Conference of the International Group for Lean Construction, Guarujá, São Paulo, Brazil.*