REDUCTION OF WORK-IN-PROGRESS IN THE CONSTRUCTION ENVIRONMENT

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ABSTRACT

"Reduction of work-in-progress" is one of the core heuristic approaches for reducing production cycle time according to modern production management theories. However, traditional management sees production as a transformation of inputs and outputs and, thus, usually ignores the large quantities of waste generated by excessive work-in-progress. In this context, this research has investigated the degree in which English and Brazilian construction companies currently apply this heuristic in construction. The analysis of empirical evidence confirmed that "reduction of work-in-progress" is not well understood among construction managers and there is great misunderstanding regarding the actual effects of work-in-progress on cycle time. The high process variability, the sequential mode of production and poor interface design between processes were major factors contributing to the poor performance of case studies in this respect.

KEYWORDS:

Reduction of Cycle Time, Reduction of Work-in-progress, Lean Production

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INTRODUCTION

This research investigates the meaning and current application of "reduction of work-in-progress (WIP)" as a main heuristic approach (rule of thumb) to "reduce cycle time" in production systems within the construction environment. "Reduction of cycle time" is fundamental principle that underlies modern theories on production management. It consists of the reduction of the period for a particular 'batch' of material or sub-products to traverse all stages of a process cycle. In production processes alone, a cycle time starts from the moment of setting up the process to produce a determined order to the moment that order is ready for delivery to the customer. The customer can be external, or internal, depending if one is analysing the flow of a complete product, or its parts.

However, cycle time is poorly defined in the construction literature and it affects the way we interpret the various approaches for compressing production time. A cycle time can be divided into set-up and throughput time, as illustrated on Figure 1. *Set-up time* include all the time spent with preparation activities and *throughput time* includes all the time spent with processing activities in one batch. For analytical purposes there should be just one set-up, and one throughput time, associated with each round of a cycle time. Therefore, even when two batches of the same product use the same set-up, measurement of a cycle time need to consider them as two separated entities.

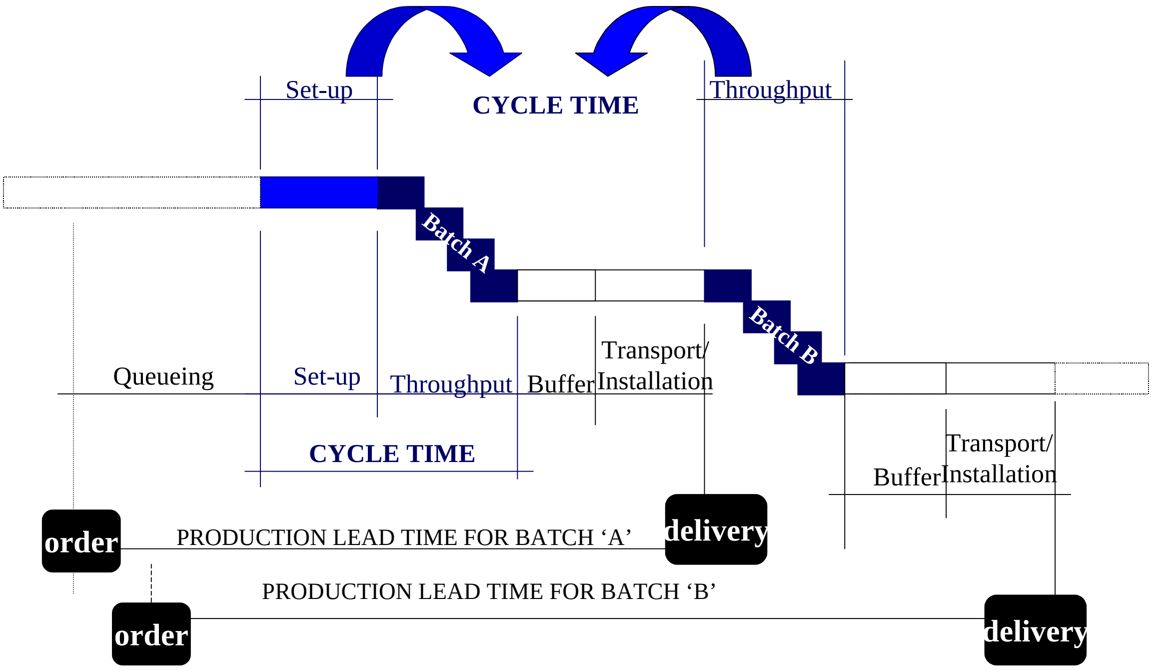

Figure 1 – Cycle Time Within Production

One of the main justifications for the emphasis on 'process cycle' is the advantage of replicating improvements from one cycle to another. However, the heuristics for reducing cycle time are also valid for other activities located externally to the process cycle. Hence, cycle time has to be considered under a holistic view of the entire flow throughout the organisation. Figure 1 shows that the total time between the arrival of an order in production to the time when this order is actually delivered to the client (*lead-time*) includes the time material/sub-products spend on queues, transportation/installation of the order and the buffer time. Thus, the lead-time for a particular batch will depend on the size of batches, number of batches, buffer size and on the speed of processing and set-up activities.

Luhtala, Kilpinen & Antila (1994) extend further the description of flows within an organisation when they describe two additional activities that usually occur before and after a production lead-time represented on Figure 1, respectively:

- *Levelling time*: period between the point where a client's order is received to the start of order processing and engineering;
- *Delivery time*: period between the point where the product (s) has been transported out of production or installed, to the moment when the client actually receives the product (s).

It is worth reminding the reader that, according to the flow model, a process cycle time is composed of transformation, inspection, waiting and moving activities and that transformation activities are the only ones that really add value to the customer. Thus, one of the fundamental approaches for reducing cycle time is acting on the processing activities themselves through improvements in the efficiency of the technology. However, non-processing activities (inspecting, waiting and moving) are usually the most time-consuming elements in most production systems and, above all, they do not add value to the customer. Thus, elimination or, at least, minimisation of non-processing activities is another fundamental approach used to reduce cycle time (Koskela, 1992; Vonderembse & White, 1996).

In general, the expansion of cycle time brings waste due to excessive movements, waiting and reworking. Therefore, the compression of cycle time can drive the reduction of waste in production systems since the cycle of deviation-detection-correction becomes shorter. As a result, people perceive the results of their actions sooner and, consequently, they can act sooner if any correction is necessary (Senge, 1990; Koskela, 1992; Luhtala, Kilpinen & Anttila, 1994).

COMPRESSING CYCLE TIME BY REDUCING WORK-IN-PROGRESS

The literature shows various different strategies and guidelines for reducing cycle time. Tom Peters, for instance, in his article *Time-Obsessed Competition,* lists some important steps towards reduction of cycle time at the organisational level such as linking communication between all parties; flattening the organisational structure; redesigning the business process to reduce delays and promoting trust with new partners (Peters, 1990).

Although many of these ideas certainly have an effect on time, they do not focus entirely, and directly, on the reduction of cycle time. Thus, these heuristic approaches can be easily confused as implementation approaches for other principles having other aims. This lack of precision is likely to cause confusion and disagreements in practical situations. In this context, the structure of approaches proposed by Koskela (1992) seems to offer a better alternative description since it has a more straightforward relationship with time compression. "Reduction of WIP" is one of the core heuristics listed in Koskela's report and the main subject of this paper.

The construction literature is scarce on the discussion of reduction of work-in-progress. This approach is one of the fundamental Just-in-Time approaches to reduce cycle time (Akintoye, 1995). In short, the existence of work-in-progress means that a material or information is waiting for an operation (flow of machine or worker) to be accomplished in order to continue its flow. Following Little's law, cycle time is reduced by reducing the work-in-progress, provided throughput remains constant (Little, 1961). Therefore, the shortest cycle time happens when work-in-progress is equal to the throughput. Deriving from Little's law Koskela presents the following formula to measure cycle time:

$$\text{Cycle time} = \frac{\text{Work-in-progress}}{\text{Throughput}} \qquad \{\text{ex: Cycle Time} = \frac{400\ \text{m2}}{40\ \text{m2/hour}} = 10\ \text{hour}\}$$

In an ideal situation, the operator and machines should accomplish all inter-connected operations of each batch unit with just one visit ('one stop operation'). If the batch unit could be delivered to the next process then the throughput and batch unit would be the same. From a managerial point of view, this can be achieved through the reduction of uncertainties and increasing the repetitiveness of production schedules. Technological innovation can also help the reduction of work-in-progress. One such innovation is the simple de-coupling of linkages between processes, allowing changes in the order of the operations and the earlier start of operations.

RESEARCH METHOD

Case Study Approach

The present research uses "case study" as the main research strategy in investigating the application of theory in construction practice. Yin (1994) defines "case study" as an empirical investigation into contemporary phenomenon operating in a real-life context. This research strategy was found to be suitable to test the validity of heuristic principles because it incorporates all the normal uncertain conditions faced by practitioners (Robson, 1993; Yin, 1994). There was an opportunity in this research to develop case studies in both Brazil and in the UK. The researchers believed that case studies in both countries could strengthen the weight of findings, particularly with respect to international generalisation. In this respect, it was felt necessary to carry out, at least, three case studies in each country in order to enable triangulation of data and increase the robustness of case study findings.

Additionally, the researcher adopted a "**meta-case**" as a complementary source of information in the study in order to complement the small number of detailed cases and improve the validity of the study. This meta-case compiled examples of good and bad practices collected in various countries and provided an integrative and broader view of current construction practice. Most of this information has been collected by fellow lecturers and researchers at the Brazilian research institute called NORIE, through research projects with Brazilian construction companies, or during site visits carried out in construction companies in various countries.

The analysis of the six case studies was carried out in two parts: "cross-case study analysis" and "intra-case study analysis". It used a process called **pattern-matching** where the researcher looked for direct replications of the theoretical propositions (Yin, 1994). In this process, the empirical evidence was considered to be:

- Literal replication: when observed results matched the theoretical predictions (e.g. a visual control that contributes to facilitate measurements);
- Theoretical replication: when the case study produced contrasting results but for predictable reasons (e.g. excessive measurement associated with a lack of visual controls).

Information obtained through quantitative and qualitative techniques was used to substantiate the pattern matching findings. In addition, boundary searching on the typical values of key quantitative indicator contributed to the assessment of the empirical evidence.

Observational Focus

None of the case studies had a clearly defined transfer batch. Thus, the central focus of attention was in any brickwall that received, at least, one visit of the bricklaying workstation. A literal replication occurred when there was only one visit to the workplace. The observations of each brickwall stopped when there was reasonable guarantee that there would be no more visits from the bricklayer. Observations were made of all bricklaying operations and the way bricklayers spend their time. Records were also made when they arrive and when they left their workstation in order to establish the average time between each visit. Other supporting evidence used to certify the accuracy of findings were the results of open-ended interviews, flow diagrams, video recording and photographs.

Since the size of a batch unit is generally variable and not clearly defined in most construction sites, this research will consider each ‘workplace’ as a batch unit. Workplace is the smallest area of work where a complete bricklaying workstation can operate. It was usually a segment of brickwall between steel/concrete columns or between two other brickwalls.

KEY INDICATOR

Two indicators that had been tested in the pilot study seemed to provide the best and most sensible measurement of performance with respect to bricklaying work-in-progress, namely:

a) *Number of Visits a Bricklayer made to the Workplace in order to Complete the Main Processing Activity*: critical analysis of the literature revealed that the number of visits a bricklayer do to the workplace has a direct correlation with the duration of bricklaying (Heineck, 1983). Indeed, due to the queue effect, the level of waiting time and process problems is likely to increase with the number of visits to the workplace;

b) *Average time between Visits to the Workplace:* for the same process, the higher the waiting time between visits to the workplace, the more work-in-progress there will be. The more time the workplace is inactive and waiting for the end of the process the more likely are the occurrence of mistakes that, in turn, lead to further increase in cycle time.

EXPECTED NUMERICAL BEHAVIOUR AND BOUNDARIES

Since there was no referential benchmarks there was a need for identifying the practical boundaries for the chosen indicators. Fortunately, the literature does provide evidence of how reduction of work-in-progress evolves with time. The researchers therefore defined this to be the natural evolution and practical boundary of his chosen indicators, namely:

a) *Number of Visits to the Workplace to Complete the Main Processing Activity*: the literature argues that cycle time tend to decrease with the reduction of visits to the workplace (Shingo, 1988). Ideally, each trade should visit the workplace only once in order to finish all operations. Observations in the case studies suggest that production performance is progressively better if the number of visits is shorter;

b) *Average time between Visits to the Workplace*: ideally, there should be no waiting time between bricklaying operations. Yet, discussions with the workforce lead to the conclusion that a 24 hour waiting time was a realistic superior limit for this indicator. The lack of evidence and the scarce literature does not allow the researcher to confirm what the effect of this variable is on cycle time. Nevertheless, the 'exponential' was adopted because it seemed closer to what is suggested by the observations in the case studies.

SUMMARY OF RESULTS

GENERAL PATTERN ACROSS ALL CASES

There were high levels of work-in-progress in all construction sites studied in this research. Table 1 shows the large number of multiple visits made by bricklayers to workplaces in order to complete all bricklaying operations. They took an average of three visits of a bricklaying workstation to complete all operations in each workplace. Furthermore, the average time between these visits varied between two to five whole working days.

Table 1 - Performance of Case Studies Regarding Work-in-Progress

INDICATOR	CASE STUDY					
	1 UK	**2** UK	**3** UK	**4** Brazil	**5** Brazil	**6** Brazil
Number of Bricklayers	6	6	2	4	3	8
Number of Days Observed	10	10	15	10	10	6
Maximum Number of Visits to the Workplace in order to Complete the Bricklaying Process	4	5	5	4	4	4
Minimum Number of Visits to the Workplace in order to Complete the Bricklaying Process	2	1	1	1	2	1
Median Number of Visits to the Workplace in order to Complete the Bricklaying Process	3	3	3	3	3	3
Average Time Between Visits (days)	5	2	4	3	5	5
Number of Workstations Analysed	**22**	**20**	**45**	**60**	**40**	**35**
Number of Literal Replications Observed	**0**	**10**	**5**	**22**	**0**	**11**

The sequential mode of production and the lack of production input at the design stage were the main contributors for this situation. In addition, schedules aimed solely at gains of production in large batches. This practice resulted in even more waiting time since the process were, in general, highly variable. The waiting time between finishing a process (e.g. bricklaying) and starting other process (e.g. plastering) was often counted in weeks or even months. Discussion with the workers indicated that, in the main, they were typically unaware of the effect that so many visits had on their efficiency or were not motivated to reduce work-in-progress to a minimum.

In all sites visited there were more examples of bad practice than good practice with respect to work-in-progress. The counter effects of the examples of bad practice replicated the expected results predicted by important writers such as Monden (1998) and Shingo (1988). In particular, the clearest counter-effect was the increase in cycle time and increase in the rework due to the lack of continuity of processing activities.

Bricklayers often postponed the construction of difficult parts of the brickwork in order to sustain high levels of productivity by concentrating on the large and repetitive parts of the work available. One important cause of this practice was the bonus system that favoured high volumes of production, rather than efficient production. In this respect, most of the bricklayers could see ‘nothing in it for me’ situations in terms of the reduction of work-in-progress. Therefore, reduced work-in-progress had not became part of their normal operational procedures. Exceptions for this were a few isolated examples of practices matching the theory.

INDIVIDUAL CASE STUDY REPORTS

Case Study 1

This was a site where there were no activities matching the approach of "reducing the work-in-progress" (*see* Table 1). Although bricklayers clearly understood the approach, none of them had carried out just one visit to complete all bricklaying operations. The lack of workflow planning made the situation even worse since, quite often, there were conflicts between the flow of equipment and the flow of material, increasing the waiting time of each brickwall. In addition, managers seemed to have conscientiously placed the workstations in extremely long distances from each other. Without surprise, the waiting time to complete a particular wall was invariably longer than the time spent strictly in the processing activities.

Case Study 2

This case study offered the best overall situation in terms of work-in-progress, both in terms of the waiting time between visits and the number of visits necessary to complete all bricklaying operations (*see* Table 1). Discussions with the workforce and managers revealed that the literal replications identified had happen due to a mix between good design solutions and the active involvement of the subcontractor on workflow planning. The reduction of distances enabled the labourers to keep a smooth supply of materials and reduce the chances of unnecessary movement among bricklayers. However, the reduction of work-in-progress in the bricklaying activity was not followed by important complementary practices such as “measuring, finding and eliminating the root cause of problems’ or the “installation of visual controls”. This situation compromised the “reduction of work-in-progress” even further.

Case Study 3

This site was generally very poor in terms of bricklaying trying to reduce work-in-progress, with only five literal replications among the forty-five workstations analysed. Discussions with the site manager made it clear about his little understanding of the implications of such an approach. He concentrated attentions on the cash-flow and deadlines without having a clear notion of the cost of waste. Table 1 shows that this site presented one of the longest periods between each visit to the workplace (five days).

Even the best ‘literal replication’ observed was not produced by the bricklayer, but by carpenters who come to the carry their operations immediately after bricklayers had reached the level of the wooden slab (*see* illustration on Figure 2). All materials had been delivered on the previous day and the tools required for the job were ready on the carpenter's van. At this point of the operations, bricklayers continue their activities in another building or the same construction site. Four days later, just when the carpenters had finished their job, bricklayers came back to continue their work. There was almost no waiting time between these two processes.

Figure 2 - Literal Replication of Work-in-Progress Reduction (Case Study 3)

The production batch was too big in relation to the number of bricklayers and equipment available. This practice resulted in the opening of too many fronts of work and, consequently, an increase in the volume of work-in-progress and transportation. The more time labourers get involved with unnecessary transportation the less efficient the main value-adding activity was.

Case Study 4

This site presented a low level of work-in-progress in comparison with most case studies. Twenty-two workstations finished all activities in just one visit to the workplace. Moreover, the average time between visits to a workplace was better than most case studies. The approach was more evident on the interface between bricklaying and electrical installations. Technological innovations in design and materials allowed electricians to install part of the electrical fittings in parallel to the bricklaying activity. These innovations produced some clear benefits to the interface between these two processes such as the reduction of rework, simplification and early correction of mistakes. Foremost, electricians also reduced the amount of visits necessary to complete their operations.

Case Study 5

This case showed no ‘literal replication’ and presented a poor performance in all indicators used for assessing work-in-progress. One of the best examples of ‘theoretical replication’ documented in this site was the excessive waiting time to construct brickwalls around the vertical pipes (see Figure 3). These walls were so small and complex, and this reduced the bricklayer's productivity. Therefore, the usual practice of bricklayers was to leave the construction of these walls until the end of the work. In addition, there was a lack of synchronisation with plumbers that forced bricklayers to delay the construction of these walls.

Figure 3 - Theoretical Replication of Work-in-Progress Reduction (Case Study 5)

With practices such as the one described above, more time was wasted due to unnecessary movements since the bricklayer had to come back to the workplace more than once. Adding to this problem, the movements of workstations within an area where brickwalls have already been built were extremely difficult. Thus, despite the intial productivity gains on the conversion activity, the total cycle time was far below the potential level.

Case Study 6

Only eleven workstations in this case study were able to conclude all operations in just one visit to the workplace. Like in Case Study 4, technological innovation was the main factor enabling these literal replications to occur. Nevertheless, this construction site had a higher level of waiting time than Case Study 4 due to poor planning, poor communication and teamwork between managers and bricklayers. The pathways were often congested due to the constant movement of workstations back and forth. Managers acknowledged the problem but focused their efforts solely on the design aspects.

DISCUSSION

The clear message obtained from the evidence collected within the six case studies was that:

i. Most of the bricklayers and managers failed to give adequate consideration to the need for reducing work-in-progress. Bricklayers preferred to do easier and faster jobs first in order to receive their productivity bonuses earlier and managers were usually more concerned with cost and deadlines;

ii. Most of the bricklayers neither plan the workflow in order to reduce work-in-progress nor question their managers about excessive volumes of work-in-progress.

Koskela's (1992) criticisms of the traditional conversion model proved to be well founded. Indeed, the problems mentioned above rest upon the concept that production is a process of conversion of inputs into outputs. The actions of production managers in most case studies reflected this since they had disregarded the importance of reducing or even eliminating waiting time from production flows. Furthermore, the typical mass production mentality among construction managers leads to production schedules aimed solely at gains of scale, with little concern for the increase of work-in-progress. All these factors demonstrate that the reduction of work-in-progress, as well as the reduction of batch size, demands a radical change in the very deep roots of thinking among managers working in the construction sector. Construction workers and managers need to be better informed on the potential benefits of reducing work-in-progress, despite short-term implications on productivity levels

The case studies also showed a poor level of integration between reduction of work-in-progress and other important complementary implementation approaches. This is at odds with examples of best practice described in the literature. The reduction of work-in-progress in a construction process is not only connected with the reduction of waiting time, but also with batch size reduction. Indeed, according to Shingo (1988), all operations in a batch unit should finish completely before the production of another batch unit starts. Thus, the production one batch unit at time, without waiting time between operations, is the point where "reduction of work-in-progress" and "reduction of batch size" converge in practice.

The analysis of empirical evidence shows that "reduction of work-in-progress" can easily be misunderstood with the approach "consolidation of steps in the process". The latter usually implies some technological innovation in order to group various operations to eliminate waiting time. After all, the more segmented and interconnected a process the more likely that waiting time will increase due to the queue effect, if the sources of variability are not properly solved. Therefore, technological innovations have an important role in reducing the number of visits to the workplace. However, the interpretation of "reduction of work-in-progress" in this thesis places greater emphasis on those managerial decisions where technology itself is not necessarily changed. So, the focus here is to those typical non value-adding activities present on construction sites since they often reserve great potential for improvement.

Another difficulty in identifying practices matching the reduction of "work-in-progress" is the need for anticipating the future movements of workstations. Most construction sites analysed in this research did not have a workflow plan and did not have a clearly defined transfer batch. This difficulty extends to the identification of the exact location and duration of movements of the workstation when the observer is not on site. The present research used the daily conversations with the workforce and open-ended interviews as an instrument to reduce doubts in this respect.

CONCLUSION

Although the literal replications observed in the case studies suggest that "reduction of work-in-progress" is a valid heuristic approach in construction, all construction sites visited during this research presented a poor performance. One important reason for this situation was the bonus system that favoured high volumes of production rather than efficient production. The sequential mode of production and the poor levels of design constructability also contributed to the poor performance of case studies in this respect.

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REFERENCES

KOSKELA, L. 1992. Application of the New Production Philosophy to Construction. *Technical Report # 72. Center for Integrated Facility Engineering. Department of Civil Engineering. Stanford University. 75 p.*

LITTLE, J. D. C. A proof for the Queueing Formula: L = λ*W*. *Operational Research, 9, 383-387, 1961.*

PETERS, T. Time-obsessed competition. Management Review. *September, 1990, pp 16-20.*

ROBSON, C. Real world research : a resource for social scientists and practitioner. *Oxford: Blackwell, 1993.*

SENGE, Peter M. The Fifth Discipline: the art and practice of the learning organisation. *Century Business, 1990, 409pp.*

SHINGO, S. Non-Stock Production: the Shingo system for continuous improvement. *Productivity Press, 1988.*

VONDEREMBSE, Mark A. (1996) Operations management : concepts, methods, and strategies */ Mark A. Vonderembse. - 3rd ed. - Minneapolis/St. Paul : West Pub. Co.*

YIN, Robert K. Case study research: design and methods. *Second edition. Applied Social Research Methods Series, Volume 5, Sage Publications, 1994.*