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REMOVING HIDDEN WAITING TIME IN CRITICAL PATH SCHEDULES: A LOCATION-BASED APPROACH TO AVOIDING WASTE

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ABSTRACT

Production waste from non-productive activities is a well understood concept in Lean Construction Management.

Waiting-time is also a well understood form of production waste. However, waste arising from the hidden waiting-time inherent in poorly designed CPM schedules has not previously been described. Hidden waiting-time is defined and demonstrated using location-based visualisation methods for construction cycles. A construction cycle refers to a repetitive sequence of work required to erect a structure. Two case studies illustrate how such waiting time can be removed and replaced by production buffers using appropriate levels of location breakdown.

What sort of waste is represented by the time reduction demonstrated in these case studies? The TFV based taxonomy of wastes includes both inefficient waste and waiting time, but combining the two to define hidden waste found in CPM schedules, requires a new category. Cycle waiting time is the waste of not planning the most efficient project structural cycle and therefore not being able to identify hidden wastes based on utilisation of location based structure.

KEYWORDS

Cycle waiting time, waste, work flow, location-based management (LBM).

INTRODUCTION

The purpose of this paper is to add to the theory of construction production waste, from both a practice and a theoretical perspective. Interest in the development of a general theory of lean construction began in the last century. Theory was derived in part, from construction project management practice and in part, through comparative analysis with manufacturing processes. This two pronged approach has provided vigorous debate, growth in the lean construction literature and expansion of the built environment disciplines (Bertelsen, 2004).

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Work flow in construction projects was one of the early lean concepts identified as needing to be distinguished from the concept applied to manufacturing processes (Akinci, Fischer and Zabelle, 1998; Kenley, 2004). Thus, a significant amount of lean construction theory development has been premised on the important distinction between process and operations. In addition, both concepts are derived from practice and theoretical perspectives (Akinci, Fischer and Zabelle, 1998; Howell, Ballard and Hall, 2001). And a growing number of empirical studies have been able to test the theoretical assumptions for improved productivity by implementing lean construction principles in the field (Abdelhamid, Jain and Mrozowski, 2010; Barreto et al., 2014; Kalsaas, 2014).

Empirical studies are possible because a number of methodologies have been developed using lean construction principles. Location-Based Management (Kenley and Seppänen, 2010) and Last Planner (Howell, Ballard and Hall, 2001) are two such methodologies that provide the ways and means to eliminate waste during construction. Thus, identifying and defining 'waste' within the theory of lean construction is important. However, Zhao and Chua (2003) caution that all types of waste affect productivity, but not to the same degree.

Bølviken, Rooke and Koskela (2014) provided a list of specific construction production wastes. The definitions and categorisation are a major step in the development of construction production waste theory. However, as will be argued below, this list can be seen as indicative rather than definitive.

CONCEPTS OF CONSTRUCTION PRODUCTION WASTE

The identification and removal of waste is one of the primary aims of lean methods of construction. A research team working with the Transformation – Flow – Value (TFV) theory developed by Koskela, have focused on creating a taxonomy of wastes of production in construction (Bølviken, Rooke and Koskela, 2014). Table 1 shows both their operational and process wastes linked to work and product flow. The attributes of these two categories indicate 'pauses' in flow (Koskela, Bølviken and Rooke, 2013). The flow perspective highlights internal resources of a construction project, time and location. Activities that pause the flow of work or pauses in product flow can have as a by-product, production waste.

Table 1: Two categories of construction waste identified from a flow perspective

In the Wok Flow	In the Product Flow
Unnecessary movement (of people)	Space not being worked in
Unnecessary work	Materials not being processed
Inefficient work	Unnecessary transportation (of material)
Waiting	

SCHEDULING: A MECHANISM FOR WASTE REDUCTION

There are two types of work flow wastes from the authors' list relevant to this paper (Bølviken, Rooke and Koskela, 2014, pp. 816-817). **Inefficient work** is defined as the waste that results from "doing (necessary things) in an inefficient way" and

waiting is defined as "workers waiting for work to be done". Can **inefficient work** and **waiting** be reduced using an effective construction project schedule?

This paper will attempt to answer the question though analysis in two case studies. *Vico Control, 2009* (Vico Software Inc., 2015) will be used to illustrate CPM schedules in a location-based projection (Flowline). Analysis of alternative schedules will be limited to alternative location breakdown structures (LBS) in accordance with location-based management principles (Kenley and Seppänen, 2010).

CONSTRUCTION CYCLES

A construction cycle refers to a repetitive sequence of work required to erect a structure (Arumugam and Varghese, 2014). Typically this involves both horizontal and vertical elements such as floor plates and columns. These cycles are location dependent, meaning that prior locations must be completed before later locations can commence (Antunes and Gonzalez, 2015).

To demonstrate, Figure 1 illustrates a simple structural cycle of activities: set-out, vertical structure (columns), horizontal structure (slabs); in a location sequence limited to floors.

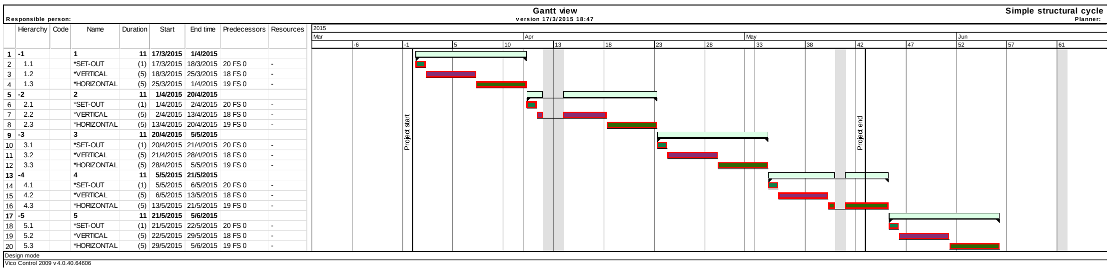

Figure 1: Simple structural cycle with three tasks through five floors

LOCATION-BASED VISUALISATION

As noted in Figure 1, most CPM schedules involve repetitive cycles of work which are location dependent. These cycles typically and necessarily involve a delay (waiting time) as crews commencing the cycle must wait on completion of the cycle below/before starting on a new location. Location-based visualisation can expose this delay by revealing the hidden waste in a construction schedule. Two case studies provide some schedule details of hidden waste within the construction cycles that provides evidence of efficient rather than inefficient work, in the sense of both planning and structural cycle completion.

FIRST CASE STUDY

The first case study is of a 14 level residential apartment building. The project was scheduled using *Primavera P6* and managed using *Microsoft Project*. The structural schedule was cast onto a location-based view using *Vico Control*. Figure 2 shows the structural cycle for the building which was planned and managed on a single pour per floor basis. The final Pour was scheduled for Day 136.

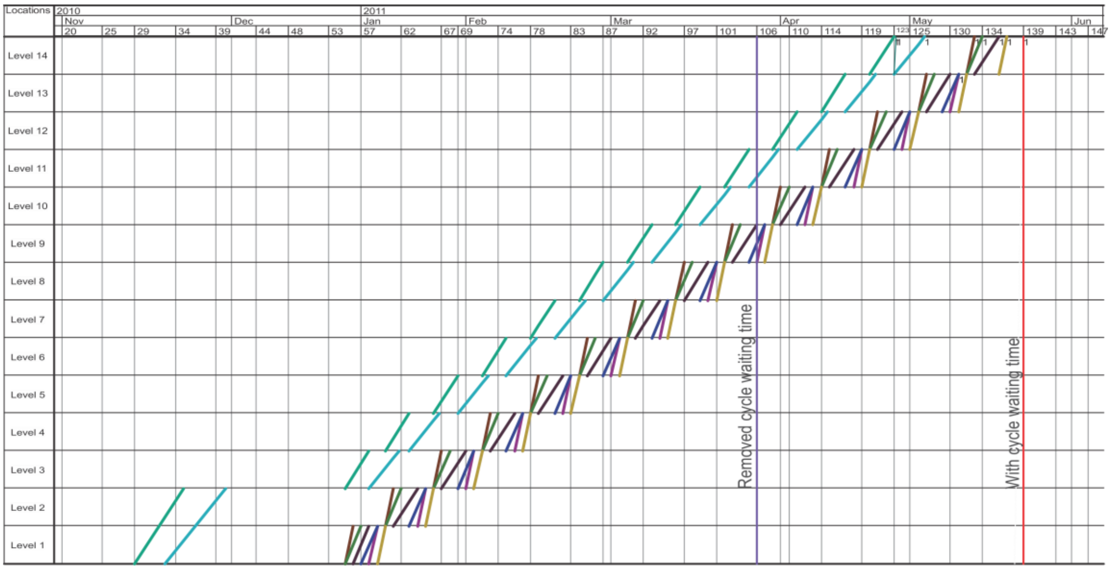

Figure 2: Apartment building planned as one pour per floor. Final Pour on Day 136

If this project is re-planned as a two pour per floor structural cycle, the resultant plan (Figure 3) has a much smoother workflow for individual trades and a total structural duration of 98 Days to the final Pour – a saving of 38 days.

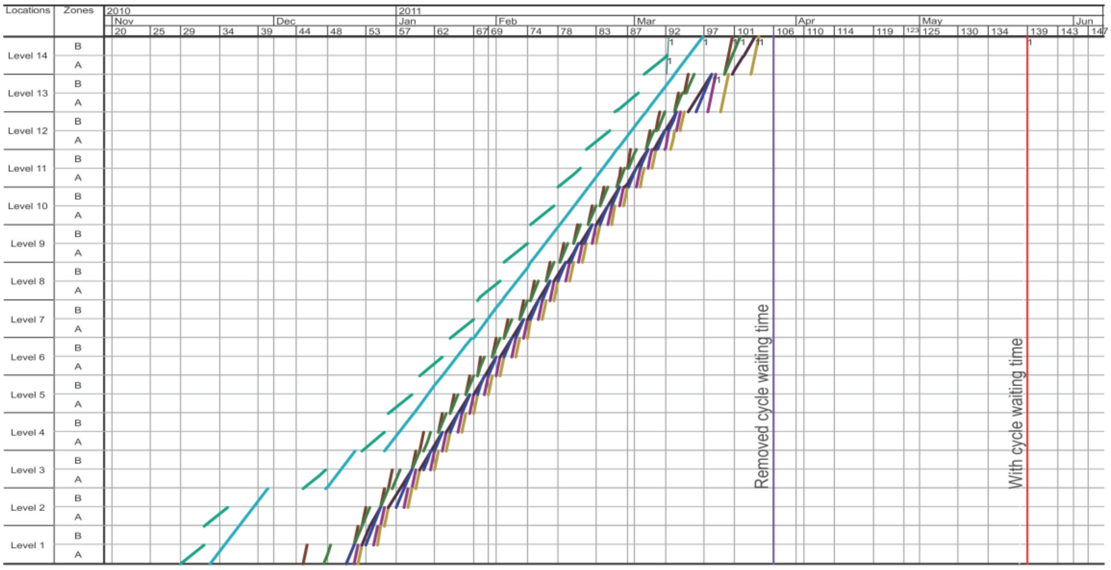

Figure 3: Apartment building planned as two pours per floor. Final Pour on Day 98

The significance of this change is that the simple act of dividing a floor plate into two construction zones can lead to a significant (and cumulative based on the number of repetitions) reduction in overall structural construction time (Akinci, Fischer and Zabelle, 1998).

SECOND CASE STUDY

The second case study is of an education building in which the structure was arranged in three large wings. The project was scheduled and managed using *Microsoft Project*. The structural schedule was cast onto a location-based view using *Vico Control*. Figure 4 shows the structural cycle for the building which was planned and managed as precast construction (columns, beams and slabs) on a single run per wing basis.

The final placement was scheduled for Day 185. The start date for each wing was fixed and could not be reduced.

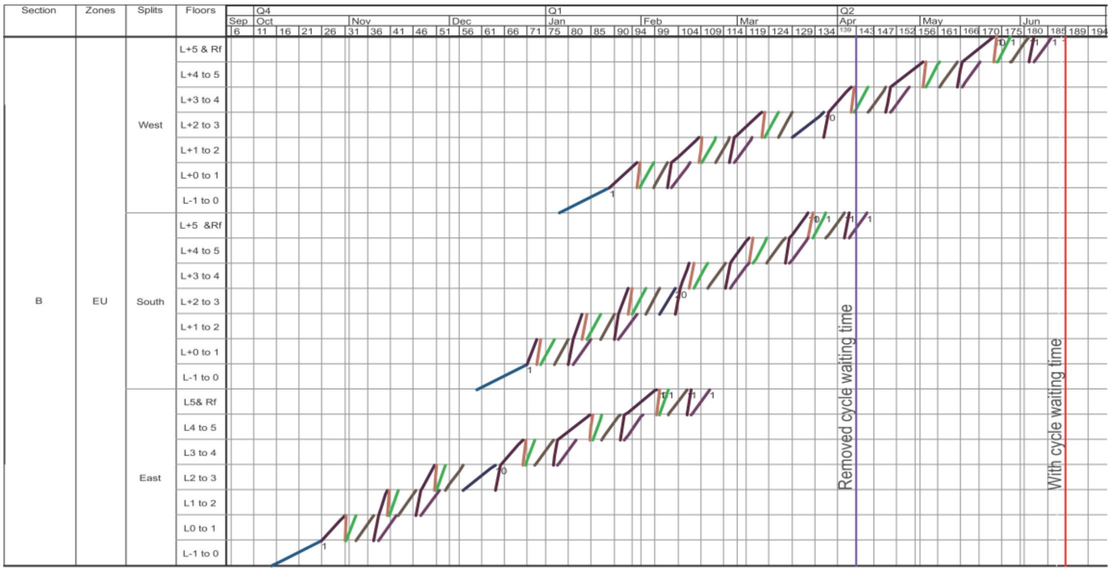

Figure 4: Educational building in three wings with the structural cycle organised as a single run per floor. Total duration 185 days, Wing 3 duration 107 days

Figure 5 shows the same project with each wing divided into two separate work areas. This change did not require additional crews but additional cranage/craneage was required (more cranes for less time = same resource use).

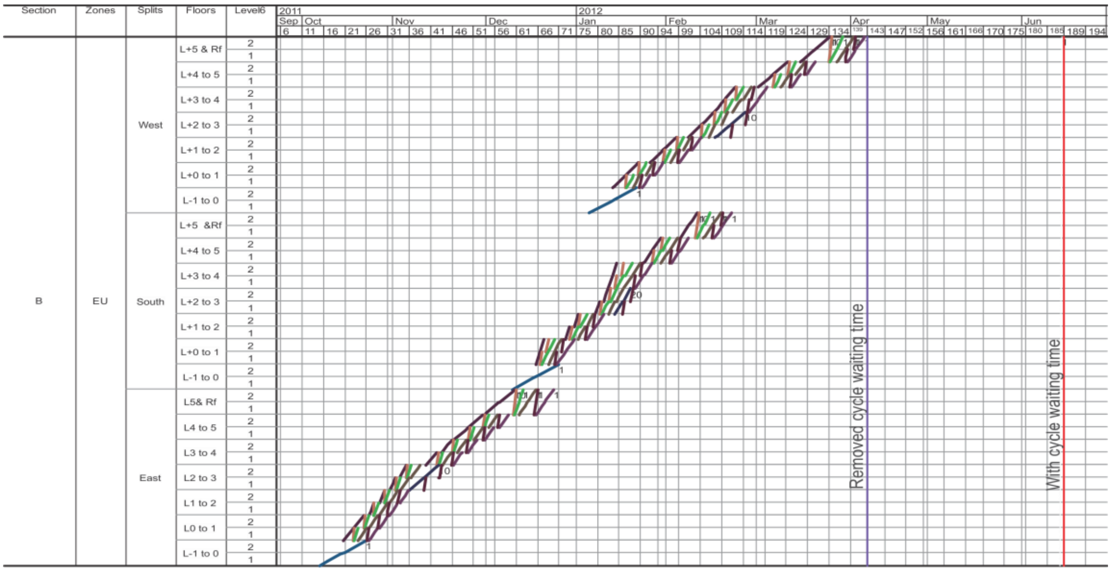

Figure 5: Educational building in three wings with the structural cycle organised as a single run per floor. Total duration 142 days, Wing 3 duration 64 days

With this version the final date for placement was Day 142, a reduction of 43 days. Importantly, as the start dates were fixed, the duration for the final wing reduced from 107 days to 64. This reduction was entirely due to not waiting to complete each work task for the entire wing per floor before commencing the next level.

HIDDEN WAITING TIME

In this special case, **waiting** time does not usually represent waste as defined from the flow perspective: lost time (Bølviken, Rooke and Koskela, 2014). Resources are generally fully utilised doing other work and there is no **inefficiency** involved in the traditional sense. Whether measured on a critical path schedule with logical links and activity durations, or measured by a pull schedule with activities on demand as work becomes available, there need be no deviation from the plan or any appearance of unproductive time (Seppänen, Ballard and Pesonen, 2010).

This improvement is a function of the removal of hidden waiting time in the schedule. The reason it is described as hidden is because traditional CPM planning tools do not reveal the **waiting time**. This simple example appears obvious and most planners would immediately argue that they would plan the project better. The reality is that complex projects planning means lots of activities. However because ignoring the work sequence is far too basic for proper activity modelling, clarity gets lost in the detail of complex critical paths (Kenley, 2005). Because the waste generated by construction cycle repetitive work is hidden, it ceases to be obvious that improvement can be made and **inefficient work** is the perceived outcome**.**

Evidence of hidden waste is demonstrated in the two project case studies. In each case (Figures 2-5) the actual project schedule is compared with an alternative location-based schedule. In the location-based schedule the location breakdown structure is altered to reduce the overall time without requiring any other change in production. And for both examples, waste must have been removed, because total work time was reduced significantly.

DISCUSSION

It is only after location-based analysis that the planner becomes aware of the potential for reducing the overall schedule duration by altering the location-based structure. Therefore, if the location-based analysis is not undertaken (as on most projects) then there is no knowledge of the opportunity to reduce time, but more importantly nor is there a perception of waste. Extending that logic further, it may be seen that a breakdown into three zones instead of two would likely achieve a further (but proportionally less) reduction – and so on until the practical cost of running small construction areas exceeds the value of time reductions (a matter of expert judgement).

Thus, the use of a well-designed schedule means no **inefficiency** is involved in following this location detailed schedule. Certainly if the schedule is met and activities completed on schedule, PPC indicators might be 100% for those activities.

While there is clearly **waiting** involved in this schedule, it might be argued that this is an unavoidable component of structural cycles and therefore not waste.

CYCLE WAITING TIME

What sort of waste is represented by the time reduction demonstrated in these case studies? The two wastes that were identified as relevant to this discussion were: **Inefficient work** and **Waiting**. However, definitions proposed appear to be context specific, rather than types of waste that can be generally applied to project work flow.

So what sort of waste is the identified hidden waste in the two case studies? It could be argued that the Bølviken, Rooke and Koskela (2014) identifiers are accurate but the definitions require revision. On the other hand it makes more sense to propose an additional work flow waste type be added to their list.

The suggestion for the identifier and definition of the type of waste found in this study be: **cycle waiting time** - This is the waste of not planning the most efficient project structural cycle and therefore not being able to identify hidden wastes based on utilisation of location based structure.

CONCLUSION

This paper has made the case for an additional work flow type of waste that can be added to the 2014 construction production waste list (Bølviken, Rooke and Koskela, 2014). **Cycle waiting time** represents a specific type of waste related to structural construction cycle repetitive activities. In most CPM schedules this type of waste is hidden, but it can be exposed through location-based analysis of the structural schedule.

This addition to the theory of wastes is supported by project management practice using a Location-Based Management mythology for lean construction. The two case studies demonstrate clear waste reduction benefits from altering the location breakdown structure for the structural schedule.

Clearly, there are benefits of removing hidden waste from a structural cycle flow regardless of the application of other lean techniques. But, more importantly, without taking into account **cycle waiting time** lean optimisation of project management will be based on a wasteful schedule and will miss the opportunity for improvement.

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