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MANAGING THE "RECEDING EDGE"

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ABSTRACT

So much attention is paid to starting construction activities, and starting new work at regular time intervals to a beat (aka. takt) that—not surprisingly—work to finish those very activities may fall behind. This paper focuses, not on the start-, the "leading edge, "but on the end of activities, the "receding edge." The receding edge articulates when work is "done-done" and the successor contractor may start their work, unimpeded by their predecessors' unfinished work or "leftovers" (e.g., areas left dirty and cluttered with remnants). This paper describes receding-edge activities related to forming, placing, and finishing post-tensioned, cast-in-place concrete slabs, observed on a project in San Francisco, California. The researchers went to the gemba, described the current situation, and exchanged ideas with the contractor on means to keep the receding edge progressing at the pace of the leading edge, that is: to improve the cycle time from start, to not just finished or "done," but to "done-done" completion of each slab. Findings include the need to define standard processes (e.g., for clean-up work) as those observed appeared defective (one of Ohno's 7 wastes) or none existed, and to designate resources to accomplish them. This paper contributes to knowledge by articulating the receding edge concept, describing challenges in managing it, and documenting lean methods as countermeasures to those challenges. When managed considering the production impact of receding-edge work on the contractor responsible for it and on follow-on contractors, the case for cycle time reduction is easy to make and worth the money.

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KEYWORDS

Cycle time, waste, defect, unfinished work, work structuring, standardization, cast-in-place concrete, takt time planning (TTP)

INTRODUCTION

We define construction activities as bounded by a "leading edge" at their start and a "receding edge" at their end. Both edges are rather fuzzy in practice, especially when an activity comprises several sub-activities. The focus in this paper is on the receding edge, as defined later. Its fuzziness is a problem, e.g., when an activity drags out, the increase in work in process and resource uncertainty may become costly to the contractor responsible for it and to the project overall as follow-on activities may be impeded by "leftovers" (e.g., areas left dirty and cluttered with remnants) from their predecessor.

To explore the receding edge concept and its impact on production system performance, our methodology was to observe, document, question using 5 WHYs, and analyse activities of Webcor, the contractor building the 55 story Transbay Block 8 in San Francisco, California. The building structure is erected using a 3-day takt between floors, with cast-in-place post-tensioned floor slabs, each slab measuring roughly1,600 m^2 (~17,000 ft^2). We also reviewed the literature using concepts related to starting and completing activities.

Construction contractors use metrics to determine progress of their work. One such metric is to account for the amount of work "done" (e.g., volume of concrete put in place, an output of production). Metrics like this serve as their basis for payment. As such, the contractors' workforce places additional efforts to increase performance as measured. That may come at the expense of the quality of their work and quality of their handoff to others. It may lead, e.g., to complications that require the contractor to return to site, thereby disrupting the contractor's work flow and being costly in other ways as well.

This paper first defines the receding edge concept. It then presents related concepts pertaining to activity definition as described in the literature. The section that follows illustrates current practice regarding receding edgework using examples from the project, which the researchers scrutinized by applying Lean Thinking to identify potential improvements. The paper concludes with a summary and questions for further research.

DEFINITION OF THE RECEDING EDGE

The "receding edge" of an activity in a contractor's scope of work includes, by definition, the work that *appears to not necessarily need to be completed* by that contractor in order for them to move on to their next activity (e.g., the next work location), but *must* be completed for the contractor to "handoff" their work to others, have finished their total scope of work on the project, and leave the jobsite. Fuzziness of the receding edge results from the difference between the work being "done" vs. the work being "done-done."

The relationship between an activity's leading- and receding edge may be depicted by a person dragging an anchor. The person is the leading edge, starting activity by breaking new ground and moving forward. The anchor is the receding edge, the final point to touch the ground before activity completion. A presumed ideal is that, when moving forward, the front and back remain connected with a constant distance in-between; this distance or time in-between defines the cycle time of the activity. Reliably achieving that cycle time is key to, e.g., implementing a takt plan and may be accomplished using capacity buffers (Frandson et al. 2015), though that is not the focus of the discussion here. In practice—and less than ideal—as the leading edge progresses, work may increasingly stretch out (it rarely shortens) so that the distance in-between it and the receding edge increases over time.

Examples of receding-edge work are removal of tools, temporary structures, equipment, and materials left behind, rework to address quality issues, and cleaning of remnants and debris. While such work may appear to make up only a small portion of the required work on a project and to not be essential to work progress(i.e., the ability of workers to move on to the next cycle), it is not immaterial. It can cause delay and costs money, especially if workers are required to remobilize and demobilize to get all work "done-done."

Receding-edge costs do not appear explicitly in traditional project controls but rather get lumped-in with various cost codes. This makes them hard to "see" and gauge their magnitude. To offer a sense of their magnitude, looking beyond the Block 8 project in focus, our co-authors from Webcor sampled18 of their structural concrete projects (ranging from $2 to $12 million in work hours) and identified the costs incurred after topping-out (i.e., placing the last floor slab). Receding edge work was embedded in cost codes pertaining to five activities. These activities were performed by unionized workers, carpenters [C] or laborers [L], all working for the concrete contractor:

1. Removing all inventory used for decking, walls, etc. out of the project [L].
2. Performing dry finishes and patching work[L]. This work may be perceived as "needed" (part of the process), but it is rework caused by work not performed earlier and to a sufficiently high-quality standard.
3. Placing concrete curbs [C] and other temporary leave-behind work (e.g., filling hand rail/leave-behind cable column/deck indentations). It may be possible to design the operation to include this scope in the leading edge (e.g., using floating curb forms so that the concrete for the curb can be placed while placing that for the deck).
4. Removing the last floors of re-shore posts [L].
5. Inspecting and cleaning all floors [L].

The division into work performed by either carpenters exclusively or by laborers stems from received tradition and a difference in pay with the latter earning roughly 70-80% of what the former earn. However, division hampers flexibility: lack of multi skilling makes workload balancing and levelling harder to do. It can lead to problems at the handoff between these teams of workers. For example, on the Block 8 project, challenges in concrete finishes that arise when laborers remove formwork can be prevented only during erection of this formwork, which is performed days earlier by carpenters. This division of labor hampers communication (e.g., to proactively develop job-site countermeasures) and discourages workers from taking responsibility for small tasks perceived to be non-crucial (e.g., managing trash). Blame for the occurrence of receding edge work is easily placed on predecessors, and the responsibility for taking care of it is easily pushed down to successors.

The work hours spent on these five activities, relative to the total work hours spent on all concrete work, varied from 4% to 36% and averaged 15%. Of note is that activity 2, finishing and patching, amounted to about ¾ of that 15%, that is roughly-speaking more than 10% of the total work hours. Further study is to indicate how many of these hours could have been avoided, e.g., by adopting lean practices such as building-in quality, redesigning operations, and using standard processes.

LITERATURE ON ACTIVITY START AND COMPLETION

Construction project planning and scheduling means figuring out when to start and finish activities. The still-prevailing conceptualization that uses the Critical Path Method (CPM) involves defining and sequencing activities, and computing which ones are critical vs. non-critical in the project schedule. CPM activities are presumed to have clearly-delineated start- and finish times, as well as unique relationships between them (finish-to-start, finish-to-finish, etc.). However, the presumed "sequential finality" (Crichton 1966 p. 45) is unreal.

Often, activities start despite being "unsound," as defined in the Last Planner® System (Ballard 2000, Ballard and Howell 2003), or without having a "Complete Kit," as defined by Ronen (1992) of what is needed to perform them, resulting in workers making-do (Koskela 2004, Formoso et al. 2011). "Starting … with an incomplete kit means more … time to finish the procedure, longer lead time, more 'work in process', reduction of throughput, poor quality and impairment of due date performance" (Leshnoand Ronen 2001). Furthermore, on many projects, activities are interdependent and overlap. Such relationships can only to a degree be modelled in CPM by breaking an activity down into smaller ones. At any level of breakdown, concern with the fuzziness of edges remains.

Fireman and Formoso (2013) studied the ocurrence of making-do and articulated "unfinished work" realized by informal work packages (activities). They stressed the need to build quality into the process of doing work and aligning activity completion with quality control (op. cit. p. 520). They also noted that methods for doing work must be well defined (e.g., developed and tested in first-run studies). Specifications of methods to achieve the needed level of process capability, with corresponding worker skill expectations and provision,are inputs to a process.

A process is defective if any of these are lacking, e.g., these inputs are lacking (so the activity itself should not be allowed to start), or the method itself is defective when in execution in a given context the process capability cannot be realized. The here-presented receding edge concept focuses on making-do, not seen as an 8thwaste, but rather as the manifestation of a means to address defects (one of Ohno's 7 wastes) in execution of an activity, and observable as unfinished work.

Handoffs of work performed by one contractor to another one, and the quality of work required should meet the standards of the contractor doing the work, of the contractor who will perform follow-on work, and of other customers. This means that the receding edge of one contractor is the leading edge of another; if one is fuzzy, the other one is too.

Traditional methods of tracking project costs and progress also overlook important production aspects of the delivery process. Kim and Ballard (2000) argued that project controls using the Earned-Value Method (EVM) fail to account for work flow or for handoffs between trades. The follow-on contractor gets blamed for delays upstream as their predecessor already has earned their value for the work completed. Moreover, the work of the predecessor may be deficient or insufficient for the follow-on contractor(s)to perform and complete their work. Kim and Ballard (2000) also show that EVM considers all hours of work to be identical and treats all productivity likewise. This presumed homogeneity of time and effort is not necessarily an adequate representation of work chunks in general. A key distinction exists between non-value-generating work and value-generating work, which could be essential to project completion. This distinction maybe lost in EVM's consideration of progress and cost. In contrast, the Last Planner® System is all about creating and sustaining work flow reliability, including managing handoffs (Ballard 2000).

Punch lists developed at the close-out stage of construction are a way for the owner, designer, and contractor(s) to capture some of this crucial work. Clean up, spot checking, and other work that must be finished prior to a handoff are included on these lists. However, punch lists tend to include only the end-of-project work, the most notable defects that were left behind, still obvious, and worth noting. Unless a built-in quality program is pursued, the intermediate activities and project phases do not have such lists to ensure such left-behind work is taken care of in a timely fashion. Both of these negatively impact a project, as either the quality of the finished product is compromised, or workers have to waste time and money remobilizing to finish work that should have been completed earlier.

Customers do not want to pay for non-value-added work, it is waste. To reduce its occurrence, quality should be built in the process (Ballard and Tommelein 2014): work must be performed to consistently meet the desired level of expectation, "done-done" the first time around, and never require rework. This is not systematically achieved on projects.

CURRENT PRACTICES& LEAN IMPROVEMENTS

We next detail observations of left-behind work (aka. unfinished work, work in process), i.e., work that is "done" but remains to be "done-done" and thus defines the receding edge. Lean Thinking, specifically the 5 WHYs applied to the unintended, negative consequences, then led to the identification of actionable root causes so the work could be "done-done."

OBSERVATIONS

Forming, placing, and finishing post-tensioned, cast-in-place concrete slabs can be categorized as activities on eitherthe leading- or receding edge. The leading edge is defined by progress made in terms of the number of floors of concrete placed and cured, whereas the receding edge is defined by the number of floors where the contractor has "done" the concrete work, yet clean-up and related processes before handoff to the next contractor(s) are still not "done-done." "Done-done" depends on how "fit-for-purpose" and more generally "quality" are defined for the project (e.g., criteria for exposed concrete ceilings will tend to be more stringent than those for concrete hidden by ceiling tile). Examples observed of work not "done-done" include:

1. **Floor Concrete Finishing**: Figure 1 depicts a floor where concrete work was "done," but still required patching before a smooth surface could be handed off as "done-done" to the finishing subcontractor.
2. **Ceiling and Wall Concrete Finishing**: Figure 2 depicts a wall/ceiling intersection with concrete leakage that occurs at the edge of the floor, causing excess concrete to dribble down and coagulate on the walls of the floor below. The resulting patches of excess concrete must be removed by a returning crew before the floor is cleared.
3. **Left-over Materials and Debris Waste:** Figure 3 depicts a completed floor ("done") where removal of debris and left-over materials is still required in order to handoff a clear space to the succeeding contractor.

Figure 1: Floor concrete holes requiring patching work

Figure 2: Ceiling and wall concrete finish requiring patching work

LEAN IMPROVEMENTS

5 WHYs on Need for Patching

Poor finishes can be addressed using one of two approaches: (1) proactively implement a countermeasure to avoid having bad finishes or (2) reactively implement a process to patch and fix the ceiling surface before handing off the floor.

A 5 WHYs analysis on defects found on the concrete floors (Figure 1) identified as a root cause a lack of cleaning and lubricating standards for concrete formwork panels. A lack of standard process results in chunks of dried concrete remaining after a placement which, if not cleaned prior to the next placement, then cause the panels to stick to the new layer of concrete. This challenge stems in part from the fact that the contractor applies no lubricant to panels (except some on the panel perimeters), prior to the next placement to prevent concrete from adhering to them.

A proactive counter measure is to put form oil on panels (ACI 2018). This is industry practice and the observers were surprised to not see it done on this project. This countermeasure would have another consequential advantage, namely that laborers would gain time and save energy when removing panels. Right now, this is difficult work for them. However, a reason for not oiling forms may stem from a concern for safety. As soon as the deck forms are put in place, other contractors will walk on them to install slab embeds to be cast in concrete the next day. A slippery surface may be hazardous especially to workers hurrying to complete their work in the day allotted. Note that the contractor does clean and thoroughly oil all panels when moving them from one project to the next. Further study to address these concerns with product quality and safety is in order so they can both be met.

As for the reactive approach, the contractor appeared to not have a standard process defining when, how, and who would do the patching. Standardization is the basis for improvement. When a process is standardized and stable, deviation from the standard can be seen and root causes found and addressed. Therefore, a standardized process must be created for patching, and with it comes the need to specify quality assurance and control (built-in quality being the goal). The quality standards must be clear and defined, so that the worker performing the work knows against what standard their work will be compared.

This project did not appear to have a process, when a floor or wall or ceiling must be patched, to ensure the quality standard would be met. A suggested countermeasure is to create reference sheets with pictures of what is or is not acceptable. Laborers performing the patching then will know how their work will be judged. The standards must be defined in accordance with the client's requirements, as the client will judge if the surface is acceptable, and developed with help of current practice and industry standards.

Quality control would happen in several steps. For example, first, when formwork has been stripped, the inspector will take pictures of all finishes that must be improved and pin these locations on a map of the floor. Then, in collaboration with the project manager, they would develop a schedule for the patching crew with dates of completion. A final inspection with pictures would approve (or not) the repairs.

Having a well-defined patching process and quality standards, i.e., defined process capability, has several advantages; without a standard, one cannot notice deviations from it (sic). A standard allows workers to not be in the dark regarding the work they have to perform, how to perform it, and what to expect as output. It gives them a way to judge the quality of their work themselves, so that less or no subsequent quality control is needed.

Of the two approaches mentioned, the proactive one, preventing the need for patching, is preferred over the reactive one, remediating the occurrence by repairing patches.

5 WHYs on Occurrence of Leakage

A 5 WHYs analysis on defects found on walls and ceilings (Figure 2) homed in on panel design and configuration constraints and identified two root cause of concrete leakage at edges. As panels are abutted to each other, there are gaps in-between them and some leakage is expected. However, leakage can be excessive when these gaps get to be too large. One root cause is insufficient consideration given during panel placement in terms of skirting and grading. Another root cause is panels shifting and therebyleaving gaps between edges. We did not investigate approaches to address the first. Approaches to address the latter are(1) preventing the occurrence of concrete drippings and (2) providing a process for removing drippings after they occur.

A preventive countermeasure is to close the gaps between the sides of panels. Figure 4 shows an example of the countermeasure observed on site, covering gaps with duct tape (or metal flashing) to ensure that concrete will not leak. These coverings had to be removed during stripping. Regrettably they also left spots to be patched by a returning crew.

Many formwork accessories exist to prevent concrete leakage. Figure 5 illustrates joint panel strips used to fill gaps between panels or between panels and edges so as to minimize leakage and thereby make it unnecessary for the laborers to later grind concrete down.

The purchase and application of junction panel strips would come at a cost (though small, as the application is only on the edges) and require time to install before concrete placement. In return, elimination of the need to remove any duct tape or metal flashing used currently (Figure 5) to cover cracks, and reduction in leakage would later save time and labor. In tandem with this, a standard process similar to the process mentioned in the previous subsection should be developed within the formwork stripping procedure to ensure that any patchwork can be completed as soon as possible after a placement is complete as concrete hardens over time.

Figure 3: Waste belonging to Webcor Concrete that required removal

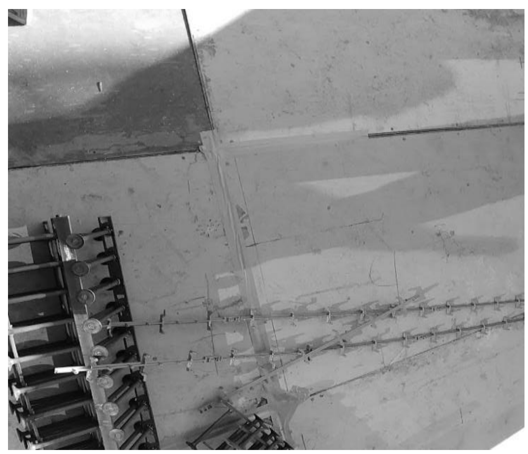

Figure 4: On-site countermeasures taken when gaps between panels are too large

5 WHYs on Left-over Materials and Debris Waste

Waste comprised left-over materials and debris (Figure 3) that laborers must clear off the floor before being “done-done.” These materials were either in excess and needed to be removed, or were supposed to be reused but were left unsorted thereby making reuse harder or misuse more likely. A 5 WHYs analysis on the presence of such waste identified as a root cause that no process was in place, or person held accountable, for cleaning up during work or after the completion of work. No standard was in place to define what is considered a clean workplace, and no process was implemented as work progressed to ensure that no waste would be left over.

Webcor promotes a "clean as you go" process to address the problem of materials left on the floor. However, this process is ill-defined in terms of steps to be taken and control to be exercised to ensure the process is performed in a timely fashion and has been performed correctly ("done-done"). The presence of waste is costly because it is potentially hazardous, it obstructs the passing of workers and handling of materials, and it impedes handing off a clean floor to incoming contractors.

Suggested countermeasures are to facilitate cleaning work on a continuous basis, a part of a built-in-quality process. Every worker, when she or he has things no longer needed, should put them in a designated cart or personal trash container (e.g., Figure 6 illustrates a personal trash container used on a project in Norway). Carts and trash containers should be on wheels and be readily available to any worker. Carts must be labelled so that workers can sort reusable items immediately when they put them down. To promote sorting practices among workers, cleaning should be brought up in daily meetings by the foreman and practices must be systematized. For example, if at the end of one day, the foreman sees waste left on the floor, the next day they would mention it. New workers should be trained so that they know that "clean as you go" is, indeed, the rule and everyday practice. This built-in-quality process should in the long term sustain itself with self-inspections, but other inspections would probably be necessary at the beginning, while worker habits develop.

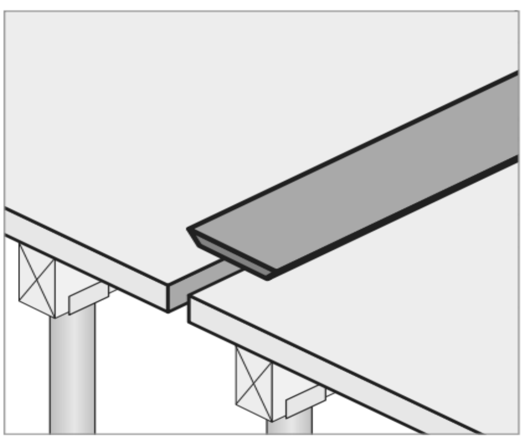

Figure 5: Example of how joint panel strips work in model (Frank 2017)

Figure 6: Use of personal trash container (Veidekke 2017)

CONCLUSIONS

Contractors tend to focus on starting work, the first and most visible part of what they are hired to do. While obtaining good production rates on their "leading edge," however, their "receding edge" with less visible work (e.g., repairing defects and cleaning) may fall behind. The consequences can be costly because this work requires crews to stay on or return to site at the end of their project scope.

This paper presented examples of receding edge work pertaining to cast-in-place concrete slabs that were "done" but not "done-done." The receding edge has not been the focus of research until recently, when Fireman and Formoso (2013) began to study"unfinished work." Observed as work-in-progress, receding-edge activities may be the consequence of defects (one of Ohno's 7 wastes) in execution due to lack of inputs (so the activity itself should not be allowed to start) or due to defects in the method itself when, in a given context, its process capability cannot be realized. A key finding is that methods must be better specified and standardized all leading- or receding edge work alike.

This study raises several questions for future research. It was presumed desirable that leading-edge and receding-edge work keep pace with each other. Under what circumstances is this the case and why? As trade specialization may hamper workload balancing and levelling, when is the division of labor "penny wise, but pound foolish" as it relates to production system performance? How can receding-edge work be made more visible (e.g., it is now embedded in various cost codes) and more manageable?

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