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PULL VS. PUSH IN CONSTRUCTION WORK INFORMED BY LAST PLANNER

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ABSTRACT

The Last Planner System (LPS) is widely characterized as a pull system. In this paper the authors question if this characterization is correct. The authors argue that LPS applies a combination of pull scheduling and push control at the shop floor level. Line of balance and Takt-time Planning are also discussed. There are no findings that support that these techniques applied in combination with LPS change the authors' main conclusion.

The goal of this paper is to provide a better understanding of LPS and to contribute to the discussion of pull-push. The authors agree that pull may not always be the best option. The authors argue that choosing pull, push or a combination of the principles should be based on the production dynamic in question.

KEYWORDS

Pull & push, Last Planner System (LPS), Line of Balance, Location-based management systems (LBMS), Takt-time planning (TTP).

INTRODUCTION

The Last Planner System was developed in 1992 by the Lean Construction Institute (LCI) (Ballard, 1993). LCI presents LPS as a production system created to produce predictable work flow and fast learning in programming, projecting, construction, performance documentation and the handover of projects[4]. LPS and lean construction was developed in the wake of lean, inspired by Toyota, which first was developed for manufacturing (Ballard, 2000; Kalsaas, Grindheim and Læknes, 2014).

Pull as a production logistical principle is central to lean manufacturing and production (Womack and Jones, 1996; Rother and Shook, 1998). It is often associated with just-in-time production, a commonly used term previous to when the term «lean» was introduced (Kalsaas, 1995). A search in the IGLC (http://www.iglc.net/) conference papers, using the keyword "pull" yielded 63 matches[5]. The query «pull scheduling» returned 2 matches.

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4 Based on a undated note downloaded from LCI's home page, 2014

5 The database includes papers from the 4th annual conference to the 22th in 2014

Ballard (2000) defines «pull» in production control, by referring to Hopp and Spearman's (1996) definition for manufacturing: "Pull systems release materials or information into a system based on the state of the system (the amount of work in process, the quality of available assignments etc.) in addition to due dates". In contrast, the push system releases materials or information into the system "based on preassigned due dates" only. Work controlled by push is based on a plan. Ballard then refines pull in construction to be "ultimately derivative from target completion dates, which specifically applies to the internal customer of each process". Arguments on pull are emphasized as part of the Lookahead-plan (pulling work from upstream production units). Ballard argues that the constraint analysis in the Lookahead-plan is utilizing a pull-mechanism, in contrast to traditional construction scheduling (e.g. the Critical Path Method -CPM) which is based on push-mechanisms. The Lookahead-plan supports Ballards claim that LPS is a pull system: "Further, making assignments ready in the Lookahead process is explicitly an application of pull techniques. Consequently, Last Planner is a type of pull system." Koskela (1999) also emphasizes the pull system as an important instrument for "ensuring that all the prerequisites are available for the assignments» as a part of the Lookahead-plan in his design criteria for production systems. Thus, the pull-mechanism is justified by the criteria that upcoming assignments are actively prepared. Kalsaas, Grindheim and Læknes (2014) considers "pull" to be one of the basic principles of LPS.

Pull-mechanisms do not seem to be support production plans involving direct construction work (shop floor level). Ballard (2000) claims that concrete delivery to a construction site is one of few shop floor level activities which is traditionally governed by pull mechanisms. This is due to the short shelf life of fresh concrete, which makes it necessary to commission it only when it is actually needed at the construction site. Long supplier lead-time for most materials and products is suggested as the reason for the domination of push-mechanisms on the shop floor level. In his doctoral work, Ballard (2000) calls for a "puller" to be included in LPS on the action item log. He is, however, not specific about what that should be.

This paper questions whether LPS is a pure pull system. The authors theorize that this is not the case, and that clearer and more precise use of terminology is necessary in this area.

This paper gives an overview over what is considered push and pull in a production logistical environment. Pull is then considered in the context of the Toyota production system. This is used as a reference for further discussion subsequently followed by a description of LPS. LPS in turn is analyzed in relation to pull and push. Lastly, the relationship between push, pull, milestone planning, LBMS, Line-of Balance and takt-time planning is discussed.

WHAT IS PULL AND PUSH?

A pull signal is dispatched when a product is procured. In construction we often deal with Engineer-to-order, and despite of the customers pull, the production might be pushed toward the contracted delivery date. In the context of this paper, pull is defined a downstream work process that pulls materials from an upstream process. This mechanism enables the amount of work in process to be reduced, when compared to the push control mechanism. Push is closely tied to Material Requirement Planning (MRP), where production schedules for each work station in a production chain are developed centrally. There are some disadvantages for this system. If problems occur in a work station downstream in the chain, work in process will build up in front of the workstation with unexpected downtime. A pull mechanism, on the other hand, reduces the demand for material from the upstream workstation, since it only produces materials according to demand. This dynamic propagates further upstream in the production chain.

One renowned pull system is known as kanban. Kanban is the Japanese word for “signboard”. Kanban cards are used as a method for issuing commands in the production of material. The kanban system was developed by the Toyota Motor Company, and it is connected to JIT production and pull. Kanban can be described as a control system for replenishing material based on actual demand. The demand can be from an external customer or from a downstream work process. The kanban system is based on the creation of buffers along the production line, which replenishes materials simultaneously with their consumption. The demand from the customer is visualized upstream in the production chain through kanban cards and kanban billboards. This provides clear management information which facilitates operator’s ability to prioritize the orders. Kanban is therefore known as a systematic method for material and information determination on the shop floor level. Designing and scaling a kanban system requires both analysis and planning. The focus of the design stage is to locate buffers and kanban loops, while scaling is focused on determining the number of kanban cards to circulate between the producer and consumer of a specific unit in a kanban loop. The number of cards is calculated from demand forecasts, assumed lead times, and the tolerances for the required security factor needed to compensate for demand variations.

The number of kanban cards (N) in a loop in its simplest form can be calculated in the following way: $N = E*L/C$, where E = demand in a defined interval, L = lead time from delivery of a kanban order to recipients, C = unit load. If E = 150 pieces per day, L = 2 days, C = 40 pieces, the loop would need 8 kanban cards. Kanban will increase the amount of material which is in process during unstable demand and lead times, e.g. when operational time for production equipment varies.

A selection of literature for production logistics, argues that the material and production control system should be based on a variety of characteristics of the production line (Hyer and Wemmerlöv, 2002; Kalsaas and Alfsen, 2009). The literature suggests that it is beneficial to use pull solutions when the following criteria are met: Low variation of demand; Short changeover time; Small batch size; Small transport batches; Simple flow patterns; Balanced bottlenecks; High levels of operational equipment time; High degree of work flexibility; High delivery reliability; High production quality; and High supplier performance;

Push solution is recommended for the opposite values of these variables. One implication of this theory is that pull solutions may not always be optimal independent production technologies if there is stability in the value chain. Ballard (1999) takes an open stand on pull-push when it comes to design management: “…it may well be true that pull techniques are inapplicable to design management. But it is clear that their absence results in considerable waste and inefficiency”. There are subsequently several approaches of combining push-pull in production control, such as the methods described by Huang and Kuisak (1998).

TOYOTA'S PULL PRODUCTION SYSTEM

Toyota's car manufacturing is done on an assembly line (Kalsaas, 1995). The value chain typically consists of three factories: chassis, painting and assembly. Cars are often painted in batches using the same color in order to reduce changeover time. Each work shift has a production goal set for them for a given number of cars. The production goals as well as the numbers displaying the current status in real time are showed on a luminous billboard visible from the assembly line. All the cars in production are presold. The buyers are generally car dealerships/dealers or end users. The day-to-day production is based on an executive plan. When a painted chassis enters the assembly band and moves from work station to work station, the product gradually becomes a car. The majority of the car parts are assembled by a number av work stations. The parts are pulled to each work station based on a kanban system with a loop to the subcontractors. The subcontractors are usually located close to the car factories in the form of production facilities and/or storage. When a loading unit (kanban) is empty for parts, production is moved to a new loading unit. The released kanban card from the empty kanban-container is then posted on a billboard. This card is used a production order/delivery order to a subcontractor or internal supplier, who is responsible for collecting the cards and refreshing the supplies accordingly.

The assembly line in this respect can strictly speaking be considered a push system. This is because there is no demand from the downstream workstation that initiates work. The belt moves the car frame using a calculated and balanced speed from workstation to workstation for assembly of parts, components and systems.

Toyota, in addition to this process, also employs a quality control system to assure that all the components are correctly assembled before being delivered to the next work station. This process is used to avoid pushing a product that is not ready to the following workstation (Kalsaas, 1995). If an operator experiences difficulties with his assembly, a string is pulled which signals a senior operator. If the operator and the senior operator are not able to solve the problem within the tolerances av predetermined time buffer, the whole assembly line comes to a halt. The system assures supply of products with correct quality before they proceed downstream.

LAST PLANNER[6] SYSTEM

Ballard, Hammond and Nickerson (2010) derived five principles from LPS: Plan in greater detail as you get closer to doing the work; Produce plan collaboratively with those who will do the work; Reveal and remove constraints on planned tasks as a team; Make and secure reliable promises; and Learn from breakdowns.

Kalsaas, Grindheim and Læknes (2014) however conceptualized six underlying principles from LPS, one of which is to "employ the pull principle as the foundation for production control".

The first objective of LPS is to identify what **should** be done via Master Scheduling and Reverse Phase Scheduling (RPS) (Ballard and Howell, 2003). The Master Schedule identifies the milestones for the project, and the focus in the RPS meetings is to pull work packages to meet the milestones thereby validating the schedule. RPS also identifies the work required in order to release work to other

[6] Trademark of Lean Construction Institute

trades and teams. The second objective of LPS is to redefine the work that **should** be done into work that **can** be done by removing identified constraints in the make ready process. Ballard and Howell (2003) identified three categories of constraints for tasks:

Directives (e.g. design documents, specifications, task assignments); Prerequisite work (work that must be finished before the activity starts); Resources (labour, equipment, space)

Koskela (1999) has identified seven similar pre-conditions to any construction work: design, components, materials, workers, space, connecting work and external conditions. These seven prerequisites are also identified as the seven flows. Work is prepared by creating a lookahead schedule for the upcoming 4-6 weeks.

The final planning objective is to commit to work that **will** be done in a commitment meeting which addresses the work plan for the upcoming week. The Last Planner, the individual who will be in the field directly managing or performing the work, commits to complete the assignment. Quality assignments should meet five criteria: definition, size; sequence, soundness and learning (Frandson, Berghede and Tommelein, 2014). In conclusion, LPS identifies what work **should**, **can** and **will** be done and lastly what was actually **done**.

ANALYZING LPS IN RELATION TO PULL – PUSH

The master plan in LPS is an executive plan made up of milestones, and contains no pull mechanisms. The one possible exception to this rule is that some milestones are adjusted or identified based on the RPS-process, where the end of a phase normally is a gate defined as a milestone. RPS itself can be interpreted as pull scheduling as the necessary work for an addressed work package is determined in the method. However, RPS incorporates planning on a more strategic level, not in production control at shop floor level.

A central aspect of the lookahead schedule is to make work packages systematically sound. This is done by removing constrains, i.e. by making materials and equipment available, completing drawings, gathering necessary information and staffing accordingly. Furthermore it enables accessibility to the work place and makes sure that previous tasks are completed with the specified quality indicators. In the weekly work plan (2-3 weeks), work packages are further detailed and specified while constraints and rescheduling are continuously addressed towards execution. The LPS method is based on getting the production done according to plan (Kalsaas, Grindheim and Læknes, 2014). In some implementations, LPS will be supplemented with short daily morning meetings to make the latest adjustments, as unforeseen events always can occur.

By comparing LPS with Toyota’s method of controlling car assembly on the shop floor it is quite obvious to the authors that LPS strives to replicate the same mechanisms. Specifically the make ready process in lookahead-scheduling is similar to Toyotas procedures which only allow a partially assembled car to pass down the line when upstream work is step by step quality controlled. The make ready process in LPS is also conducted on a more detailed level in the weekly work plan. It is also possible to halt the work if all prerequisites to complete a work package are not sound. However with LPS, work from a backlog of sound buffer work packages can be included. It is the authors’ understanding that halting work completely rarely occurs in construction projects using LPS, like it does in Toyota’s case. However, work in an

LPS system might be rescheduled in the lookahead-process and/or in the weekly work plan, when necessary.

Pull scheduling is obvious an attribute of LPS, but it is more difficult to identify pull-mechanisms in production control at the shop floor level. A crucial question in this regard is whether the make ready process in LPS represents a pull mechanism. The authors do not believe this to be true. In the make ready process the constraints are removed in order to make the plan achievable. This principle is quite similar to the process in CPM where effort is increased to remove constraints and rescheduling is done as needed. A specific difference between the two is the possibility of halting production in LPS. However, halting production from upstream to downstream, no matter how efficient, is not considered a pull mechanism.

Toyotas method for car assembly cannot be characterized as pure pull production, since the assembly line is ”pushed” out from a predefined takt and speed customized for each work station. Toyota does still have a pull system that pulls the components to the assembly line, and a system build around the assembly line to ensure that work is delivered with the correct quality to a process downstream. In conclusion, Toyota combines pull and push production in their control of car assembly.

If construction projects are to achieve the same level of pull in production as Toyota's system for car assembly, it is necessary for the different components in the seven flows to be established and pulled to production, e.g.: Drawings, equipment and materials, staffing, the work place. Establishing pull on drawing, equipment and materials are manageable, and there are examples of this being done e.g. vendor managed inventory controlled by min/max levels and cargo terminals which deliver small batches of bulky material. Terminals are used as buffer storages outside the construction site, which facilitates optimal material availability. This is set up according to the optimal delivery schedule for the supplier and the main contractor (economy of scale in transportation and order size). The construction sites can pull material from the terminal to the construction site as needed. Since the goods can be both confirmed to be correct and the quality can be controlled on the terminals, the construction sites can manage to have a tight and precise delivery, and avoid excessive stock at the construction site. The degree of on time delivery seems to increase with the use of terminal supply systems in construction[7].

When it comes to a resource plan for labour, the plan resembles a push based plan just like any other MRP plan. It is difficult to see how it is possible to achieve a pull-mechanism for labour when the workers' interests must also be accounted for. By applying work buffers, increased flexibility can be achieved for labour demands.

MILESTONES AND PULL – PUSH

The master plan in LPS is a milestone plan, which often is part of the contract between a professional client and the main contractor in Design-Bid-Build. “Construction of exterior skin” is a commonly applied milestone which differentiates between the finish of exterior and start of interior work in construction.

The focus of the RPS meetings is to pull the plan to the milestones in order to validate the schedule (Frandson, Berghede and Tommelein, 2014). The challenges

[7] Experiences from Skanska Norway

that emerge from the use of the RPS process are commonly associated with the need to make changes in regards to the “exterior skin” milestone. This is necessary to enable a production process characterized by effective utilization of resources within the time available. This challenge has been experienced first-hand by a large Scandinavian contractor. This contractor usually starts a project by organizing the RPS process, not only for the intermediate milestones, but for the entire project. The challenge arises when the date of the milestones cannot be changed in the contract, which most likely stems from a lack of trust. This lack of trust can be explained by the terms asymmetric information and opportunistic behaviour in the transaction cost theory (Williamson, 1975). An Integrated Project Delivery (IPD) contract is likely to provide improved conditions for collaboration when it comes to trust and establishing milestones.

However, whether a milestone is determined in a collaborative RPS process or is strictly a bureaucratic decision becomes inconsequential in regards to shop floor control. The determination of a milestone can be described as a point in time where the building project is expected to have reached a state or degree of completion. The work itself might be pushed towards this point. As a result of this the production level is associated with how the work progress is controlled on the shop floor, as explained earlier in the paper.

However, it seems unfavorable that central milestones applied by different disciplines and trades are decided without collaborative planning (RPS) and joint understanding of processes and methods. Functional milestones pre-established solely with the client could enhance the workers sense of being pushed in a way that is not resource friendly or appropriate.

LOCATION BASED MANAGEMENT, TAKT-TIME PLANNING AND PULL VS. PUSH

The location based management system (LBMS) (Kenley and Seppänen, 2010; Kala, Mouflard and Seppänen, 2012) for construction and takt-time planning (Frandson, Berghede and Tommlein, 2013; Linnik, Berghede and Ballard, 2013; Yassine et al., 2014) is frequently combined with LPS (Seppänen, Ballard and Pesonen, 2010; Frandson, Berghede and Tommlein, 2014). In this section the authors discuss if location based management and/or takt-time planning can affect the author’s previous conclusions about LPS.

LBMS (Seppänen, 2014) is related to both Line-of-Balance (LoB) (Lumsden, 1968) and the flowline technique (Mohr, 1979). LoB addresses repetitive work, while flowline technique removes that constraint and uses location rather than quantity of elements. LoB does not consider flexible location breakdown structures. In his LBMS development, Seppänen (2014) also refers to Arditi, Sikangwan and Tokdemir’s (2002) integration of LoB, CPM and Russell and Wong’s RepCon (1993). The main contribution of LBMS is the use of a flexible location breakdown structure. It combines a CPM algorithm to a location based technique through layered logic and a cost and risk model which accounts for workflow continuity. It also adds buffers between locations, and a production control system which forecasts future progress based on past production rates (Kenley and Seppänen, 2010).

Takt-time is originally a lean manufacturing concept. The focus of this concept is to enable all work operations and processes to generate a product that is synchronized with the customer's demands and requirements while staying within the available work time (Rother and Shook, 1998). When applied to construction, takt-time has been defined as the maximum number of days allowed to complete work in each location (Frandson, Berghede and Tommelein, 2013).

According to Linnik, Berghede and Ballard (2013) the priority of LBMS is to maintain labor utilization. The priority of the takt-time is to have work flowing continuously. Both systems will in ideal situations eliminate downtime for both the staff and the line. LBMS allows the duration of a task to vary when the quantities are different between locations, while takt-time requires task duration to be the same. Tolerances allow for corrective actions in LBMS (Seppänen, 2009). The takt-time is calculated based on the production rate of the bottle neck task or project requirements. A challenge in the takt-time approach is the risking loss of capacity for faster tracks following the bottleneck trade.

The purpose of LBMS is to organize production in production lines. Usually procedures are performed in order to run the production lines parallel, since this reduces the time required for construction. Parallel lines can be accomplished by moving production between different production lines, splitting lines that appear to be too long, and combining lines that seem to be too short. In addition, adjustments related to available personnel, production equipment and the share of prefabricated materials etc. can be made. In some instances it is possible to decrease construction time by reducing a selected discipline`s workforce.

In the context of LoB the authors are trying to conceptualize that the pull signal actually comes from the zone/control area, e.g. special rooms or floors. The signal shoes that the preceding trades have finished up their work in the zone, and as a result the subsequent disciplines can begin their activities. It is necessary to conduct an educated estimate in advance av operations to determine the timeframe a discipline needs to conduct their operations in the relevant zone. If there are possible uncertainties in determining lead time, a time buffer should be added to mitigate any risks. It is unrealistic to assume that subsequent disciplines would be on stand-by and ready to move into the control area regardless of when it is ready. It is common practice for certain disciplines to work in different control areas dictated by the project schedule. This means that there is no true pull mechanism present for production at the shop floor level, even though one can argue that the planning is pull based.

In takt-time planning the takt time is decided by a central decision maker on behalf of all trades, which can be regarded as the customer. However, as with LBMS, the implementation of production appears to be pushed based, as the production train runs its pace based on pre-calculated durations, and not because of pull signals issued based on the state of the object in a specific location. It is apparent that the "will do" mechanism in LPS is violated in takt-time planning.

CONCLUSION

It is necessary to distinguish between different levels in production when deciding which mechanisms of pull and push should be applied to the organization of construction projects. The first level can be described as shop floor control. This deals with how production orders are issued and gives input to "how much of what" should be produced at a workstation. In practice, this can be done by using kanban cards (pull) or by using a centrally calculated production schedule (push) for each workstation in the value chain. The second level can be described as strategic planning. In a kanban system there needs to be a strategic planning phase to identify the required number of kanban cards. The master plan, RPS and lookahead scheduling are all part of strategic planning in LPS.

It is obvious that LPS covers pull scheduling, but the paper argues that production control at the shop floor level is basically push based without any pull mechanism on the work plan level. However useful, the make ready process is push based, even though it can be argued that it can be used to halt production.

Toyota's control of car assembly is also a combination of pull (materials to the line) and push (the moving belt). This indicates that LPS needs to be able to pull materials, equipment, drawings etc. to production to achieve a level of pull control as seen with Toyota. In this paper the authors have also discussed if a combination of LBMS and LPS, or takt-time planning and LPS, would change the conclusion. The result is that both approaches are also comprised of predefined schedules to direct work based on zones/control areas. This means that none of these options represent a pull based system. It is not sufficient to simply remove constraints in order for work to flow in and between disciplines.

The authors believe there is a need for a more nuanced and critical overview of how the term is used. LPS, LBMS and takt-time planning do not automatically become inferior for not applying pure pull concepts. Pull is therefore not necessarily the best technique for organizing production logistics at the shop floor level.

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