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# COMPARISON BETWEEN LOCATION BASED MANAGEMENT AND TAKT TIME PLANNING

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## ABSTRACT

Construction planning methods may or may not explicitly model space as a resource. This paper compares two methods that do. The first method is used in the Location Based Management System (LBMS). The second method is Takt Time Planning (TTP). Both are iterative design methods for planning and controlling construction work, both focus on creating a balanced production schedule with a predictable timing of work while also preventing spatial interference between trades, but they differ in how they achieve these goals. The contribution of this paper is to (1) highlight the similarities and differences between these two methods and (2) describe a proposal for future exploratory research to evaluate the systems using common metrics.

## KEYWORDS

Location Based Management System (LBMS), Line of Balance (LOB), Takt Time Planning (TTP), buffers, resource continuity.

## INTRODUCTION

Space is a resource to consider when planning construction projects (for brevity, we use the term "planning" to include scheduling); despite being omni-present it is often overlooked. Space is important especially in construction because, unlike manufacturing where the work moves to the people, on a construction site the people move to the work (Ballard and Howell, 1998).

Two planning methods that take space into account are compared in this paper: (1) the Location Based Management System (LBMS) and (2) Takt Time Planning (TTP). This paper follows the comparison of planning methods presented by Seppänen (2014) that was based on his deep understanding of LBMS but his narrow interpretation of TTP.

First, this paper presents background on location based planning in construction. Second, it will describe the two methods of planning. Third, it discusses the

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similarities and differences between these two methods. Finally, the paper describes a proposal for future research to evaluate the systems using common metrics.

## HISTORY OF LOCATION BASED METHODS

Location based methods for planning and control have a long history. In the late 1920s, builders of the Empire State Building used location based quantities and a kind of flowline diagram to plan and control the work. Their goal was to establish a production line of standard parts (Willis and Friedman, 1998). In the 1940s, the Goodyear Company developed a systematic method for location based planning called Line of Balance (LOB). LOB was deployed for industrial programming by the US Navy in WWII (Lumsden, 1968) but also applied to repetitive construction. LOB was a graphical technique that relied on repetition, so it was implemented in highly repetitive building projects, such as housing development programs (ibid.), road construction, etc. Suhail and Neale (1993), Arditi, Tokdemir and Suh (2002), and others continued modelling location based planning using LOB lines consisting of Critical Path Method (CPM) networks with tasks that are repeated between locations.

The flowline method (a term coined by Mohr in 1979) was based on work by Selinger (1973, 1980) and his supervisor Peer (1974). A difference is that LOB diagrams do not explicitly show the movements of crews because tasks are presented as dual lines, whereas flowlines represent each task as a single line. Flowline thus requires more detailed planning because it is necessary to be explicit about resources use. Mohr (1979) discussed the detrimental impact of work breaks on production, and the risk of return delay when crews leave the site.

The next developments attempted to integrate CPM and location based models in such a way that they could be computerized and allow for non-repetitive construction. Russell and Wong (1993) developed a method termed *representing construction* that allowed for multiple types of CPM logic within a location based model, free location sequencing and non-repetitive tasks in addition to other features. They allowed for work to be continuous or discontinuous, part of workable backlog or cyclic. Logic could be typical or non-typical. Harris and Ioannou (1998) reconciled the work on location based planning done by others and highlighted that one cannot minimize the duration of a schedule while maintaining continuity of resource use at all times.

Much work related to methods of location based planning has been done by Kiiras (1989) and Kankainen (e.g., Kankainen and Sandvik, 1993). That work was based on planning to manage schedule risk through continuous flow of work and control aimed at reducing interference. Over 30 action research case studies were documented in masters' theses.

## LOCATION BASED MANAGEMENT SYSTEM (LBMS)

### LBMS PLANNING METHOD

Kenley and Seppänen (2010) developed their Location Based Management System (LBMS) by building on this previous work. Their innovations on the planning side include (1) layered logic and (2) calculations adapted from CPM that make it possible to optimize the schedule while allowing the enforcement of continuous work. Flowline remains the means to visualize schedules.

As starting data, LBMS requires the Location Breakdown Structure (LBS), tasks, quantities for each location and task, labor consumption rate for each quantity item, workhours and workdays (calendar) for each task, optimum crew composition for each task and logic between tasks. Tasks can include several locations of similar, repetitive work in sequence of production. By default the schedule calculation is based on achieving continuous flow by delaying the start date of early locations (Kenley and Seppänen, 2010, pp.123-162).

Kenley and Seppänen (2010, pp.204-213) present guidelines for defining the LBSs of a project. LBS is a critical planning decision because it impacts the quantity take-off, the number of logic relationships required to schedule a project, as well as variation of quantities between locations. LBMS calls for physical, clearly defined locations so that there is no ambiguity about location boundaries. Kenley and Seppänen (2010) propose that the same LBS should apply to all or most trades, and certainly to all trades in the same phase. For interior work, they recommend dividing locations by type of space (e.g., office vs. corridor), because different trades' working different functional spaces with different logic and different quantities. These spaces can be grouped by location and then type (e.g., North patient rooms vs. North operation rooms). Finally, they propose eliminating implicit buffers by planning small locations and using finish-to-start relationships. Implicit buffers arise when locations are large enough for multiple trades and finish-to-start relationships are used because it would be possible to start the successor earlier without causing interference. Seppänen, Ballard and Pesonen (2010) proposed that LBS be defined in a collaborative process involving trades in Last Planner® phase planning meetings.

Tasks are defined based on work (1) that can be completed by one trade in a location before moving on to the next location, and (2) that has the same external dependencies to other tasks (Kenley and Seppänen, 2010, p.216). Tasks and dependencies can be planned collaboratively in phase planning meetings. Typically, logic will be defined separately for each space type (e.g., corridors, office rooms, operation rooms, etc.) because the required logic may vary (ibid, p.219). In practice, this requires a different phase plan for each space type (but not for different locations including several spaces with the same type).

Seppänen, Ballard and Pesonen (2010) recommend that between two phase planning meetings trades collect quantity data and labor consumption rates. Trades estimate quantities for each identified task in each location and labor consumption (manhours/unit) for each quantity line item. A task can contain multiple quantity line items if there are different types of work performed by the same crew in the same location (e.g., large vs. small diameter ductwork). The selected labor consumption should be the optimal rate for production of the work for optimal crew (the natural rhythm as defined by Arditi, Tokdemir and Suh, 2002). This rate assumes that all the prerequisites of working will be available and workers will be able to work continuously without interference from others (Kenley and Seppänen, 2010, p.218). The goal of LBMS control mechanisms is to ensure that these optimal conditions are achieved for as many trades as possible, prioritizing tasks with high manhour content.

Optimization is done collaboratively with trades in the second phase planning meeting. The starting point of the meeting is a location based plan with one optimal crew for each task. This will result in a plan with tasks, some progressing at a gentle slope and others with a steep slope in a flowline diagram. In the meeting, workflow is optimized by starting with trades that have the gentlest slopes, so-called bottleneck trades (Seppänen, Ballard and Pesonen, 2010). The available optimization tools in order of desirability are (1) changing slopes by changing the number of crews or scope, (2) changing location sequence, (3) changing soft logic links, (4) splitting tasks (planned breaks) or making tasks discontinuous .The goal is to find a common slope for each phase (Kenley and Seppänen, 2010, pp. 221-230).

Finally, meeting participants analyse schedule risks (the likelihood of a delay occurring) and add time buffers so control actions can be taken if needed. The goal is to find a schedule with minimum cost that achieves the duration target and has an acceptable risk level. They may analyse the risk level through Monte Carlo simulation or qualitatively based on decisions taken to achieve the required slope. Risk is minimized first by trying to minimize variability. To account for any remaining variability, time buffers are added between the tasks to protect hand-offs. Their size depends on variability of the preceding task, the dependability of the trade, and the total float of the task (Kenley and Seppänen, 2010, pp. 233-239). Simulation can be used to inform buffer sizes. In terms of social process, Seppänen, Ballard and Pesonen (2010) propose that buffer sizes are discussed in the optimization meeting.

## LBMS CONTROL METHOD

The control method of the LBMS includes monitoring progress, calculating performance metrics, and forecasting future production based on actual production rates. Alarms are calculated when there is a risk of interference between trades (Seppänen, 2009). The forecast is adjusted to prevent production problems by planning control actions (Kenley and Seppänen, 2010, p.254). The analysis of alarms can be done by a dedicated production engineer who identifies any deviations, prepares material for team review, and facilitates a control action planning session with trades to get commitments to implement control actions (Seppänen, Evinger and Mouflard, 2014). The development of the forecasting method and empirical research on its effectiveness in addressing production problems has been researched by Seppänen (2009) and Seppänen, Evinger and Mouflard (2014). It should be noted that this system is based on having time to react with control actions before interference happens. This requires buffers in the location based plan.

LBMS control includes tracking of actual production rates and labor consumption at least weekly, but preferably daily for any tasks affected by committed control actions. Progress data is self-reported by trades and validated through site walks by the production engineer and superintendents (Seppänen, Evinger and Mouflard, 2014). The root causes for any deviations are analysed. Main deviation types are start-up delays, production rate deviation, splitting of work to multiple locations, out-of-sequence work and interrupted work (Kenley and Seppänen, 2010, pp.346-348). The impact of deviations is analysed by the production engineer using the schedule forecasts and alarms and validated with the superintendent(s). Finally, the production engineer initiates a collaborative control action process involving all affected trades to get back on track (Seppänen, Evinger and Mouflard, 2014). Possible actions include changing the production rate, changing the work content of the task, breaking the flow of work, changing the location sequence and overlapping production in multiple locations (Seppänen and Kankainen, 2004). Additionally resources can be assigned to work on workable backlog tasks if they would otherwise need to leave the site (Seppänen, 2014).

If there is insufficient time to react with control actions or control actions are not taken, an alarm can turn into an actual production problem. Production problems can be (1) start-up delays (a trade is unable to mobilize when committed), (2) discontinuities (a trade demobilizes), or (3) slowdowns (a trade's production rate decreases due to interference) (Seppänen, 2009). If (1), the forecasts are used to pull the trade on site when locations are available. If (2), the forecasts are used to find out a suitable return date. If (3), one of the trades will get to own the location and the other(s) must work on workable backlog or demobilize. All these decisions are made collaboratively with the trades based on the production engineer's input.

# TAKT TIME PLANNING (TTP)

## TAKT TIME PLANNING METHOD

The use of Takt time to plan construction work is rooted in the use of Takt time in (lean) manufacturing to set production rates that match the demand rate (e.g., Hopp and Spearman, 2008). Takt time is defined as: "the unit of time within which a product must be produced (supply rate) in order to match the rate at which that product is needed (demand rate)" (Frandson, Berghede and Tommelein, 2013).

Frandson and Tommelein (2014)—knowledgeable in CPM, LOB, and numerous space scheduling methods—developed the TTP method described in this paper and tested it on a pilot project; they have follow-on research underway. They see TTP as a method for work structuring (Ballard, 1999; Tsao et al., 2004) in order to design the production system for continuous flow. The objective is to produce a production plan (a plan used to steer and control construction work on- and off-site) that provides a balanced work flow for a certain scope of work in the time allotted. That scope typically spans a construction phase (e.g., overhead MEP installation, in-wall rough installation, interior finishes), that is, a period of time during which a number of trades have to perform interrelated work. "Balanced" refers to the desire to create a stable pace of work (matching the demand rate) for each trade, with each trade proceeding through a sequence of zones (not necessarily the same sequence or the same zones for all trades). This is similar to the "week beat" scheduling described by Court (2009). As is the case for locations in LBMS zones are "physical, clearly defined locations so that there is no ambiguity about location boundaries" and they may vary from one another. Zones, pace, and sequence are all system parameters that get determined through the iterative process called production system design.

A key characteristic of TTP is that each trade must complete their work in each assigned zone within a set amount of time, namely the Takt time. This design parameter, once set, is constant throughout the phase. In order to accomplish reliable work completion (the hand-off to the next trade), after driving out all variation that can be driven out yet recognizing that numerous uncertainties can hamper the execution of work, TTP uses capacity buffers. Trades must underload their production units, that is, assign them to work at, e.g., 70 or 80% of capacity.

One source of variation that is driven out through the design of zones is the variation in work density. "Work density" refers to the situation in an area on site based on (1) the amount of work required by one trade in a particular area, (2) the trade's crew sizing and capabilities, and (3) the trade's means and methods (when prefabricating off site, the work density decreases). As such, some areas have a higher work density than others (e.g., compare electrical work in a lobby compared to an operating room). Different trades will have different work densities as well. Thus, through data collection and design of the zones this work density variation from zone-to-zone and trade-to-trade can be reduced.

## PROCESS OF TAKT TIME PLANNING

Frandson, Berghede and Tommelein (2013) described TTP as a six step process consisting of (1) data gathering, (2) zone and Takt time definition, (3) trade sequence identification, (4) determination of individual trade duration(s), (5) workflow balancing, and (6) production schedule finalization. The first five steps occur iteratively, similar to the 'rough to fine' production system design described in Ballard and Tommelein's (1999) paper on continuous flow.

**Data Gathering:** Developing a TTP requires collecting production data from each trade individually and the team as a whole well in advance of construction. A master schedule may have been established, but before any production planning is done, data gathering begins with a production team meeting, consisting of trades involved in the work and the general contractor (GC), to discuss the product of TTP. The team must set their overall production target (e.g., "a chosen Takt time, with a consistent trade sequence through out every zone and balanced work zones"). The target may be specific and based on previous experience with similar work, or more general if the work and production team are new to using Takt time. It must also reflect the time the team will have to complete the work and milestones in-between (e.g., specified in the contract including the master schedule).

The data to gather in conversation with the trades is specific to them, their work, and the project context. How do they want to move through this project's space? What alternatives are available? What are the material and manpower constraints, or work method alternatives? What work needs to be performed before they start work? What is the sequence of work internally (e.g., electricians want to set trapezes, run conduit, and then pull wire)? Can the sequence be split, or can the work be performed in a later phase (e.g., does the electrician have to pull wire immediately after the conduit is run)? Trades may color up plans in order to show their desired work flow, what can be completed and when and under which assumptions. In order to understand the set of options deemed feasible for a trade, though perhaps not optimal from their perspective, alternatives must be discussed with each trade so as to allow for a set-based approach in developing the phase schedule. Each trade's set of options can then be tested against the sets of options available to other trades, so as to develop a combined plan that is better for the project as a whole than could have been obtained had each trade individually offered only their most-preferred option, or had the GC pushed a schedule on the trades to comply with. A GC schedule embodies too many assumptions and constrains the trades' abilities to do what they do best. Better plans can be developed when the team is incentivized to address the "Who pays and who gains?" question with overall project optimization in mind.

The trade representative in the conversation must be able to provide this level of detail, e.g., the foreman able to commit to doing the work. The benefit to planning early with these details is that people develop deep understanding of both their production capabilities and the resulting plan from the collected information.

**Zone and Takt Time Definition:** Zone and Takt time definition relate to one another because the duration required to complete a task is dependent upon where and what needs to be built. Zones are defined by means of an improvement process, starting from zones, e.g., (1) already established in previous work phase. (2) created using the data gathered in a holistic manner (i.e., all the trades are considered when creating the zones). (3) designed to best satisfy (and then improve upon) the work of one trade because it is evident from data that their work will be the “bottleneck.” This initial set of zones is the starting point for iteration.

**Trade Sequence Identification**: Given a set of zones, the trade sequences are obtained from each trade individually and then combined through phase planning in order to honor sequential dependencies while working through the construction documents or building information model with the team. When identifying the trade sequence—which doesn’t need to be a line sequence (as in the Parade of Trades (Tommelein, Riley and Howell, 1999)), it’s important to document the requirements each trade has in order to correctly hand off zones from one trade to the next.

**Balancing the Plan:** Balancing the plan occurs in a rough-to-fine fashion. From the proposed zones it is now possible to refine the task durations for each trade. Typically trade task durations will vary through the zones. Once the variation is known, the production team can begin to balance the production system.

The production team has several methods to balance the work flow and design the production system. We list these methods next but do not mean to imply any order in which to apply them. The team can iterate upon the zones. If the zones are consistently uneven across the trades, the team can redesign them. Ideally, if it is early enough the actual design of the project could be changed to improve production. Zones may be unbalanced due to the nature of what is being built (e.g., an operating room contains more work of certain kinds than a standard patient room). As such, some trades may have to leave out certain work and perform it “off Takt.” The team can also revisit the work methods, trade scope (providing the contract structure enables money to flow across boundaries), and restructure the trade sequence in order to balance the work. Perhaps a trade can individually, or jointly with other trades, prefabricate more work, thus reducing their field installation times so they can meet a lower Takt time. The trade sequence could also change by splitting the trade work into multiple tasks (e.g., split electrical conduit installation from pulling wire) and thereby enable a faster Takt time. The overall schedule then shortens because a reduction in Takt time scales across the number of zones the trades move through.

**Production schedule finalization:** Finalizing the production schedule requires validation, i.e., every trade needs to ascertain that their sequences are feasible and that they can perform the work in each zone to which they are assigned in the given Takt time. A sequence deemed infeasible can possibly be made feasible by “flipping” the sequence between two or more trades through zones in order to maintain the overall production schedule.

Finalizing the production schedule also provides an estimate for the planned buffer in capacity every trade in the sequence must have. This planned buffer in capacity may be used to absorb variation in the field or to help perform the work left off Takt. While the latter may enable the off Takt, “leave out” work to be scheduled more closely, the trade-off is the buffer in capacity is reduced.

## TTP CONTROL METHOD

Successful execution of a TTP demands that every trade makes their hand offs, thus it is critical to control the schedule at levels shorter than the Takt time in order to gauge if the hand off will likely or not occur as planned. This creates a sense of urgency on the project (Frandson, Berghede and Tommelein, 2013). Visually communicating both performance and the plan to everyone is an important part to distributing control, identifying deviations, and maintaining the schedule.

Should one Takt time be missed by a trade, then the work for that Takt may be completed immediately with overtime, completed during the following Takt time provided it doesn't interfere with the succeeding trade, or left out. The work may be left out if the problem is unique to that particular zone (e.g., missing design details) or it can be picked up in a future task providing no work depends on it (i.e., the work cannot be structured in any other way). The reason for the miss should be researched and a countermeasure developed so as to avoid repeatedly impacting future tasks. The benefit of using Takt times to the project is that problems are identified and corrected quickly, instead of passing that production variation to the succeeding tasks.

### SUMMARY

TTP requires collaboration among production team members to develop a plan deemed best for the project overall, and time to iterate from a production strategy to a detailed, feasible production schedule that is balanced. The planning first begins with gathering support from the team to proceed with TTP. Each team member then communicates their individual production system requirements and explores alternatives. Then the team works in an iterative fashion to identify the most suitable sequence, set of zones, and duration to work through the space.

## DISCUSSION

Comparing LBMS with TTP shows more similarities than differences. Both methods aim for continuous flow of work through production areas at a set beat for each phase of work. Both methods also use the ability to trade scope (esp. when commercial terms encourage it) in order to improve the production system. Differences to highlight are how each method uses buffers, control, and how resources are allocated.

Construction planners can use four types of buffers: (1) time, (2) capacity, (3) space, and (4) plan buffers (workable backlog). LBMS buffers with (1), (3), and (4). Time is the preferred buffer, but space is also used when work is scheduled in areas larger than what a crew requires to complete their task productively. In contrast, TTP buffers with (2), (3), and (4). Capacity is the preferred buffer, accomplished through underloading. Space (zones) unoccupied by any trade during a given Takt can also serve as a buffer.

The two methods differ in controlling the schedule. LBMS starts with a top down approach of engineers tracking progress, running forecasts, and identifying problems that are then solved collaboratively. In contrast, TTP starts with visual workplace to make clear to all, who is doing work, and where, in order to distribute control. While the trades may provide frequent updates to the GC, they're OK to work as long as they are completing what needs to be done in the space and time allotted.

The resource allocation difference discussed here focuses on people. LBMS chooses to fully load resources on production tasks and use the same crew size continuously. The durations on the fully loaded production tasks assume optimal production rates ("optimal" here is defined as free from any causes for interference). The tasks are then buffered with time in order to maintain the productive use of people. In contrast, TTP chooses to underload crews on production tasks in order to maintain a timely, predictable hand off. Thus , people are expected to finish ahead of the Takt time, and can then work on "off Takt" work (e.g., workable backlog or leave out work), prepare for the next Takt sequence, conduct first run studies, train, or innovate to improve their work. If crews are working much too quickly, then less manpower is required to complete the production task reliably within the Takt time.

## CONCLUSION

The dearth of empirical data on the use of TTP hinders a more fact-based comparison between the two methods. In order to allow for a deeper comparison, future research should gather data including:

- For each location and trade: planned and start/finish dates, resource graphs, production rates, resource consumption (manhours/location)
- days locations were suspended (no work in location)
- days tasks were suspended (no workers working on a task in any location)
- workable backlog locations / tasks, hours and dates spent on workable backlog

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