AUTOMATIC GENERATION OF A DAILY SPACE SCHEDULE

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ABSTRACT

Construction team members who develop and analyze a schedule for production must identify workflows, solicit trade partner input to look for opportunities for improving production, identify production constraints, and communicate the schedule to craftsmen in the field. To clarity field work, such schedules must consider the resource 'space.' Space scheduling helps to visualize a critical path method (CPM) schedule or a line of balance (LOB) schedule developed using a location-based management system (LBMS). Additionally, production team members need to keep their schedules current. To address these needs, this paper presents a program to quickly generate and adjust a visual space schedule, by project phase. This provides the production team with a visual control mechanism, a means to perform space conflict and sensitivity analysis during planning, a means to track daily goals during execution, as well as a starting point for more detailed 4D CAD analysis. The researchers developed their space scheduling program during planning and are currently using it in the construction of an urgent care center at an existing hospital in northern California. 20 out of 146 days (14% of the scheduled duration) were identified in the space schedule as potential savings and 12 of those days have been realized thus far. Expected results of this implementation are improved productivity due to detailed space scheduling and the daily goal setting; increased communication between trades when they need to negotiate impinging for some time on the space assigned to another trade; and an increased awareness of the work flow at a daily level by trade partners due to the visual schedule. This results in greater predictability of the project's delivery.

KEYWORDS

Location-based scheduling, space scheduling, takt-time planning.

INTRODUCTION

Construction is complex and subject to numerous uncertainties. Planning and scheduling a construction project therefore is a wicked problem (Rittel and Webber 1973). A construction schedule must meet several constraints. It must meet the completion time a customer demands, yet also meet their budget constraints; it must show a logical sequence of activities, yet also allow for subcontractors to work continuously and efficiently; and it should be detailed enough to be project-specific,

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yet also easy to control and update. In addition, it must maintain a safe environment and also provide enough time for quality installation. In all, finding the global optimal solution is likely impossible.

One strategy to manage complexity and uncertainty in a schedule is to apply buffers between activities (Howell et al. 1993). Time buffers as a means to account for space in the schedule help with providing work area access, defining clear handoffs, coordinating successive trades, and managing uncertainty about constructability (Russell et al. 2013). "Space is omnipresent and all too often overlooked" (Tommelein and Zouein 1993) and research shows that failing to account for space as a resource in the schedule may lead to productivity losses (Akinci et al. 1998).

The computer program presented in this paper developed out of a need to communicate how different trade partners would move through a construction space during each phase of an interior retrofit project. The interior phases of work followed the overhead, in-wall, and finish 'parade of trades' (Tommelein et al. 1999). The project was a $3-million dollar, retrofit of an urgent care center on one side of one floor in an existing healthcare facility. The project used an Integrated Form of Agreement contract, the Last Planner™ System, and Takt-time planning (Frandson and Tommelein 2014).

The research described here uses an action-based approach to test a solution to improve communication of the production schedule by making the schedule more visual. The objectives of visually communicating the production schedule were (1) to identify how the resource space was used in the schedule (including how it was used as a buffer); (2) to have trade partners analyse the space schedule for improvement opportunities and space-time conflicts; and (3) to make the information accessible to the superintendent in the field.

METHODOLOGY

This research used an approach deriving from literature on action research (Lewin 1946), design science (Cole et al. 2005) and prescriptive research (McElroy 1982). The reason for selecting the action-research approach is that the "diagnosis of problems does not suffice" and that while there is value in identifying a problem, the diagnosis of a problem must be complemented with experimentation that attempts to solve the problem (Lewin 1946). As such, this research focuses on the construction of an artifact that attempts to solve the practical problem of communicating a construction schedule visually (Cole et al. 2005). Furthermore, applying a strictly epistemic approach would likely fail due to the wicked nature of planning and scheduling (Flyvbjerg 2005).

This research employs four guiding principles for prescriptive research (Ahlemann et al. 2011). First, the researchers began with a problem analysis. Second, they designed and programmed a solution. Third, they evaluated the solution. Finally, they documented the research (including this paper).

The researchers developed and then evaluated their daily space scheduling program (the design artifact) in two ways. First, they evaluated the solution based on the following criteria via survey: innovation, performance, usability, reliability, and flexibility (Ahlemann et al. 2011). Second, they evaluated the solution based on the questions 'Was there any positive improvement in the schedule that developed from use of the tool?' and if so 'How much improvement was there and could the improvement have occurred without the use of the tool or in another manner?'

BACKGROUND

Line of balance (LOB) scheduling is a method to account for space in a construction schedule. It is not new. The Empire State Building's project production system used LOB scheduling from design document completion to construction of the building (Willis and Freidman 1998). This research used the LOB in the context of the Last Planner™ System (Ballard 2000). The researchers jointly with the trade partners on the team developed a Reverse Phase Schedule (RPS) for each construction phase and then produced a LOB schedule for it. In a follow-up meeting with the entire production team they reviewed these schedules and then optimized the RPS, informed by the LOB schedule (Frandson and Tommelein 2014).

While LOB schedules provide a one dimensional representation of space in a schedule and the associated activity's production rates, other factors must be considered when planning for space allocation. Tommelein and Zouein (1993) provided a tool for managing and modelling changes to temporary facilities, material flow, and equipment use on projects. Thabet and Beliveau (1994) identified three classes of space demand for each activity. Class A activities require the entire space scheduled to itself. Class B activities require a fixed amount of space but not the entire space, such that other activities may be scheduled concurrently providing the space exists. Class C activities require staging of material before the activity begins. Their research also provided a method to model space use in order to acknowledge the relationship between productivity and scheduling work in congested environments. Bonnal et al. (2005) classified activities as linear space-constrained, discrete space-constrained, or non-space-constrained. Riley and Sanvido (1997) presented a 16 step methodology for space planning. Four key steps in their methodology are: (1) identify space constraints, (2) identify the space layout, (3) sequence the work, and (4) resolve conflicts.

Due to the capabilities of building information modelling (BIM) software, including space as a resource into the schedule has become more prevalent over the past decade. Hessom and Mahdjoubi (2004) identified the trends in 4D CAD beginning in the 1990s. One trend identified that still exists today is that 4D CAD is primarily used as a communication tool to explain design and construction plans, as opposed to a tool for production planning. Since 2011, Autodesk provides this 4D capability in Navisworks (Autodesk 2011). Akinci et al. (2002) automated the generation of a 4D CAD simulation that performed more detailed time-space conflict analysis using unique industry foundation classes (IFCs) for elements that considered both the space required and the method to install different building components. The research in this paper pertains to a similar time-space conflict analysis but it is based on two dimensional floor plans, rather than the BIM model, in order to meet the last objective of those that are described next.

DAILY SPACE SCHEDULING PROGRAM

REALIZATION OF A NEED AND PROBLEM DEFINITION

To initiate the research, the team began their takt-time planning before the first RPS meeting (Frandson et al. 2014). The takt-time planners held one-on-one meetings with each trade partner and discussed each one's desired and potential alternative workflows. Workflows are the movements of people and materials through the construction space. The trade partners described their workflows in two ways: (1) directionally (e.g., clockwise, North to South, left to right, etc.), or (2) in relation to objects (e.g., work from the vertical shafts out to the perimeter, work out from the electrical room, etc.). The takt-time planners considered these workflows and characterized them as movements through zones. They produced a series of visuals characterizing the workflows for the mechanical, electrical, piping, drywall, and fire sprinkler trades through zones.

The team sequenced their activities and associated workflows through the zones for each phase during the RPS process. Follow-up meetings also used a LOB schedule to account for space using Vico Control (Vico 2009). The takt-time planners did not use actual quantities of work from the BIM model, but rather the crew size and durations from the RPS to populate the LOB schedule. While the resulting schedule did not obtain quantities from the BIM model for the project, the LOB schedule was still useful in identifying areas to improve the scheduled generated from the pull planning process. Using Vico Control in this manner also acted as a proof of concept for the general contractor, for they had the software license but had not used it on a project before.

While the LOB schedule accounted for the movement through the zones in the desired sequence for each trade, it failed to communicate what the zones actually looked like to the trade partners; the trade partners had been much more receptive to the initial colored floor plans generated prior to the RPS meetings. Generating the colored floor plans took a considerable amount of time because it was a manual process of translating the LOB schedule to a series of floor plans. The takt-time planners considered a 4D approach to this problem, but decided against it as it would require maintenance to remain current and it would be cumbersome to implement directly in the field without installing a computer and training the entire team how to use the 4D model. As such, the team identified a need to develop a tool to automatically create the schedule in a visual format (i.e., the daily space schedule). The space scheduling program (problem definition) needed to communicate the following: (1) the activity performed, (2) who is performing it, (3) where it is performed, (4) when it is being performed, and (5) what effects may result from it not being completed in the allotted time (conflict analysis). Last, (6) the output of the program must also be printable and easy to use by all trade partners and the superintendent.

Figure reflects the information flow for the production and distribution of the daily space schedule. The information flow follows the four step procedure outlined by Riley and Sanvido (1997). Input information for the space schedule came from the initial pull plans from the RPS meetings, resulting in a separate daily space schedule for each work phase. The RPS meetings also identified the non-space constrained activities that are in the actual construction schedule but not on the daily space schedule. All activities were made ready and committed to in the weekly commitment planning meeting, thus all steps in the Last Planner™ System were applied.

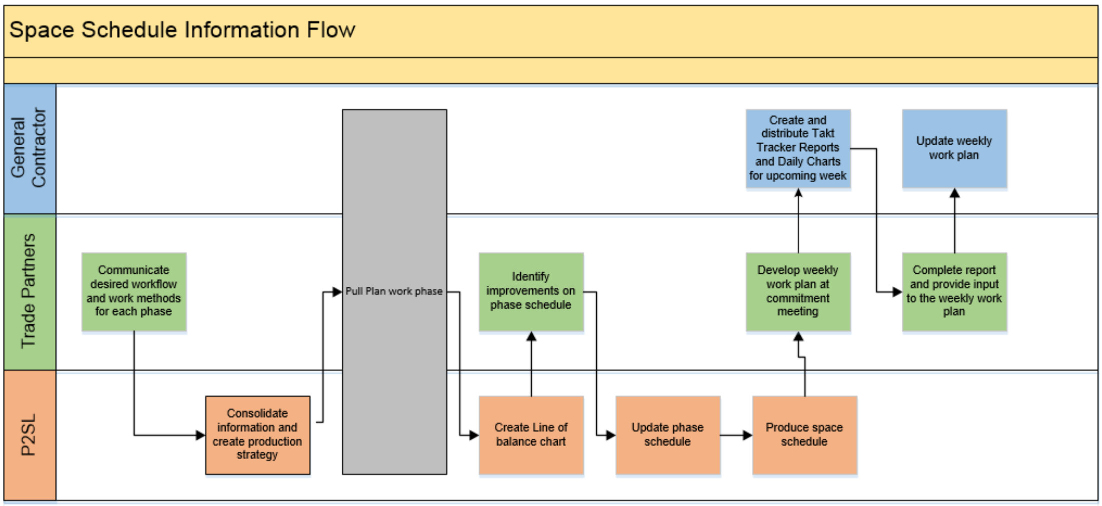

Figure 1: Information flow for production and distribution of space schedule

CONTENTS AND OUTPUT OF THE DAILY SPACE SCHEDULING PROGRAM

The daily space scheduling program is a set of modules the researchers developed in Microsoft Visual Basic for Applications 7.1 for Microsoft Excel (Microsoft 2012). The program creates a colored-up floor plan for every trade, every day, and lists the activity performed. Figure 2 is an example Excel output for 3 days of work for 3 trades. When zoomed out, the entire space schedule for a phase is viewable (Figure 3). The program will also format the floor plan to print to pdf and can be uploaded onto an iPad for use in the field.

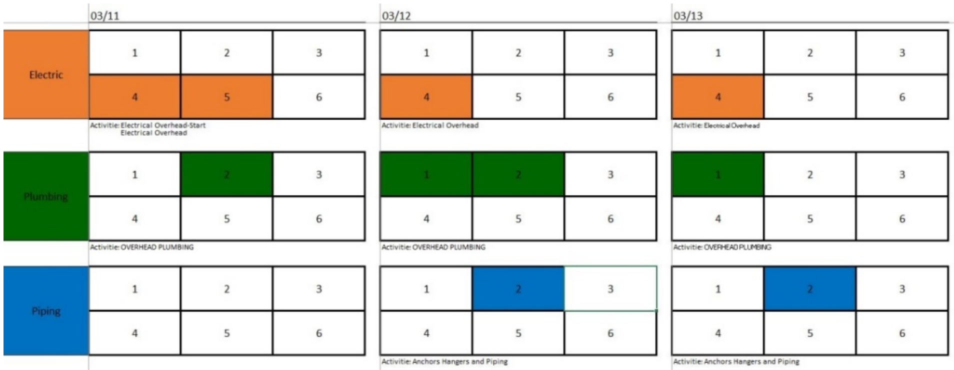

Figure 2: Example output for 3 days of work for 3 trades for a 6 zone floor plan

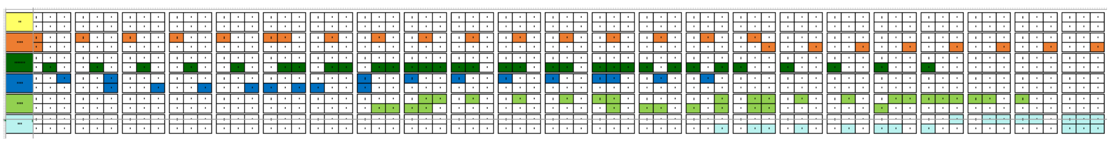

Figure 3: Example output for an entire phase of work

REQUIRED INPUTS AND HOW THE PROGRAM WORKS

Figure 4 is an IDEF0 diagram (DAUP 2001) for the initial creation of the daily space schedule. The program requires four user inputs: (1) a construction schedule, (2) the configuration of zones on the floor, (3) supplier names and (4) their associated colors.

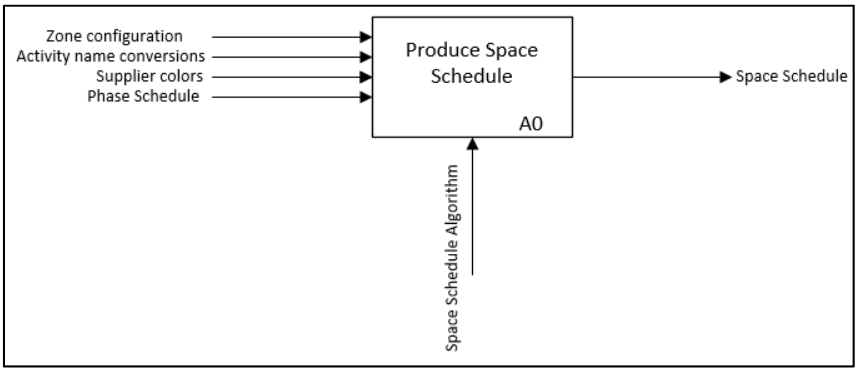

Figure 4: IDEF0 diagram of space schedule

Creating the daily space schedule is a six step process.

1. **Zone configuration** (Figure 5): Create the zone configuration for the given floor plan, in this case, a plan modelled on a 12 rows x 18 columns grid in Excel.
2. **Name the suppliers and their colors** (Figure 6): The names are case sensitive and need to align with the schedule imported. If the imported schedule does not have a supplier column or it is incomplete, then a new column must be created reflecting this information inside Excel.
3. **Name the zones** (Figure 7): The daily space scheduling software requires a means to align the zone names in the zone configuration with their names in the schedule.
4. **Import the schedule**: At a minimum, the imported schedule must contain the activity name, the supplier, start and finish dates.
5. **Convert activity names to zones** (Figure 8): This step developed out of necessity. The names of activities vary depending on the location hierarchy designated in Vico Control. This step is to make sure that the program will identify all the correct zones and make sure the zones' variables are of the correct data type.
6. Run "Create the charts" and "Create the zones."

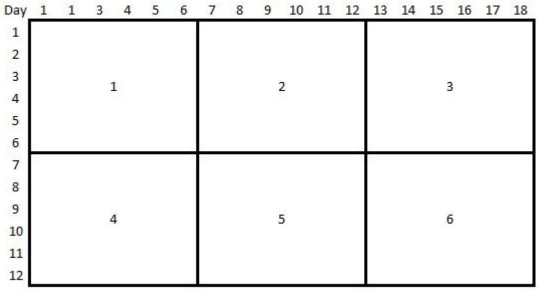

Figure 5: Step 1: Zone configuration

Supplier Name
Drywall
Electrician
Plumber
Piping
Ductwork
Firesprinkler

Figure 6: Step 2: Name and assign supplier colors

Zone Names		Zone Count: 6
Zone1	1	
Zone2	2	
Zone3	3	
Zone4	4	
Zone5	5	
Zone6	6	
Zone7		
Zone8		
Zone9		
Zone10		

Figure 7: Step 3: Name zones

Unique Name list	Zone Assignments
DRILL AND ANCHORS ALL TRADES	
TOP TRACK	
PRIORITY WALL AT DUCT FRAMING	
Priority Wall at Duct Framing Zone 5	
5->1	5
Priority Wall at Duct Framing Zone 2	
2->1	2
PRIORITY WALL FRAMING	
PRIORITY WALL MEP ROUGH IN	
BOXING AND STUBBING (ELECTRICAL AND PLUMBING)	
ELECTRICAL OVERHEAD	
Electrical Overhead-Start	
Electrical Overhead	
FRAMING INSPECTION	
2->2	2

Figure 8: Step 5: Convert activity names

Creating the initial charts runs a first routine to identify the number of suppliers (n), the zone configuration, and the number of days in the schedule (m). A second routine sets up a blank grid of (n x m) floor plans so that space may be allocated to any supplier for any day. The last routine identifies all weekends in the schedule.

First, clicking “Creating the space schedule” runs a routine for every activity to identify the zone, supplier, start date, and end date. Second, for every day an activity occurs, color the zone where that supplier is to work on the floor plan for that day.

CONTROLLING AND UPDATING THE DAILY SPACE SCHEDULE

The activities identified in the daily space schedule all derived from activities in the construction schedule. The activities in the construction schedule were decomposed into tasks and made ready via the make-ready process. Tasks that were made ready and selected for execution appeared on the work plan for the week, accompanied by a daily colored-up progress report generated from the daily space schedule (Figure 9). If activities were not made ready or the schedule changed, the daily space schedule could be updated quickly (under 10 minutes) in the Excel file by importing the schedule update. The daily space schedules were printed and displayed on a board in the work space for the entire construction team to see (Figure 10). The on-site assistant project manager performed the updating and managed the daily space schedule process.

RESULTS

The researchers successfully created a computer program that produced a daily space schedule for use on-site. The senior project manager, project manager, 3 foremen, and an owner's representative were all surveyed on their evaluation of the solution (Table). Overall, the space schedule was appreciated by the team. However, they critiqued the visualization, namely the lack of detail shown on the floor plan (e.g., blueprint details), and they critiqued choices made in the planning process, namely that the work zones were too small. The entire team felt the tool accomplished the goal of making the schedule more visual. Foremen commented that the visual schedule in the field helped them clearly identify where they needed to work, where their crews should not be working, where they were working next, and where open space was available to perform workable backlog. The visual schedule also provided the foreman with 'ownership' of areas. This forced new conversations between trade partners when one needed to work briefly in an area designated for use by another trade.

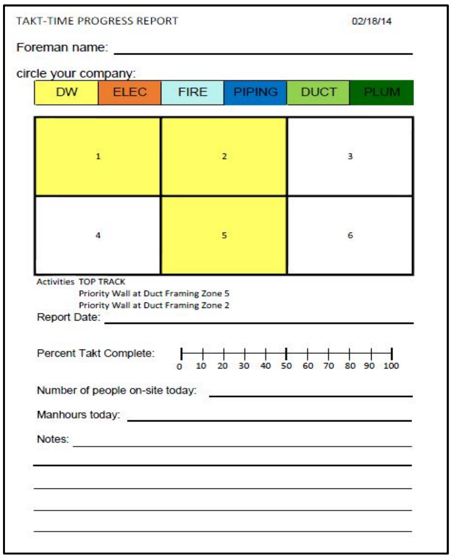

Figure 9: Takt-time progress report output from daily space schedule

Figure 10: Space schedule in the field

Table 1: Results of daily space schedule survey (6 respondents)

Evaluation Survey	Low	High	Median	Average
Innovation	2	4	4	3.6
Performance	3	5	5	4.1
Usability	3	4.3	4	4.3
Reliability	3	5	4	4
Flexibility	3	4	4	3.6

This space scheduling approach was used to schedule 146 work-days. The combination of the space scheduling program with LOB scheduling helped identify

20 days for potential improvement. 12 of the days have already been realized and the Overhead Mechanical-Electrical-Plumbing (MEP) installation sequence finished ahead of schedule (32 days instead of 44). 8 days were identified in the in-wall rough installation phase for improvement. Had the LOB schedule been used by itself to identify available space, it would not have been possible to identify if new sequences of work were feasible from a workflow perspective for the individual trades. The representation of the zones on the floor plan was not only critical to validating potential schedule improvements, but the team also acknowledged that communicating the production plan in the field via the daily space schedule helped them see opportunities to improve schedule.

CONCLUSION

This paper described and evaluated a solution to a common challenge in construction: properly communicating a daily construction schedule to the entire project team. To solve the challenge, the researchers together with the trade partners used a work structuring method, namely Takt-time planning. The resulting schedule was communicated using software to create a Gantt chart and a LOB schedule, and also using manually created color-ups of the floor plan. The researchers developed a program to automatically generate the daily space schedule because the trade partners valued the color-ups medium over the one-dimensional space representation of the LOB schedule. The daily space schedule was displayed on a board in the work space in order to clearly show everyone where trade partners were working, what they were doing, and for how long. Using the daily space schedule and the clarity it provided into the production plan, combined with the LOB schedule, 20 days out of 146 work days were identified as potential days to improve the schedule without incurring additional project cost. To date 12 of the days have been realized and the project is pacing to finish ahead of schedule. A limitation of the daily space program is that it does not produce a colored-up floor plan, but rather a simplified colored version of the floor plan. Nevertheless, it helped the project team understand all trade partners' work flows during the interior phase of construction. This approach using daily space schedules needs to be further tested on other projects.

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