SIMPLEAN: AN EFFECTIVE TOOL FOR OPTIMIZING CONSTRUCTION WORKFLOW

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ABSTRACT

Achieving continuous information flow and effective coordination between construction teams is becoming increasingly difficult with the increase in complexity of construction project organizations. Information has to travel through a busy bureaucratic structure and is often distorted, delayed or even deliberately hidden. The aim of this paper is to develop a solution to this problem that consists of a visual information software platform. The proposed software -SimpLean- allows easy and simple coordination of activities, staff and resources. Live information would be exchanged between construction teams via hand held electronic tablets. The software operation mechanism enables the application of Lean Construction concepts and the Last Planner® System (LPS®) with minimal training and adaptation time. Such software could be considered as a transition tool for contracting firms looking to implement Lean concepts, without requiring deep and radical process changes. The effectiveness of implementing the software in the construction environment is tested using computer simulation.

KEYWORDS

SimpLean, visual information systems, Lean Construction, transparency, Last Planner System.

INTRODUCTION

The use of Lean Construction methods is proven to have great benefits. However, the implementation of Lean methods in construction environments that are unfamiliar with it requires a great effort from both construction teams and specialized Lean experts. Also, numerous case studies have shown that even some of those who implement Lean concepts do not follow the recommended guidelines and end up with a partial and incomplete implementation (Hamzeh et al. 2012). It was also shown that without proper understanding of these concepts and regular support from management and dedicated Lean facilitators, contractors will tend to go back to traditional construction methods (Leigard and Pesonen 2010). In this paper, the authors address the following research questions: 1) Can a simple visual information

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management system help construction teams implement Lean Construction methods? 2) How could a simple communication tool be used to guide construction personnel towards a Lean thinking environment?

The desired software system would have to intrinsically encourage the use of Lean concepts in the management of construction without requiring deep knowledge of the underlying theory or continuous support and motivation. This would allow construction teams to autonomously learn about Lean concepts and acquire the proper understanding of these concepts as they are applying them.

Earlier Research demonstrated the effectiveness of the implementation of a Building Information Modeling (BIM) integrated information management software such as 'KanBIM' (Sacks et al. 2012). This research paper investigates the design and simulation of a novel software system -SimpLean- that can be used as a transition tool and differs from BIM-based systems in many respects; the most notable are the following:

- The software does not use BIM, and can therefore be used by any contractor and on any project even if no BIM model has been developed
- The software does not compute any statistical parameter, instead, it graphically shows relevant information that construction teams want and need
- The software focuses mainly on facilitating, recording and directing communication between the different parties involved
- The software is designed to intuitively direct users towards Lean Construction thinking and embodies the spirit of the Last Planner® System
- The software facilitates a set-based selection of the activities[1] to be completed

LITERATURE REVIEW

BENEFITS OF CENTRALIZED INFORMATION IN CONSTRUCTION

The idea of storing digital information on a common network that is accessible by different users in construction is not new. In the 1990's, common data transfer methods combined Internet and file transfer protocol (FTP) technologies. Most companies today, have a central Internet-based information system that can be accessed by project members (Sulankivi 2003). Numerous commercial applications that help in document managing, time control and construction planning have been created by application service providers (ASPs) and are becoming increasingly commonplace in the industry (Sulankivi et al. 2002). The results associated with using such systems are all positive but greatly vary between companies in Northern Europe and America; this can be attributed to cultural differences regarding communication (Sulankivi 2003). These applications however do not provide any incentive for using Lean management practices.

[1] In this paper, the terms "task" and "activity" are used interchangeably with no differentiation in the level of work to be done.

LESSONS LEARNED FROM SOCIAL NETWORK ANALYSIS

Social network analysis (SNA) models the social structure of an environment by representing each individual as a node and establishing interaction links between these nodes. The interaction links represent information exchange that may be formal (written requests or approvals) or informal (opinions, ideas or warnings). The analysis of the modeled network allows the location of where information is being lost and where talent and worker innovation are not being used (Alarcon et al. 2013). An application of SNA in the AEC industry conducted by Alarcon et al. suggests the following:

1. The network used for regular information flow is almost the same as the one used for problem solving. Therefore improving the information flow network also improves problem solving.
2. The average degree of the Trust network is the lowest when compared with that of other networks (Interaction, information flow, problem solving and planning). This shows that the system lacks transparency.
3. The work environment is highly hierarchical and this has generated bottlenecks and workload unbalance related to inefficient information transfer.

Vitally Priven and Rafael Sacks hypothesized in 2013 that the reason why even partial and incomplete implementations of LPS® has positive results is that a good quality social network develops among construction teams through weekly work meetings. This encourages communication, trust, reliability and thus improves workflow (Priven and Sacks 2013). This makes us question whether developing the social network among construction teams without implementing LPS® could have the same results.

VISUAL REPRESENTATION OF CONSTRUCTION MANAGEMENT DATA

The application of visual analytics (the science of using interactive visual interfaces to aid analytical reasoning) has potential to improve processes in the construction management industry (Russel et al. 2009). It enhances understanding of the project status, improves communication among project participants and facilitates decision making. Furthermore, it eases the process of detecting potential causal relationships, predicting future events based on lessons learned to date and understanding as-built situations based on past data (Russel et al. 2009). Construction data that is visually represented is directly usable by construction personnel without a requirement for specialized knowledge or expert assistance.

HUMAN-CENTRIC VIRTUAL COLLABORATIVE ENVIRONMENTS

The limitation with current technology solutions based on BIM and CAD is in their information-centric nature that doesn't allow project teams to effectively communicate and coordinate activities. In 2013 Fernando et al. developed and tested a system architecture that supports collaboration in design review meetings with positive results. The system turns the information-centric BIM and CAD systems into human- and team-centric environments by introducing a custom user interface. The interface includes a synchronized public space as well as a separate private space. This co-existence encourages team discussions and collaboration without hindering individual work (Fernando et al. 2013). However, the developed software was only used in design review meetings. This inspires the development of human- or team-centric system that can be used in construction and that can be used by crew leaders and management personnel.

BIM-INTEGRATED WORKFLOW MANAGEMENT SYSTEMS

A BIM-integrated software capable of both task planning and work management called kanBIM™ has been tested in 2012 yielding good results: PPC increased from 33% to 47% after the first test and to 67% after the second (Sacks et al. 2012). It must be noted however that a special meeting was held between the first and second test that introduced construction teams to the Last Planner® System. The software uses the BIM model as a foundation and thus can only be used by companies that already use BIM. Another limitation is that the crew leaders have to be familiar with LPS® in order to get good results.

THE NEED FOR A TRANSITION TOOL

The great effort and training required in order to entirely implement the LPS® could discourage construction companies from fully adopting it. Research indicates a poor implementation of lookahead planning and the LPS® on many construction projects characterized by:

- Sluggish identification and removal of constraints.
- Poor linkage between the master and phase schedules with the weekly work plans (Hamzeh et al. 2012, Hamzeh 2009)

Current LPS® products on the market such as ourPlan© (www.our-plan.com) and vPlanner© (www.myvplanner.com) could hold the solution to these problems. However, these software systems appear to be intended for construction companies that are already implementing Lean Construction and seek improvements

What the industry needs is a transition tool that can facilitate collaboration and introduce the LPS® to construction companies that may or may not be familiar with it. This is particularly beneficial to construction companies in developing countries that are not yet prepared to commit to deep process changes or invest in new technologies such as BIM.

METHODOLOGY

The objective of this paper is to propose a novel visual management tool and demonstrate why this tool is important and needed in the construction industry. Following a review of the literature regarding visual management in construction, the authors determine the features required in a software tool that could address the issues with current practice. A prototype user interface is then developed and the corresponding information flow process is analyzed. The task constraint assignment process via the tool is modeled and simulated using AnyLogic discrete event simulation. The assumptions and reasoning behind the model are detailed in the *AnyLogic simulation* section. The simulation results are used to emphasize the benefits of using the proposed software system. The authors finally show how the software features lead to the application of Lean management concepts such as the Last Planner® System and Toyota's set-based design/selection process.

OVERVIEW OF 'SIMPLEAN'

The authors propose that both crew-leaders and section engineers have access to a novel management tool called 'SimpLean'. This tool consists of a graphic and minimalist software system that improves transparency in the construction social network across different levels of hierarchy. Users can access the software interface via different electronic devices but for best results, we recommend that crew-leaders do so through portable electronic tablets.

The main idea is that the tasks that are being done currently and throughout the following week by every crew-leader are posted to the system and are visible to everyone. This enables sub-contractors to know the tasks that other sub-contractors aim to complete in the near future. For every new task posted to the system, all sub-contractors are required to check if there are any constraints or prerequisites related to their trade. A pop-up window with an overview of the task appears on the software screen and sub-contractors have the ability to state the constraints, provide comments or simply indicate that there are no constraints on their part. For example, in Figure 1, the MEP sub-contractor (Sub C) added a prerequisite to the task "False Ceiling Installation" by using the "Add Prerequisite" button. In this case, the software enabled the MEP sub-contractor to signal a prerequisite that could have easily went unnoticed otherwise, therefore avoiding the possibility of later rework. The sub-contractor that will be executing this task will be motivated to meet and coordinate with the sub-contractors that assigned the constraints in order to solve them.

Tasks are usually assigned and posted by the Last Planner®, but sub-contractors also have the ability to add new tasks that he/she might have missed. The Last Planner® has additional administrative control over the software; he/she can sort or modify tasks according to their place in the schedule and their readiness. The software features a customized schedule table for each different user and discussion forums that can be as effective as weekly work meetings. Construction teams would have to be required to check these forums a minimum of twice per day. The forums can also act as tool to supplement and enhance the quality of daily huddles.

PROTOTYPE USER INTERFACE

Figure 1 is a prototype user interface of the SimpLean software as it would be seen by a crew-leader.

The 'My Tasks' window displays the tasks that the crew-leader has to perform chronologically. A click on any of the task's thumbnails expands the task window and allows the crew-leader to edit the task properties (such as expected duration and completion date), address the comments posted by the engineer or other sub-contractors and even attach a photo that would be taken with the built-in tablet camera.

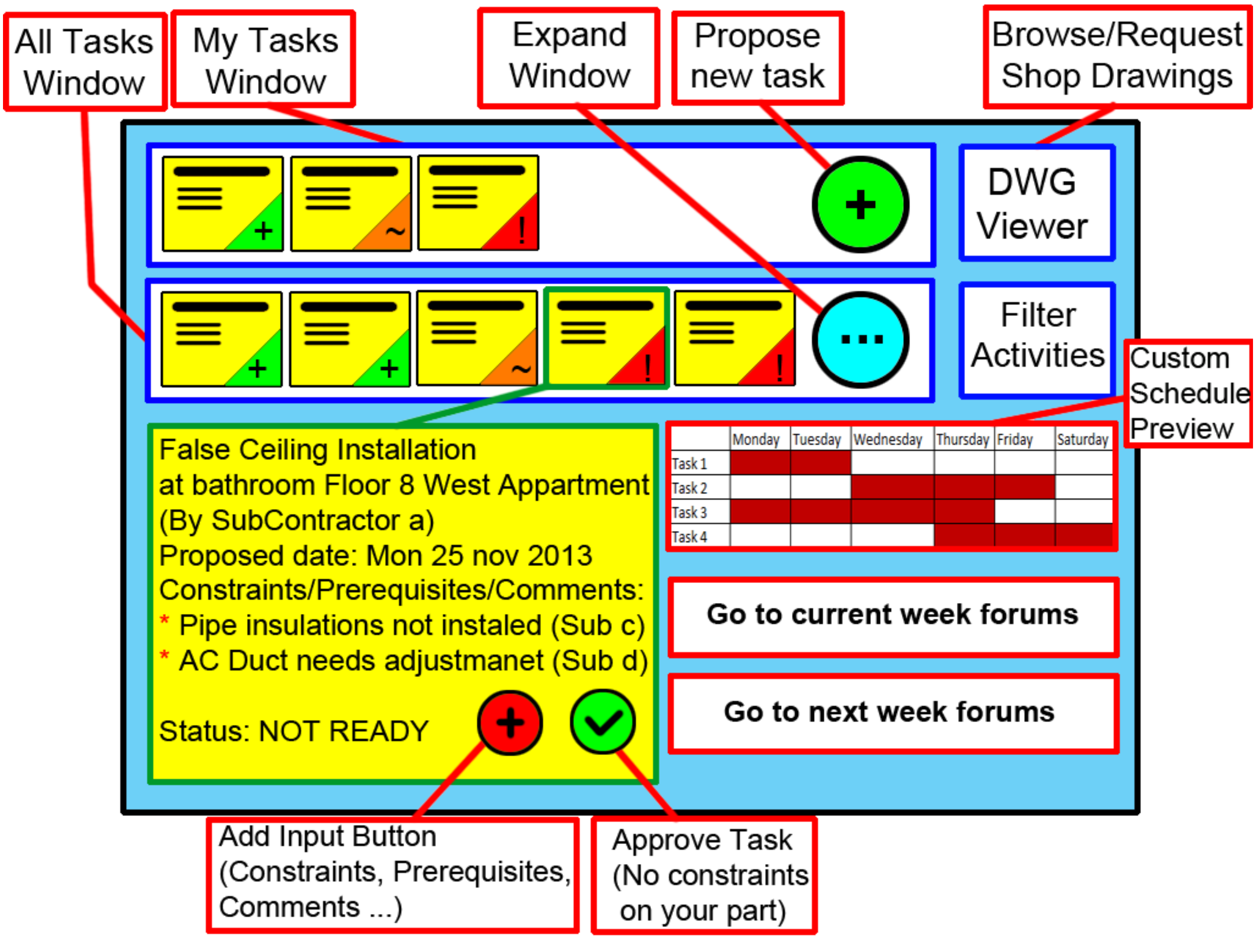

Figure 1 Prototype User Interface

The ‘All Tasks’ window is common to all sub-contractors and crew-leaders. It allows users to view the tasks that are being or will be undertaken by other users. The tasks are sorted by the Last Planner® according to their chronological sequence. A click on one of the task thumbnails allows the users to view task details, add input (constraints, comments, prerequisites …) or simply indicate that they have read the details and have no problem with the task being executed as soon as possible.

The ‘DWG Viewer’ allows crew-leaders to instantly access all types of updated construction and shop drawings. This is very convenient because crew-leaders won’t have to wait for drawings to be handed out by the engineer and won’t have to deal with things like accidentally using out-dated drawings or holding up large sheets of paper in heavy winds. The crew-leaders can also zoom in and out as needed; this reduces possible errors such as misreading small printed values.

The ‘Filter Activities’ button allows engineers and crew leaders to easily find tasks they are looking for in the ‘All Tasks’ window by filtering the displayed tasks according to their properties. The tasks can be filtered by status, date, location or responsible subcontractor.

The ‘custom schedule preview’ shows every user a schedule relevant to his scope of work and aids them to get a holistic image of what is happening.

Note: The colored triangle at the bottom right corner each task thumbnail represents the task status. The green triangle with a cross inside indicates that the task is ready; the orange triangle with a tilde inside indicates that the task can be made ready by the time it is scheduled, and the red exclamation mark indicates that the task is constrained and cannot be made ready soon.

ANYLOGIC SIMULATION

Figure 2 summarizes the process of task management using 'SimpLean'. In order to get a more precise and quantitative understanding of how the information flows, the process of task constraints assignment is simulated using 'AnyLogic'.

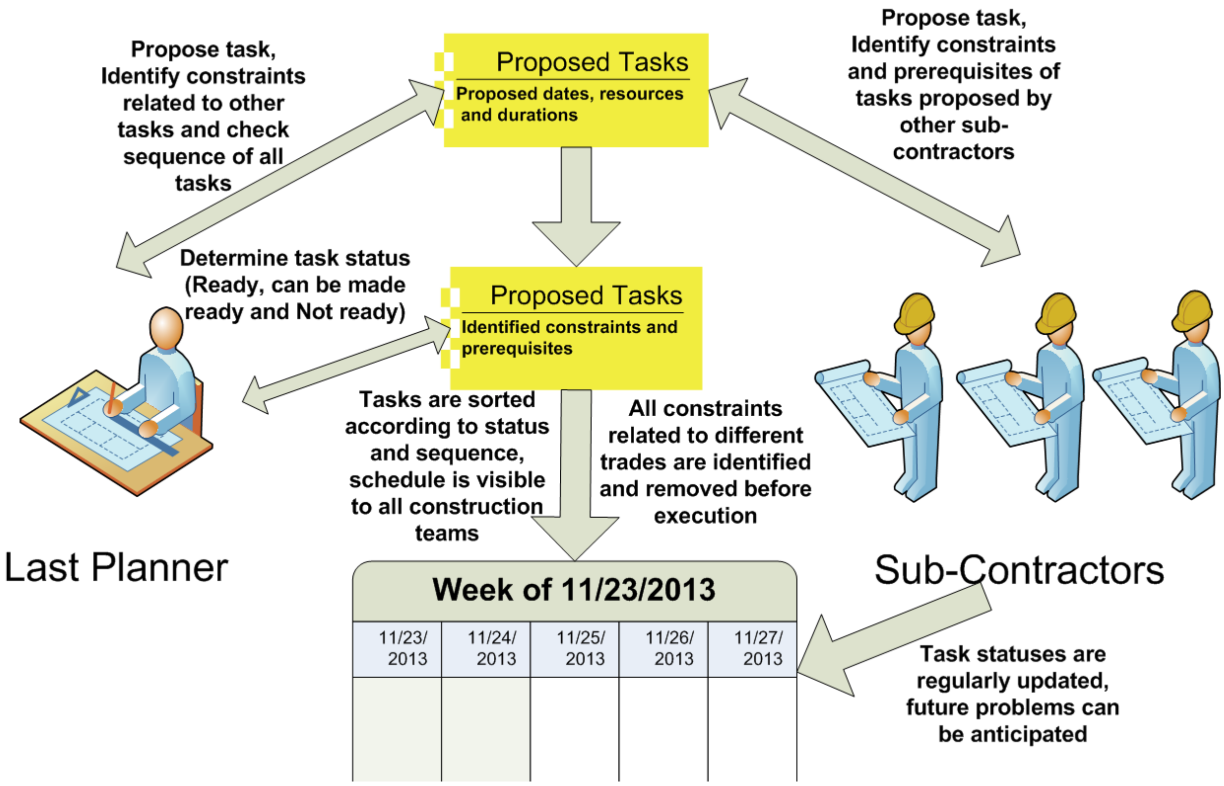

Figure 2 Task Management Process Using Proposed Software

OPERATION DESCRIPTION

In this model we study the interaction between 10 construction teams (9 crew-leaders + 1 Last Planner®). We assume that for each construction team, three tasks will be posted to the system within the first two hours of the working day, at least one of which is scheduled to start on that same day. These tasks are assumed to be of the lower levels of detail (level of production processes/operations) since they are part of the weekly-work-plan. The authors also assume that no more than a total of fifty new tasks will be posted per day (this number does not include the tasks that are created from the prerequisites or constraints of other tasks). This is modeled by a source object that generates the tasks with the following properties:

Arrival Rate $\frac{30\ tasks}{120\ minutes} = 0.25\ task/minute$ and Maximum number of arrivals = 50 tasks

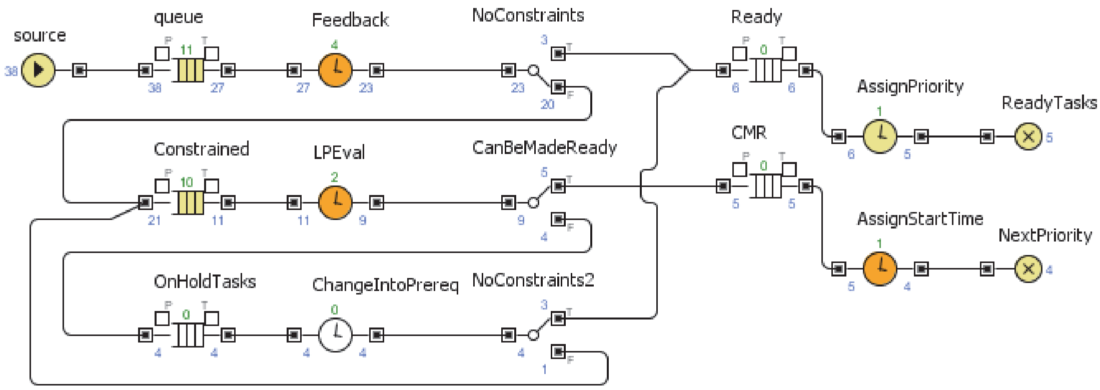

Figure 3 Constraint Assignment Process as Simulated in AnyLogic

Within ten to thirty minutes, feedback from the construction teams for at least four tasks is expected. The authors assume that 30% of the posted tasks should not have any constraints since most of these tasks would be currently in progress. It takes the Last Planner® around fifteen to twenty minutes to rapidly go through the tasks that are ready (four tasks at a time), verify they are in sequence and determine the priority of each task. Within 20 minutes, tasks that are constrained will be evaluated by the Last Planner® (two at a time) and divided into tasks that can be made ready soon (CMR) and tasks that will not be ready soon enough. The time it takes the Last Planner® to evaluate these tasks is short because all the required data is already obtained from the crew-leaders' feedback. Since all the constraints are known, we assume that 40% of the constrained tasks can be made ready and then assigned new start times within around ten minutes each. Tasks that have major constraints, i.e. tasks that cannot be made ready, will be put on hold and new tasks that aim at removing these major constraints will be created by the Last Planner® and posted to the system. We assume that these newly created tasks are part of the original scope but were not anticipated in the weekly work plan. This very simple process is assumed to take around five minutes per task. The authors assume that around 30% of these newly created tasks will have their own constraints and will therefore be sent back for evaluation by the Last Planner®. The remaining tasks are ready and will be assigned priorities. Figure 3 is a visual representation of the process, a detailed description of the components in Figure 3 is presented in Table 1.

The authors believe that this model is rather on the conservative side because at steady state, the daily number of tasks generated will be much smaller and most of the tasks would have been already evaluated several days before their scheduled date. Also, the Last Planner® is not modeled as a resource unit, i.e. at any point in time the Last Planner® is performing several tasks at once (LPEval, AssignPriority, etc.) because the software interface allows the user to multitask. This is accounted for by assigning longer durations for every single delay object.

Table 1 Input parameters in AnyLogic

Object Name	Type	Description	Characteristics
source	Source	Tasks are posted by Last Planner® and crew-leaders	Rate = 0.25 tasks/minute maximum number of arrivals = 50
queue	Queue	Tasks are waiting for feedback from other construction teams	N/A
Feedback	Delay	Feedback on each task is given by construction teams	Delay time: triangular(10, 20, 30) Capacity = 4
NoConstraints	Select Output	True if posted tasks have no constraints, False otherwise	True probability = 0.3
Constrained	Queue	Constrained tasks are waiting for evaluation	N/A
LPEval	Delay	Last Planner® evaluates is constrained tasks can be made ready	Delay time: triangular(15, 20, 25) Capacity = 2
CanBeMadeReady	Select Output	True if evaluated tasks can be made ready, False otherwise	True probability = 0.4
OnHoldTasks	Queue	Tasks that cannot be made ready are put on hold	N/A
ChangeIntoPrereq	Delay	Last Planner® replaces 'On Hold' tasks by their major prerequisites and sends them back into the system	Delay time: triangular(2, 4, 5) Capacity = 1
NoConstraints2	Select Output	True if prerequisite tasks have no constraints, False otherwise	True probability = 0.7
Ready	Queue	Ready tasks are waiting to be assigned priorities	N/A
CMR	Queue	Can be made ready tasks are waiting to be assigned start times	N/A
AssignPriority	Delay	Ready tasks are assigned priorities	Delay time: triangular(10, 15, 20) Capacity = 4
AssignStartTime	Delay	Can be made ready tasks are assigned start times	Delay time: triangular(5, 10, 15) Capacity = 1

MODEL RESULTS AND DISCUSSION

For one thousand model runs, the relevant data were recorded in datasets via Anylogic and later exported to excel for analysis.

Table 2 is a summary of the average results. The results show that it takes around 8 hours to obtain a schedule of approximately 75 tasks that are planned in great detail (all constraints are identified and evaluated). The 75 tasks include the 50 tasks that were originally posted (25 of which are put on hold due to major constraints) and an additional 25 tasks that were created in place of the tasks that have major constraints and that aim at removing these constraints. The timely discovery of these new and necessary tasks, part of the original scope but inadvertently left out of the original plan, could save contractors from facing major delays and productivity loss. It is also alarming that on average, 42.9 out of 50 proposed tasks turn out to be constrained. One feature of SimpLean is that it makes the planners aware of these constraints and brings them to light early on thus making them easier to manage. In this case the average waiting time for tasks in different queues has little importance because the tasks will have to wait for their start dates anyway. The model shows that for the assumed data, 60-70% of the total tasks can start on time because all constraints were identified prior to the execution date. It's also worth noting that around one third of the new tasks identified through the use of SimpLean turned out to have constraints of their own and were fed back into the system.

It is reasonable to expect that the total amount of tasks analysed per day is at least equivalent to a week's worth tasks. This shows that the application of this management system is in accordance with principle #1 of the Last Planner® System: Plan in greater detail as we get closer to doing the work (Ballard 2009).

Although the input data is mostly assumed, the authors draw the conclusion that for any given conditions the use of the proposed management system can yield great results by allowing the fast and easy identification of all constraints related to many tasks.

Table 2 Simulation Results

Parameter	Average Count
Simulation Time (hours)	8.07
NoConstraints (true)	14.875
Constrained	42.929
CanBeMadeReady (true)	17.107
OnHoldTasks	25.822
NoConstraints2 (true)	18.018
ReadyTasks	32.893
Total Tasks Processed	75.822

RELATION TO LEAN CONSTRUCTION

The most important feature of using the proposed software is that it forces the users to identify constraints early on and take the necessary actions. This is similar to applying the Last Planner® System but instead of using six week forecasts, the users work on identifying and removing constraints for as many future tasks as possible. Moreover, the use of the proposed software has many Lean features, most notably:

- It facilitates communication and coordination between construction teams. The intuitive UI also directs the discussions towards identifying and removing constraints for future tasks. This cooperative effort strengthens and improves the quality of the construction social network.
- It encourages a set-based selection of activities reminicent of Toyota's set based design process, by identifying constraints for all activities in parallel.

- It solves the problem of workers receiving different and sometimes conflicting instructions from different management teams, by clearly showing each crew-leader what to do.
- It allows management teams to have a clear idea of what is happening on site and what the level of progress is. Crew leaders have the option of taking pictures on site and attaching them to the corresponding tasks.
- Crew leaders can become more cognizant of common planning issues in the long run.

CONCLUSION

Centralizing information, visual representation of construction data and construction social network development are individually proven to significantly improve construction workflow. The authors of this document propose a software system that intuitively combines the above mentioned concepts along with many more features that could be effectively used in construction management. The software can act as a transition tool for construction companies that are interested in applying Lean construction but are not yet ready to invest in advanced tools and training. A prototype user interface is presented along with an explanation of how every component can be applied. The effectiveness of the task management process, particularly when many sub-contractors are on board, was confirmed by simulating the process in AnyLogic. Finally, the benefits of implementing the proposed software system lie in the fact that it encourages the use of Lean management concepts (Last Planner® System, Toyota's set-based design process) without requiring deep knowledge from users about the theory behind these concepts.

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