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ANALYSIS OF HVAC SUBCONTRACTOR MECHANISMS FOR JIT MATERIALS SUPPLY TO A CONSTRUCTION SITE

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ABSTRACT

Industrialization has been pointed out as a major requirement to improve efficiency, quality, and safety in construction projects. Nonetheless, some of the side effects of industrialization are increasing the complexity of construction by including new technologies, engaging different subcontractors; increasing interdependencies between trades; and so forth. The aim of this paper is to develop a planning procedure for facilitating the integration between off-site fabrication and on-site installation, for achieving a just-in-time delivery, based on an action research study conducted with an HVAC subcontractor. It is part of a wider research project, aiming to develop a planning and control model for engineer-to-order (ETO) prefabricated building systems. The procedure developed in this research helped the team to review the schedule proposed by the GC in terms of constructability, get team consensus regarding installation sequence, improve communication between contractor and fabricators, support fabricators in defining fabrication rhythms and mix of production; and helped the project team solving logistic challenges. The main challenge faced in this research was related uncertainty and unforeseen changes to the developed plans. As a result, we also explored a way of tying fabrication plans to critical activities in the job site to facilitate matching fabrication rate with site demand.

KEYWORDS

ETO building systems, Feedback mechanisms, Production planning and control systems, Just-in-time, pull-production.

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INTRODUCTION

The growing use of industrialized components in construction has contributed to make the construction industry more efficient, increasing the reliability of construction projects in terms of delivery time and quality, and reduced the risk exposure in construction sites. It is a movement of mirroring the environment of the manufacturing process. Lessing (2006) describes the idea of industrialized building as a complex concept including technical and organizational aspects as well as the supply chain and information-related issues. This type of conceptualization reveals the complexity inherited in the use of industrialized techniques.

An important competitive advantage in this context is the focus on engineered-to-order (ETO) production systems, which means that the customer order is a unique project and the outcome is the final assembled product (Bertrand and Muntslag, 1993). In this study, ETO prefabricated building system refers to one specific building sub-system, namely the Heating, Ventilation, and Air Conditioning (HVAC) system, delivered by a single company.

In an ETO production system, the products have not been specified when the customer places an order and the main criteria for deciding to choose a company is the price and lead-time for production (Bertrand and Muntslag, 1993). For this reason, the interface between the design, fabrication, and site installation of these components have to be analysed in an integrated manner, in order to check whether the company is able to deliver the product keeping the price and the delivery time previous agreed.

This research addresses the challenges of managing ETO components in a complex and fast construction project, from a subcontractor perspective. This study was possible thanks to a partnership between the Project Production Systems Laboratory (P2SL) at UC Berkeley, and Superior Air Handling, a mechanical contractor specialized in the market niche of complex construction projects. Two different papers report the findings of this investigation. This first aims to develop a planning procedure for facilitating the integration between off-site fabrication and on-site installation, in order to make the subcontractor able to make just-in-time deliveries in the site. The second paper (Tillmann et al., 2015) discusses the challenges faced while transitioning from design to production, and the role of different mechanisms, e.g. BIM and lean techniques to support that transition.

RESEARCH METHOD

The research approach can be framed as a design science research (March and Smith, 1995), since a planning procedure was developed to enhance the communication between the subcontractor superintendents, the different fabricators, and with the general contractor of the project. The study was held from September 2014 until February 2015, as part of the collaboration between the P2SL and Superior Air Handling. The main sources of evidence were (1) document analysis, mainly schedules and productivity data from previous projects; (2) interviews with the superintendents, project managers and vice-president of the company, and with the fabricators; (3) direct observation on internal meetings for weekly work-plan and for internal progress status, (4) visit to different fabrication facilities.

The authors of this paper worked collaboratively in the HVAC contractor project office, understanding the demands from the general contractor and the capacity of the different fabricators. The outcomes of this investigation have been discussed with the team members who had an important role in improving the procedure shown in this paper. During the period of the research, two workshops were carried out in order to share the knowledge developed.

ABOUT THE PROJECT

The project investigated has almost 300.000 sq meters of building area, located in a construction site of almost 780.000 sq meters, and its cost is of around 5 billion dollars. The project used mainly industrialized technologies, to improve efficiency and deal with a fast pace schedule. There was also little space in the job site for contractors to keep any inventory, which contributed for the decision to carry out most of the activities off-site.

In the beginning of the project, the general contractor developed the first schedule for the whole project. The general contractor makes a differentiation of the role of some subcontractors. Some subcontractors are responsible for critical path activities, which means that a delay on their activities could pose a threat to delivering the project in the promised date. This was the case, for instance, of subcontractors responsible for the concrete and the steel structure of the building. These subcontractors had an important role in the production planning and control system of the project as their production frequently dictates the pace of the other subcontractors. In this paper, we call them "**critical**" subcontractors, as their work compound the critical path of the project.

Another important characteristics of a subcontractor work identified in this research was what we called "**window of opportunity**". When analysing the schedule, we observed that the work of MEP subcontractors were allocated between critical activities that cannot be delayed. MEP subcontractors tend to plan their work based on how much time they have to install the equipment after the area is made available for them and before the next activity blocks their access to the area, e.g. time after concrete slab is available and before roof structure is installed, which would make it difficult to bring large equipment. Those windows of opportunity were the main source for the HVAC subcontractor to plan their work and establish the production strategy. This window could fluctuate in time, and sometimes be compressed or extended, as shown in the different versions of the GC schedule in Figure 1. Here, the windows refers to the work in the penthouse of the building. The release for starting the work was delayed two months, and the time available was prolonged. The need for working with a flexible plan within this window of opportunity determined the implementation process, as described in the next section.

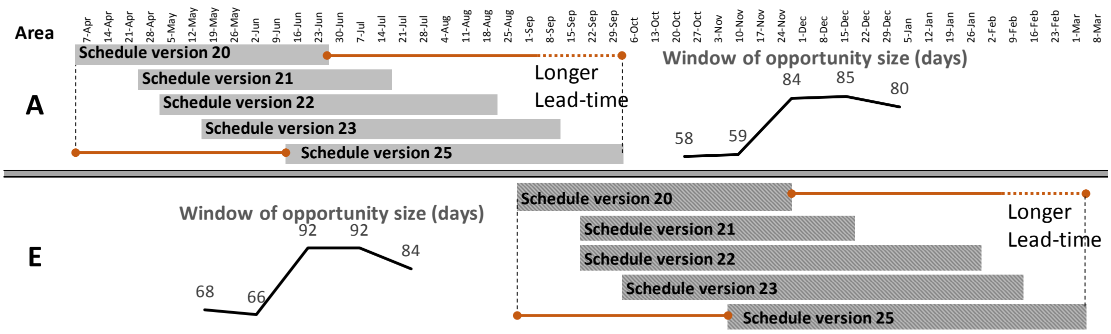

Figure 1: Changes in the window of opportunity for a given activity

RESULTS

The desire to achieve just-in-time delivery of mechanical components was the main driver for developing and implementing a planning process that integrates site installation and fabrication. Three critical activities were analysed: (a) installation and fabrication of risers; (b) installation and fabrication of air-handling units (AHUs), and (c) logistics and installation of different equipment in the penthouse.

RISERS

A riser consists of a vertical sheet metal duct connecting the ductwork of each floor to a fan and a plenum unit in the penthouse. The installation of risers is critical because it comes in one single 24-meters-heigh piece, which has to be hoisted, rotated and installed at once, in half of a day. There are 80 risers throughout the project, the crane for the mechanical contractor installation was shared with an electrical team, who had to install a riser in the same shaft. Because of this interrupted flow the rhythm of installation was on average of one riser each 1,5 (one and a half) days. The analysis consisted in four steps:

a) Creating an installation plan

The first step was to analyse the window of opportunity in the master schedule, which was defined by placing of topping slab (predecessor) and the start of roof activities after risers were installed. We worked with the electrical and mechanical superintendents also to confirm the installation rhythm, since they were planning to share the same crane. Figure 2 shows the difference between the schedule proposed by the general contractor and the confirmed schedule taking into account the optimized crane utilization.

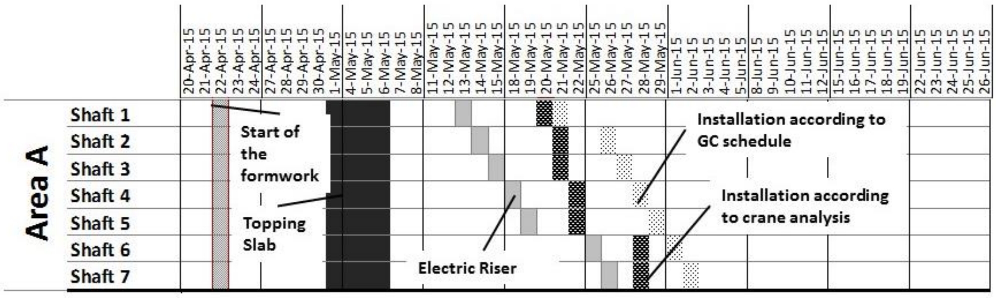

Figure 2: Details of the installation schedule, according to the crane utilization

b) Creating a fabrication plan

The second step was to take the information from the fabricator regarding lead-time and how many risers could be produced concurrently. Each riser should take 5 workdays to be produced and there was enough room for producing two of them concurrently. This was the data used in the first scenario for production, as shown in Figure 3. As it is possible to see in the LOB, the difference in the rhythm of field installation and the rhythm of fabrication, lead to a huge amount of riser, which would need to be stored.

For this reason, the HVAC contractor decided to rent a warehouse so that they could buffer the fabricated risers avoiding the uncertainty of the construction site. The idea was to have a backlog for the start of the installation process. The problem in this strategy was that it required the fabrication to start 15 weeks before the installation. However, at this time, the client have not decided yet about the insulation material of the riser and, therefore, the design could not be released to fabrication. There were also some space constraints, since the warehouse was able to store 20 risers, while the total accumulated in this scenario was 32 risers.

The second scenario developed for the fabrication of the risers, simulated a larger capacity in the fabricator. This scenario could be achieved if the fabricator build more capacity, however the need for training new people for welding is still an issue at that time. Figure 3 shows that the fabrication could start only 5 weeks before the installation. In this case, the beginning of the formwork of the topping slab could be set as a trigger for the fabrication, so it would be possible to make the fabricator react according to what was happening in the field. The amount of risers that need to be stored would be much lower, a maximum of 20 risers, which is within the capacity of the warehouse.

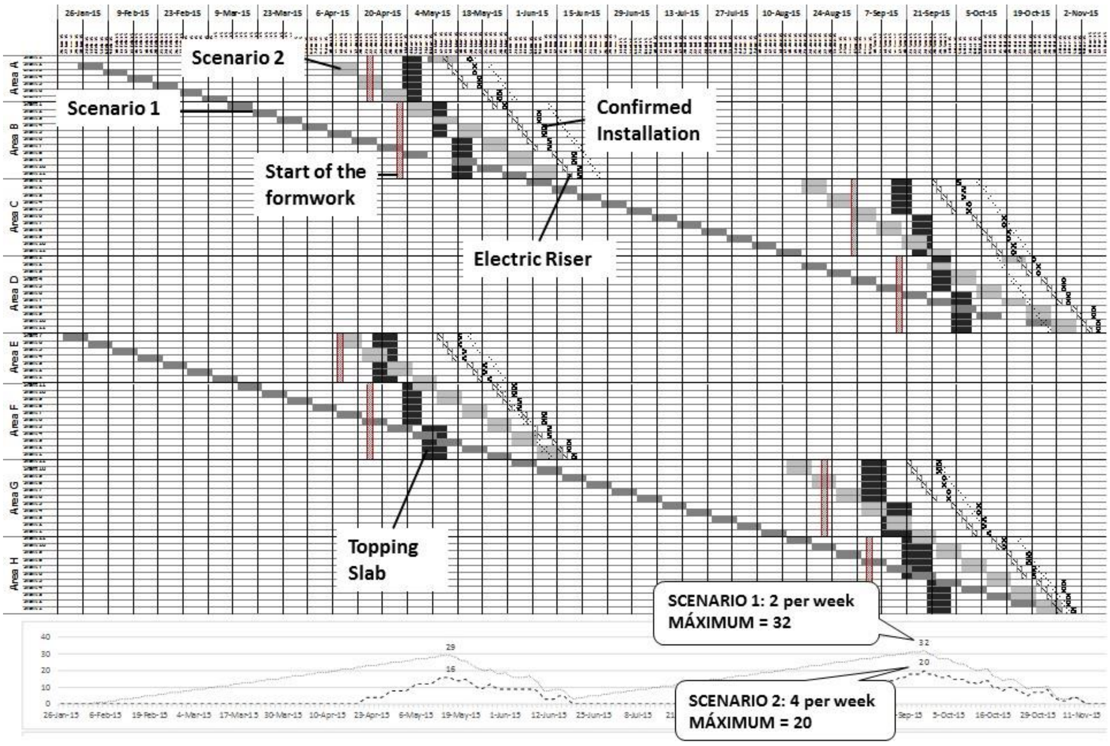

Figure 3: Scenarios for the fabrication

c) Defining the mix of production

An important characteristic of the riser is its modularity. There are five different types of risers, two of them are one-of-a-kind, while the other three types can be used interchangeably in the project. Therefore, the third step of the analysis was to examine the mix of production, for fabrication. Figure 4 shows the different types of risers and how they are distributed in the project. Because of its modularity, the risers have fewer chances to suffer with the matching problem, as discussed in Tommelein (1998), and Sacks et al. (2003). The production can easily deal with changes in the project sequence, without delaying the installation.

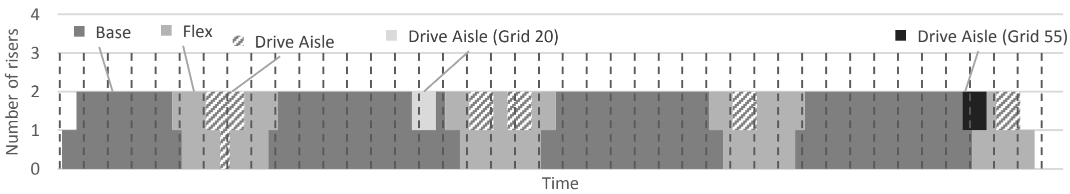

Figure 4: Riser Types / Production mix

d) Establishing a feedback mechanism

The biggest challenge we faced in this project was the constant changes in the schedule. In order to establish a feedback mechanism we tried to link fabrication plans to critical activities in the job site to facilitate matching fabrication rate with site demand. In the case of the risers, we observed that the topping slab could provide us a trigger for fabrication, e.g. when topping slab in Area A starts, we should be done fabricating risers for Area A and start fabricating Area B.

AHU

The Air Handling Units (AHU's) regulate the air circulation in the HVAC system. There were 90 units in the project. The critical part of its production was the storage constraints. The AHU's should be produced and sent directly to the site for installation. The general contractor also required that the wiring from the automation system to be installed in the fabrication facility, which could affect the lead time of the final assembly.

The AHU's contains different types of components such as fans, filter racks, soundproofing systems, and dampers. The fabricator was able to produce the final assembly in 1,5 – 3 days, and could produce up to 16 units concurrently in the 8 cells of the plant. However, the production of the components could take up to 8 weeks, and there was not much room for design changing, since the design should be delivered 16 weeks before the final assembly. Given this, there was a need to send the designs early in the process, but the final assembly could be postponed to the last responsible moment.

Differently from the risers, there are almost 20 different types of AHU's, what makes it more important to confirm the production of the unit that can be installed in the field. Because of the time required for the fabrication of the components, even decreasing the number of units in the final assembly, there is a need to produce the same number of components concurrently. Moreover, making the final assembly right before the installation avoid spending resources in handling the units for a storage place.

a) Creating an installation plan

The first step of the analysis of the AHU's was to consider the installation as planned by the general contractor. However, in this case there would be a need to use more than one crane by the subcontractor in each released area of the building. We revised the schedule with Superintendents, taking into crane use, as a means of defining installation dates. This scenario can be seen in Figure 5.

b) Creating a fabrication plan

The fabrication plan then was developed based on the installation plan. We pulled back the activities from final assembly of components, to fabrication of sub-assemblies and included finalization of detailed drawings to support fabrication.

c) Establishing a feedback mechanism

The short lead time of the final assembly, together with the large capacity of the fabrication plant made it possible to link the start of the final assembly to the predecessor of field installation: the waterproofing activity. Based on this information, the factory could better deal with stock issues by keeping the equipment as subassemblies, i.e. easier to store than the final AHUs.

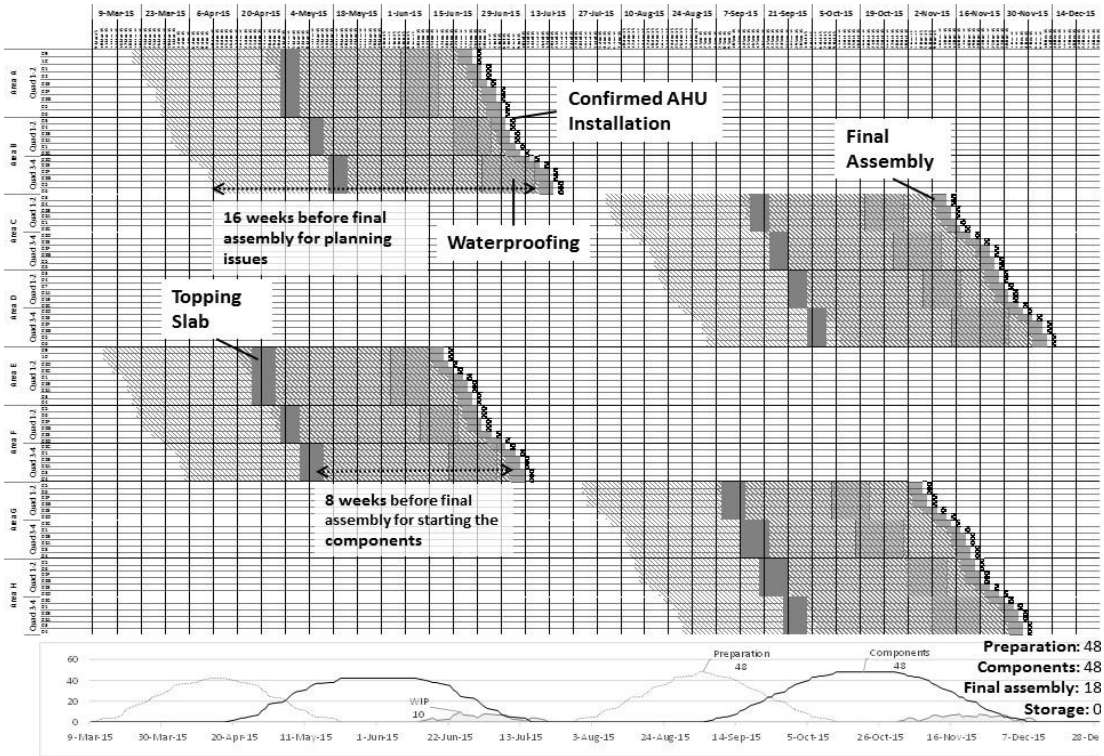

Figure 5: Scenarios for the AHU's production, according to the crane use

PENTHOUSE

The Penthouse was the most challenging installation area of the project for the mechanical contractors. In that area, the window for installation starts after the waterproofing of the slab, and finishes when the structure of the roof starts. The structure of the roof was a steel structure that would physically lock the installation work in the level, and makes it unfeasible for further loading. The level of detail of the general contractor schedule was low, considering a large batch of installation spread along a certain amount of time.

Therefore, like in the previous analysis, after defining the window, the following step was to confirm the installation dates according to crane and sequence constraints. Figure 6 shows the confirmed days of installation, and the number of cranes required in this process. By postponing the beginning of the installation of the mechanical equipment in the penthouse, it was possible to assure a more uninterrupted flow of installation, which could also benefit the fabrication, as seen in the case of the AHU's and the fabrication of the ductworks of this area as well.

The representation of the required rhythm of installation for the penthouse ductwork allowed the fabricator to accommodate that demand in their shop. The analysis also facilitated the identification of logistic challenges due to the shared use of the crane among the different activities of the subcontractors, and also due to interaction between the subcontractor crane and the one from the glass installer.

The analysis of this area of the building was also a source for the refinement of the AHU`s installation analysis, since the first confirmation of the installation dates were made, according to the main logistics constraints. As the project is under construction, there is a need to make new confirmations in the course of its development. This analysis was an important starting point for this understanding.

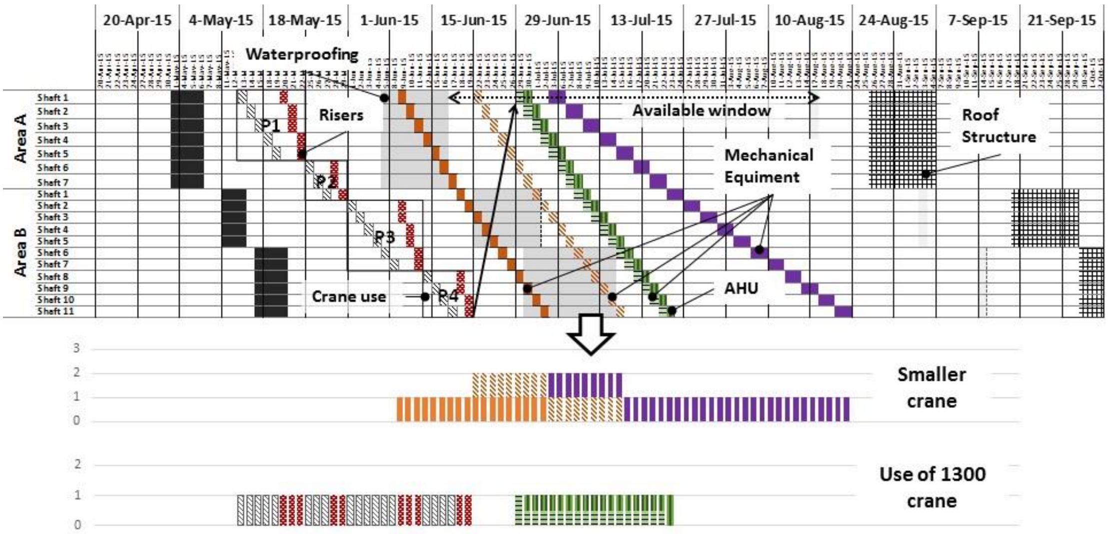

Figure 6: Penthouse analysis

CONCLUSIONS

This paper attempted to develop a planning procedure to facilitate the integration between off-site fabrication and on-site installation of ETO components by a mechanical contractor in a large and fast pace construction project. Due to changes in schedule, especially schedule compression through time, it was not clear to all project participants the demand for fabrication for all the different components under the responsibility of the HVAC contractor. There were changes in construction sequence, and on the installation rates, which also caused changes in the fabrication demand through time.

The procedure adopted in this research enabled different participants to understand better how the schedule was changing and the impacts that would cause in fabrication, logistics and in installation. Four steps were followed: (a) developing an installation plan by revising the schedule with superintendents; (b) developing a fabrication plan based on manufacturing capacity and site demand; (c) understanding the fabrication mix based on installation sequence; and (d) creating a feedback mechanism to update fabricators about the current status of the job site and forecasting changes. An important characteristics of steps a, b and c was to combine the information from the schedule and the most important quantitative analysis from that schedule, such as number of equipment used (in the case of the penthouse), or amount of product stored (in the case of AHUs and Risers)

This modelling exercise allowed the different actors in the supply chain to plan their work based on the most current data about when and in what rhythm they had to deliver their components in the jobsite. Establishing a feedback mechanism that anchors installation activities to fabrication progress enabled the team to anticipate potential impacts and threats to match installation demand. Benefits of this exercise were not only observed for the HVAC contractor, coordinating the work but also for the other members of the integrated supply chain.

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