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OFF-SITE PREFABRICATION: WHAT DOES IT REQUIRE FROM THE TRADE CONTRACTOR?

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ABSTRACT

The purpose of the paper is to show what is required to industrialize a building process from the standpoint of the trade contractor. Rationalization of building processes has, over the years, caught the attention of numerous IGLC papers. Although significant contributions have been made to further understand and improve existing construction processes, relatively few contributions have focused on the opportunities for industrialization from the trade contractor's perspective. This paper uses an in-depth case study to address the deployment strategy for off-site fabrication techniques and processes used for modular plumbing fixture carriers deployed on two large-scale hospital projects in the United States. Findings include the organizational and technological arrangement for prefabrication. The paper applies value stream mapping to visualize the process and improve it. Because this work looks at only one case study, the conclusions are limited in generalizability to other prefabrication operations. However, it represents an important in-depth case from the trade contractors' perspective and will contribute to the growing body of research focused on industrialization and prefabrication in lean construction. .

KEYWORDS

Lean construction, modularity, prefabrication, standardization, value stream mapping (VSM).

INTRODUCTION

Industrialization includes the process by which a traditionally non-industrial sector of the economy becomes increasingly similar to the manufacturing industry. The process implies variations of greater use of prefabrication, preassembly, modularization and off-site fabrication techniques and processes (National Research Council 2009). By definition, the production performed outside of the construction area in a temporary or more permanent workshop off site, is named as prefabrication (Gibb 1999, Ballard and Arbulu 2004). Among the benefits attributed are improved production control due to reduced variance in the material and information flow (Lennartsson et al. 2009),

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decreased complexity of the on-site construction process (Larsson and Simonsson 2012), improved quality and productivity in construction (Viana et al. 2013), schedule savings and reduced on-site labor (Antillón et al.2014), just-in-time delivery, zero defects and customized products (Bildsten et al. 2010), and reduced lead times (Ballard and Arbulu 2004).

All the potential benefits considered, one might expect the construction industry to embrace industrialization. The majority of works on building sites are, however, still performed manually. "The primary categories of work involved in construction are the handling and transport of materials, the fabrication of elements or modules, fittings and connections, the positioning and fixing in the corresponding place, and the prior and subsequent processing steps using special tools" (Girmscheid 2005). These work steps are not very different from other areas of industrial production. Nevertheless, the challenges or constraints facing construction industrialization seem to be substantial and diverse, amongst others including the low degree of standardization in products and processes (Hermes 2015); the lack of design-production interface (Tillmann et al. 2015, Larsson and Simonsson 2012); the low IT integration in the industry (Blismas 2007); the multiple project environments creating a high level of uncertainty (Bertrand and Muntslag 1993); the market-driven, short term buyer-supplier relationships (Bildsten et al. 2010); the lack of trust between contractors and suppliers (Melo & Alves 2010); the reluctance among suppliers to adopt new standards (Lennartsson et al. 2009); the lack of holistic thinking in the product design (Björnfot and Stehn 2005); and the demand variability from the contractor, the late receipt of design information, the frequent design changes and frequent changes in installation timing and sequence (Ballard and Arbulu 2004).

Furthermore, there are some repeatedly mentioned ideas about realizing prefabrication in construction in the literature. One group claims that a high production volume is a prerequisite in order to apply prefabrication (Pan et al. 2007, Jaillon and Poon 2008 and Jonsson and Rudberg 2014). Some others add that large investments and sophisticated production is necessary for different trades to work on prefab modules. "A module is almost never the output of a single trade but must be seen as a product designed and manufactured by a number of different trade experts and most often installed at the site by the manufactures' own, specially trained crews" (Bertelsen 2005).

This paper takes the above mentioned challenges into consideration and it focuses on off-site prefabrication from the perspective of the single trade contractor. The case company is one of the largest mechanical, electrical, and plumbing (MEP) building system experts in US. The company has proven to be successful in its strategy to industrialize part products and provide services related to their installing. The paper's particular interest is on what is required for this strategy to become economically viable. In an attempt to answer this question, we emphasize the industrial fabrication including the use of standardized working methods and tools as well as new information technology; the logistical planning related to production facilities, storage of materials and the transportation and installation of modules on site, and; the use of contract models to support the industrialization.

CASE STUDY

The case company, Southland Industries is one of the largest mechanical, electrical, and plumbing (MEP) building system experts in US. The case company is currently engaged in delivering two large-scale new hospitals for Sutter Health located in San Francisco, California. St. Luke's Replacement Hospital is a 20,900 m2 (215,000 square foot), 120 bed project and Van Ness and Geary Hospital is a 68,750 m2 (740,000 square foot), 274-bed project (CPMC 2020). The case company has signed an Integrated Form of Agreement (IFOA) to deliver these two hospitals. This IFOA approach requires pain and gain sharing, where all team members share in the risk and reward for delivering the hospital on time and on budget.

To maximize production efficiency for the two hospitals, the two projects are leasing a large warehouse on Treasure Island in the San Francisco bay. A part of that warehouse is dedicated for the case company's prefabrication of modular plumbing fixture carriers. This is in addition to more typical prefabrication of the mechanical ductwork produced for other projects as well in the case company's main factory. At the time of the study, the case company had begun work on both the St. Luke's Replacement Hospital (STL) and the Van Ness and Geary Hospital (VNGC). Most of the work done so far is VNGC but work at STL is beginning now.

METHODOLOGY

Our case study proposes a map to visualize the flow of resource usage, including time, labor, and inventory through implementation of Value Stream Mapping (VSM) (Rother and Shook 1998). For this research, we conducted as a group and individually a number of visits to the final construction site and temporary workshop where the manufacturing takes place. Our observations are based on our participation in big room meetings, interviews with contractor and trade project managers, architects and owner representatives. Moreover, we have had the privilege to observe and take time records of the manufacturing work performed by the use of jig modules in the temporary workshop. The current and suggested future state Value Stream Maps will be shared in the analysis section and finally improvement suggestions at macro and micro level will be given in the discussion and conclusion section.

ANALYSIS

In analysis section we will present the value stream map (VSM) of operations for the case company, followed by a description of several of the areas. Furthermore, areas of improvement suggestions presented on the same figure 1 with circles on the VSM then are discussed in detail in the discussion section.

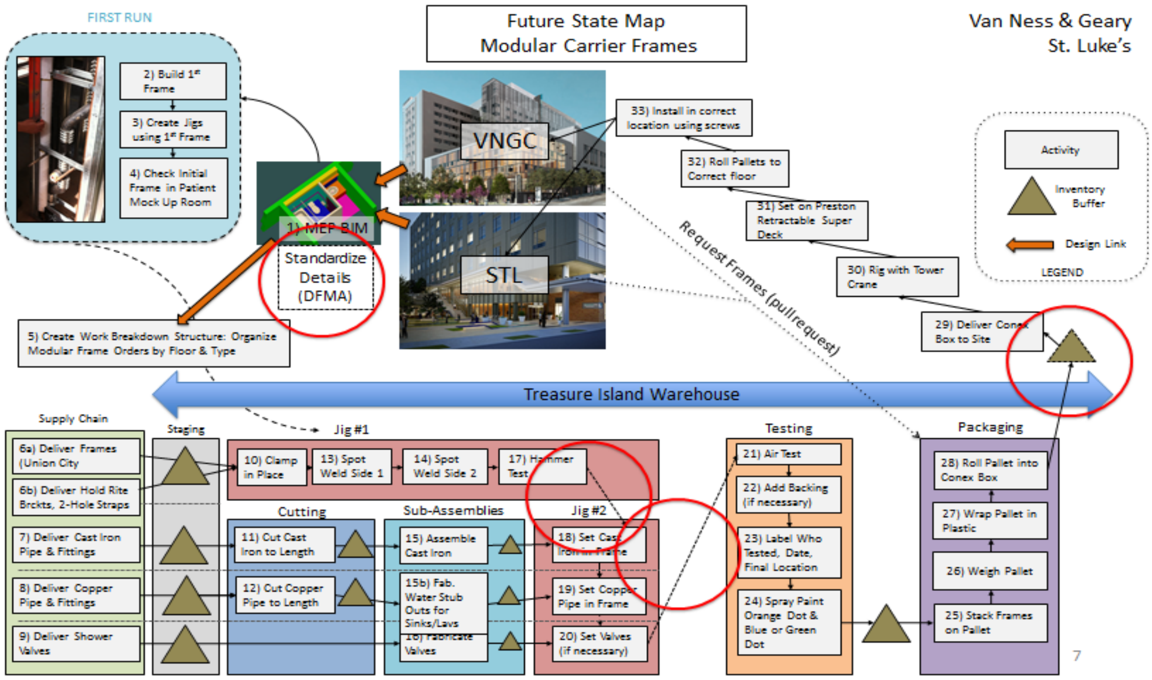

Figure 1 Value stream map of the modular frames

Value stream map (VSM)

First Run

The process begins with a fixture carrier design created using Building Information Modeling (BIM). As the creator of the modules states "it wouldn't really be possible without the BIM." BIM allows the practitioners to see the overall picture and therefore catch the similarities in design in different parts of the structure. Therefore, it becomes possible to identify each repeating module with number or repetitions and then create a jig in order to build it if it is feasible. From cut sheets that come from the BIM, a "first run" to create an initial set of jigs for a carrier frame is made. Then the first frame is built without a jig, and then that frame is used to create the initial set of jigs. Jigs are checked continuously for both accuracy to the BIM and easy to use for the workers. Altogether, twenty jigs have been made. Some of the jigs have adaptors so they can have additional configurations. It is difficult to estimate how long it takes the creator of the jigs to make one. However, after the experience gained during the process it takes now only couple of hours to build a jig.

In addition, there are many common elements between the two projects. Therefore an economy of scale is possible by using the same jigs with some little modifications in order to build for two projects. A few of the first VNGC carrier frames are mounted in the patient mock-up room to make sure that they fit. Birch and seven-layer plywood are used to make all parts of the jigs. This is easy to work with and reconfigure as necessary. There is no leveling or measuring required. Everything is set by stops and jigs, and locations can be calculated and fixed. This not only avoids the risk of making measurement mistakes, but also saves considerable time for the worker who does not have to bother with placement, leveling and tolerances during operation.

Supply Chain

The supplies for the modular carrier frames are delivered to the warehouse and brought in with a forklift. The frames for the carriers are made in the main factory and are delivered. Because the main factory has many competing project needs, occasionally those frames are not delivered before the previous set runs out, causing the team to work on something else for a short while. The cast iron pipe and copper pipe is delivered in long stock lengths and staged in large stock quantities in the warehouse.

Cutting & Sub-Assemblies

Separate cutting stations are set up to cut the cast iron and the copper pipe to length. Special consideration has been given to ensure cuts can be made using blocks and a stop, to reduce the need for workers to measure. Once pipe is cut to length, it is pre-assembled and readied for placement in Jig #2.

Jig #1 & Jig #2

At Jig #1, rhe strut is spot-welded to the metal frame for the fixture. The following work activities that occur on the current state map: 10) Clamp in Place; 13) Spot Weld Side ; 14) Spot Weld Side 2; and 17) Hammer Test. The purpose of the activity is to spot-weld square strut across the metal frame as shown in Figure 2 on the left hand side, which serves as strength for the frame and provides the attachment points for the cast iron and copper assemblies. Before the activity can take place, the frame material must be assembled and delivered by Southland's sheet metal shop in Union City. Jig #2 is the location where the completed frame is set in place and the cast iron and copper pipe assemblies are installed in the correct location. Jig #2 also uses a wheel to rotate and flip the frame around, so that the worker is always able to perform the work most efficiently.

Figure 2 Welding jig on the left and stock of prefabricated modules on the right

Testing

An air test is completed on all finished assemblies, which are now considered rough-in modules. Once passed, a label is fixed to the module stating who did the testing, at what time the testing occurred, and where the final location (site, level and room) of the fixture is. A green paint dot is sprayed on the rough-in module to indicate that it has passed the test. The case company also uses different colored paints for a second dot, to distinguish between the two jobs. VNGC is painted with a blue dot and St

Luke's with a red dot. Each finished item has a code written in black permanent marker pen on the bottom of the frame. For example, we saw LV-1 for the lavatory frame type 1.

Packaging and Storage

The completed rough-in modules are stacked together on a pallet and weighed. The frames are grouped by their floor location. Each shipping container can hold with 7,25 tons (16,000 lbs.) and the case company is very careful not to go over this weight. Currently they are storing completed and wrapped pallets on the Treasure Island floor and then moving them into the completed Conex Box. It would be preferable not to move the pallets twice but because the fabrication is far ahead of installation, it is necessary at this point. Right now the first and second floors of VNGC are completely fabricated and in storage as some of the prefabricated modules can be seen in Figure 2 on the right hand side, while installation of these items is not until mid-2016 at the earliest. Temporary shop will accumulate a very large inventory buffer on site before it is time to begin delivering the rough-in modules.

Delivery

The delivery plan is the part of the current state map that has not occurred yet because the construction sites are not ready for the rough-in modules. The current plan is for each site (VNGC or STL) to call temporary shop when they are nearing the point when rough-in modules are required on a certain floor. At that point, Treasure Island will deliver the container to the site. The entire container will be rigged using a tower crane, and the pallets will be rolled onto the retractable Super Deck at the correct floor for their installation. However, one of our hosts mentioned that the site has changed delivery projections almost on a weekly basis. This current delivery process has not begun and is likely the most uncertain part of the process to date.

DISCUSSION

By employing lean construction concepts, the case company has set up a successful prefabrication operation for rough-in modular frames. The current state of operations represents a commitment to the lean construction philosophy. The decision to use prefabrication is a long-term philosophy, the use of the production line will greatly reduce (material and time) waste, and the tasks have been standardized and "mistake-proofed."

The work is exceeding expectations already. Although the delivery and installation of the rough-in modular carriers has not started yet, there is reason to believe the team will continue to successfully meet the new challenges as they arise for the overall benefit of the project. We tried to investigate the improvement possibilities by applying lean approach defending the optimization of value stream in a manufacturing process. The case we have chosen is a an example of a large scale hospital building construction in the context of California that can be taken as an example by worldwide construction professional building large scale facilities.

This case study is a clear example of what a single trade contractor can do to boost product modularity. The improvement suggestions studied for this case serve to the purpose to achieve standardized work for the future projects to come. As the off-site production observed is the very first attempt, neither we nor the host company had the previous project records to compare the work done. According to the company professionals, the man-hour estimates in the planning phase were made based on the similar type of work performed at site. They had foreseen six employees working for both St. Luke's Replacement and Van Ness and Geary Hospital projects but during the execution of the manufacturing the project team realized that three full time employees were sufficient to serve the project pace on site. Even this man-hour reduction alone proves the benefit of batching different construction project works together in a workshop. Moreover, the project team all agreed that hospital construction required far more sophisticated prefabrication operation than a typical project would normally do. Therefore, we believe that the current successful prefabrication operations can provide a standard to be improved for the future projects.

The improvement suggestions for the off-site manufacturing are parallel with the lean spirit of continuous improvement. Although, the suggestions are very much case specific and the starting point can generically be applied to other off-site manufacturing operations as well.

An overall analysis of the current value stream map shows three opportunities to improve. First, the case company could look to reduce inventory buffers and attempt to achieve more of a continuous flow. The current state map reveals that the process uses many inventory buffers (shown with a triangle). These inventory buffers act as a decoupling mechanism to separate tasks with different cycle times. Inventory is identified as one of the seven types of waste in a production system (Ohno 1988). While some decoupling buffers are necessary, future work could look to reduce inventory between tasks and achieve a more single-piece (e.g. continuous) flow (Viana et al. 2013). To exemplify, a typical inventory buffer between the production lines can be mentioned: When a batch of frames is done at Jig #1, they are stored out of the way in groups around ten to twenty as they await the availability of Jig #2. By setting activity at Jig #1 and Jig #2 to a similar takt time, frames could move directly from the Jig #1 station to the Jig #2 station (with a small inventory buffer of 1-3 frames in between). This would reduce the need for additional storage and the motion of carrying and stacking the frames after each batch.

Packages waiting in the inventory for the shipment to the site are again other great sources of the waste. It is very understandable that managers want to have a buffer between the site work and the workshop. However, missing communication and plan changes at the construction site cause the workshop to work with a greater contingency than required.

Second, the case company could use the success at workshop to cross-train others in the company. This includes management through the lean "go and see for yourself" philosophy and the workforce through the principle of creating challenging and meaningful work to develop the skills of all employees.

This would give management insights and vision should they want to replicate this operation for future projects. In addition, the workshop staff could seek opportunities to challenge their workforce through additional cross training of employees. The operations at the workshop are somewhat specialized at this point. By switching in additional employees or rotating the tasks for current workers, case company can continue to develop the skills of all employees. This would ensure that existing workers have challenging and meaningful work and that new workers have confidence in the tasks if the same prefabrication is attempted on future projects.

Moreover, such a close relation between site and workshop management will increase the efficiency in communication and help to solve the extra inventory buffer problem described above.

Third, case company has the opportunity through BIM to standardize the design of future plumbing carriers so that many of the same jigs can be reused. While this may not always be within trade contractor's control (for example, a project might employ a different MEP engineer who requires different details), it would be a great benefit to continue this prefabrication on future projects. Future BIM designs could use the existing jig setups. Furthermore, case company team have gained valuable insight into what type of fixture design is easy to assemble and which is more challenging. If this feedback can be communicated to the design team, future BIM designs could make assembly even more productive. This concept is referred to as design for manufacturing and assembly (DFMA) and could give case company the opportunity to leverage the gains at the workshop and increase productivity on the next project.

This will also allow for continuous improvement of the current process using DFMA principles. Furthermore, more reliable manufacturing and installation schedules will be planned based on the data from previously completed projects.

The three above mentioned improvements support each other. More efficient results can be achieved by the implementation of all of them simultaneously.

Finally, with the repetitive work and the production volume the productivity will increase and the improvements will become more visible. In order to make best use of the present modules created (jigs) for the manufacturing in the future, the design of the projects to come should be developed according to the design for manufacturing and assembly (DFMA) principles. The project team has already very valuable experience in different types of modules. Some modules are easier to adopt and to work with while some others are difficult and more time consuming. Why not to make the most favorite modules best practice for the next projects?

CONCLUSION

Our case study focusing on the prefabrication process of the mechanical works is a clear example of the achievements that can be made even as a single trade contractor in a large scale hospital construction. Moreover, contrary to the barriers mentioned in the literature the modules created during the prefabrication process do not require high volume production or high capital investments. Although, those modules are created to serve the current project design, they represent proven solution for the future projects to come.

Furthermore, an implementation of standard modules not only facilitates the manufacturing in a controlled off-site location and assembly on construction site but also help the design phase to be more consolidated. Moreover, the applied modules increase the cost and scheduling predictability both during the manufacturing and assembly.

Once the work is performed by implementation of standard modules reducing the product variety (Mohamad et al. 2013), the next level of improvements will be the main topic. We believe by standardization of the manufacturing operations a level of dexterity will be attained and improvements will require more radical changes such as involving other trades into the manufacturing operations.

The involvement of different trades in order to execute offsite production of modules has many product design and organizational challenges. Therefore, the early involvement of the pain and gain sharing philosophy of Integrated Form of Agreement (IFOA) will make the next level of modularization possible. Although, the observed projects are executed with IFOA, there is a missed opportunity to modularize the production units such as entire bathrooms or patient rooms requiring the cooperation of multi-trades. Observed off-site manufacturing case study can be baseline for future case studies in order to move from one-a-kind type of production to standard work. And then modules having multi-trade functions finally can be realized.

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