APPLYING LEAN PRINCIPLES, BIM, AND QUALITY CONTROL TO A CONSTRUCTION SUPPLY CHAIN MANAGEMENT SYSTEM

Ning (Tony) Dong, PhD, tonyd@dpr.com
Atul Khanzode, PhD, atulk@dpr.com
Hannu Lindberg, PhD, hannul@dpr.com
DPR Construction, Redwood City, California, United States

ABSTRACT

Supply Chain Management (SCM) is increasingly gaining popularity in the construction community, particularly firms with intense manufacturing, distribution, and logistics requirements. One major trend of research in this field is to investigate the adoption of SCM concepts to construction projects from a technological perspective. Few studies have been conducted regarding SCM integration to real-world construction projects, especially from the perspective of a General Contractor (GC), even though they play a crucial role in the SCM design and implementation for a project. The study in this paper proposes a framework to facilitate the SCM integration to projects from a GC's perspective. Using an on-going project as a case study, this paper provides insights regarding the application of lean principles, quality control methods, and BIM and other techniques in the SCM integration. A GC's responsibilities and actions to be taken at each step of the SCM integration are also explored. Findings, lessons learned, and areas for future research are summarized at the end of the paper.

Keywords: supply chain management (SCM), lean construction, building information modeling (BIM), quality control, field mobility, barcode, radio frequency identification (RFID)

1. INTRODUCTION

In response to the global sourcing of materials, advancement of transportation technologies for pre-assembled components, shortage of craft labor, as well as client's increasing demands for faster construction processes with higher quality, the construction industry has come to recognize the importance of supply chain management (SCM) to improve project efficiency. Correspondingly, researchers have made much effort in integrating and implementing SCM to construction projects. Dawood (2009) proposes a prototype that integrates project planning and look-ahead scheduling capability to a web-enabled SCM system to support construction management teams' decision making. Cheng and Law (2010) describe a web-based system for construction SCM integration and depict scenarios such as onsite project schedule adjustments based on the material delivery information presented in the system. At the front end of SCM, researchers have focused heavily on field mobility, especially potential RFID applications in construction. Such areas of application include automatically tracking the delivery and receipt of pipe spools (Song et al. 2006), tracking and locating precast component in a manufacturer's storage (Ergen et al. 2007), adjusting procurement plans and construction schedules based on the material status information automatically collected (Ren et al. 2011), RFID-aided concrete lab inspection and data sharing (Wang 2008), and managing precast production from a subcontractor's perspective (Yin et al. 2009).

Although general contractors (GCs) play a critical role in SCM integration to a construction project (O'Brien et al. 2002), their responsibilities at different phases of the project are rarely discussed and explored. This paper illustrates, from a GC's perspective, how a SCM system is proposed, designed, and integrated into the project. The applications of lean principles, quality control methods, and BIM and other techniques to the SCM system are also discussed. The motivation of this paper came from a case study project to which SCM was integrated. The GC decided to use the SCM system in the project to achieve goals such as (1) high transparency in production, quality control, and construction, (2) higher quality conformance and rigorous quality checking, (3) proper tracking of long-lead items including prefabricated components and pre-assemblies, and (4) efficient monitoring and control of subcontractors' production and installation.

This paper focuses on SCM integration to one project instead of all projects of a GC. Tommelein et al. (2003) claim that a company will benefit most from SCM when it is practiced across all projects. However, the integration of a SCM system to a project is significantly affected by factors including the type of contract, type and scale of the project, available resources of the GC, owners' recognition of SCM and their willingness to cover its cost, and the managerial commitment to SCM at different regional offices. This paper focuses on SCM integration to one project while identifying general rules which could be applied at the company level.

2. RESEARCH METHDOLOGIES

We divide the integration of SCM to a construction project into three main phases: (1) decision making, need discovery, and early design of SCM, (2) design and implementation of SCM, and (3) operation of the SCM system. This way of phasing resonates the key milestones of a project. The first phase can start very early, even in the conceptual design stage of the project. This phase ends when the bid package is completed for the first main trade because the critical tools for the SCM integration must be written into the bid instruction to ensure the eligibility of the subcontractors and their use of these tools. Towards the end of this phase the GC should have a good understanding of the overall data structure, information flow, and workflow of the SCM system to establish uniformity at the project level. The second and third phases are subcontractor-specific. A GC needs to work with each subcontractor to customize the SCM system to determine key data elements such as types of component to be tracked, SCM status, and quality checklists. The third phase starts once the production starts at the subcontractor's facility. The second and third phase for one subcontractor does not need to go in parallel with another because subcontractors could be selected and ordered to production at different point of time, especially in large projects. Figure 1 illustrates the steps a GC needs to undertake at each phase. These steps are further discussed in the following sections.

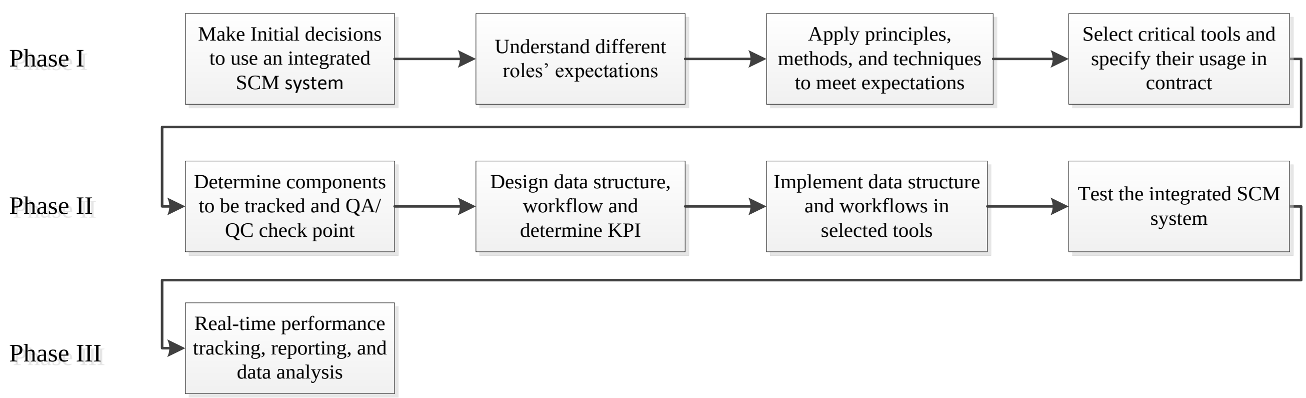

Figure 1: The proposed framework of SCM integration to a construction project

3. CASE STUDY DESCRIPTION

We use an ongoing commercial office building project in California for the case study. This 350,000-square-foot, seven-story construction project features large amount of structural precast components (about 5,600 pieces), limited site storage spaces, and global suppliers such as glasses for exterior skins. The owner requested a very aggressive construction schedule – a total of 18 months from excavation to grand opening. Therefore, in the early design and planning phase of the project, precast and preassemblies are heavily used to shorten the construction duration. Although the GC (DPR Construction) has a good track record of using integrated project teams to practice integrated project delivery (IPD) and apply lean design and construction to project execution (Eastman et al. 2011), the owner chose to use a combination of design-build and design-assistant for different packages in the contract. The GC attempted to award the subcontractors as early as possible nonetheless to add cost certainty and constructability knowledge to the design as it was developed. All authors of this paper are from the GC and intensely involved in this project.

4. DECISION MAKING, NEED DISCOVERY, AND EARLY DESIGN OF SCM

4.1 Initial decision making

The early decision making regarding the use of SCM in a project is primarily the GC responsibility instead of the owner because the latter rarely has the experience and knowledge to understand the complexity and gravity of the project from the construction perspective. An experienced GC, on the other hand, can quickly identify the key drivers which render it necessary to integrate SCM to the project. Such drivers in the case study include (1) aggressive schedule, (2) extensive use of pre-fabrication and modular assembly which require long lead-time, (3) global suppliers, and (4) more sophisticated quality control and conformance. Without properly tracking and managing the productions of the components with long lead-time in the (global) subcontractors' facilities, it is almost impossible for the GC to keep the project on schedule. Without effectively integrating quality assurance program into these productions, the GC will face the uncertainty of having defective/unsatisfactory components shipped to the job site, which will lead to project delay and cost overrun. After investigating the potential benefits of SCM in construction projects, the GC decided to integrate SCM into the current project management workflow. Such decision was made at the early phase of procurement when the aforementioned key drivers were identified while all bid packages still under development.

4.2 Understanding different roles' expectations

Since the SCM in a project involves multiple participants (O'Brien et al. 2002), as the initiator, the GC needs to fully understand their expectations about the SCM system before its design and implementation. Otherwise it would be setup for failure. The way of identifying the expectations varies by the roles of the participants. It is crucial to first capture the owner's expectations because they not only will cover a portion of the SCM implementation cost but also will be using the system for subcontractors' production and quality assurance metrics. Prior to collecting owner expectations, the GC needs to help the owner to recognize the value to the client and project and convince them to approve the SCM system. In the case study, the GC setup a series of formal meetings with the owner to present how the integration of SCM will add value to the project management and control, emphasizing its potential cost, schedule, and quality assurance to the project. Discussions on the benefits of SCM centered around process improvements instead of advanced features of tools and platforms on the market. The GC also demonstrated their qualifications and resources available to deploy the SCM system to ensure proper implementation and execution. The owner's questions and concerns were answered using examples or scenarios in the project. These questions and answers were well documented for the owner highlighting the SCM benefits and value adding parts to the project. Once the owner is onboard, the GC can setup another series of meetings to sit down with the owner as well as the architect and engineer (AE) to collect their expectations.

At this expectation management phase, subcontractors are not yet awarded. Consequently, the GC needs to take a different approach to obtain subcontractors' conformance. In the case study, internally, company-wide surveys and interviews with project executives, project managers, technology managers, and package managers were conducted. Externally, the GC surveyed and discussed with main trade subcontractors (such as precast, exterior skin, and mechanical) in the GC's regional prequalification list. All expectations collected were compiled and summarized.

As for the GC's expectation, internal meetings of the project management teams and regular discussions with the operations team were made. The project technology manager formally consolidated and documented the expectations and shared with the project teams. Inputs from experts outside the project and case studies from other sources were also taken into account.

The expectations collected from different roles are listed in Figure 2. The owner and AE's expectations were more at the strategic level while the GC's and subcontractors' more at the operation level. This is understandable because the later handle the execution of the project and care about the means for the effective management of their scope of operations. On the other hand, multiple roles may share certain expectations. For example, the owner, AE, and GC all expected to use more electronic files to save the amount of paper documents they need to review, sign, and save. Subcontractors may not share this expectation if it requires drastic change of their exiting workflow.

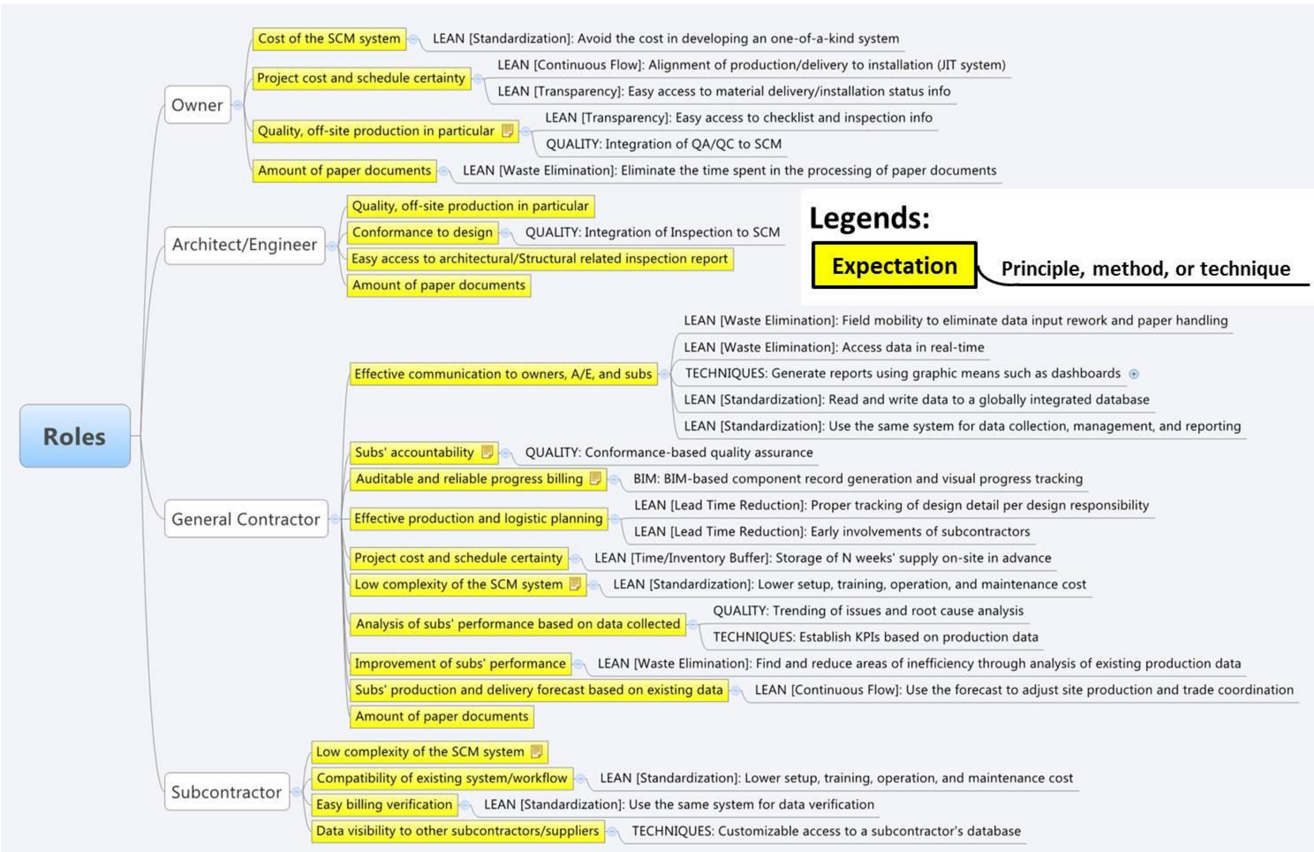

Figure 2: Expectations and requirements deduced from different SCM roles (map designed in XMind)

4.3 Meeting the expectations

As discussed in the previous section, different roles' expectations were not at the same level. In addition, there remained a gap for the GC to directly convert expectations to SCM implementation plans. So the GC needs to apply one additional step for such a conversion. In this step we apply lean principles, quality control methods, and BIM and other techniques to meet the expectations so that specific requirements can be created for SCM integration. Lean principles such as continuous workflow, lead time reduction, time/inventory buffer, waste elimination, standardization, and transparency were applied and corresponding requirements were specified in the case study project. Similarly, requirements related to quality control, BIM, and other techniques were defined. These requirements are illustrated in Figure 2 after each expectation. Requirements for expectations shared across multiple roles are only listed once. From Figure 2 we discovered two things. First, the majority of the requirements were related to SCM integration while certain requirements were less relevant in this regard. Some requirements were more relevant to operational plans such as providing storage of N weeks' supply on-site in advance, proper tracking of design details per design responsibility, and early involvement of subcontractors. Some requirements were about how to leverage the SCM integration to enhance project management such as alignment of production/delivery to installation and establish Key Performance Indicators (KPIs) based on production/quality data to enable proper tracking. Second, the SCM integration related requirements can be consolidated to better evaluate existing commercial tools for SCM integration of the project. These consolidated system requirements include:

- In general the SCM system in the project should have relatively lower cost and be easy to setup and customize, robust, with low complexity and user-friendly interface, and compatible with commonly used SCM applications by subcontractors, if any.
- The SCM integration should include field mobility (downstream at subcontractors' facilities and the job site), real-time data access, sharing and system connectivity with other applications at both downstream and upstream (at the GC, owner, and AE's end), and effective data exports and reporting.
- The field mobility part of the system should (1) enable the integration of conformance-based quality insurance in the field, (2) allow subcontractors and inspectors to update production related status and fill out quality checklist and inspection forms in real-time, and (3) share the data collected with upstream participants in real-time.
- The data access and connectivity part of the system should (1) allow users to access data stored at the central database in real-time, (2) enable users to control and customize the accessibility to ensure the right people retrieve the right information, and (3) possess good compatibility and interfaces with existing SCM systems and applications used by other participants.
- The data output part of the system should (1) have a certain level of capability to graphically present production and quality data to users, (2) be able to produce spreadsheets to allow users to conduct analysis and audit subcontractors' progress based on the data collected, and (3) have the capability to periodically send reports and alerts of the current SCM status to the right group of users.
- The system should integrate with and make use of information in BIM

We tried to keep the wording of the consolidated requirements less specific in the hope that they can be used and replicated in other types of projects. For instance, the requirement of BIM-based component record generation and visual progress tracking in Figure 2 was absorbed into the third requirement of the data access and connectivity part because this BIM-based requirement is related to the interoperability and interface between BIM and the SCM system.

4.4 Selecting critical tools for SCM

At the procurement phase of a project, it is almost impossible for a GC to predict and encompass all the project characteristic and conditions once production and construction start. Therefore, it is hard for them to make an early decision in selecting all the SCM and decision support related tools for production and quality control. However, critical tools that are to be used by multiple participants especially the subcontractors must be selected so that they can be written into the contract. Such a mandatory and formal requirement would overcome organizational hurdles in a project and hold the subcontractors accountable to use the SCM system.

In the case study project, the GC used the requirements summarized in Section 4.3 to select from existing tools for the SCM integration. In-house development of the tools was first excluded because it did not make sense to develop a platform just for one project considering the cost and resource available. In terms of system platform, the GC first evaluated existing ERP systems and found that they were mostly intended for company-wide implementations in the manufacturing industry and not suitable for construction projects. Then the GC evaluated Autodesk® BIM 360™ Field system based on past test projects and the features the system provides. Most of the requirements regarding data access, system connectivity, and data output parts can be met by the web portal component of BIM 360 Field system while the app version of the tool (in tablets) can satisfy the requirements for field mobility.

In addition to the software platform, the field data capturing method was also specified as it directly related to how data should be collected, transmitted, and shared. Barcode and radio frequency identification (RFID) are the two most commonly used technologies in this field. In the academic arena much research have been done about RFID and its advantages over barcode are widely identified including larger on-tag storage capacity, no requirement of line-of-sight, longer read range, more durable in harsh environment, reading of multiple tags at the same time, automated data capturing, etc. (Li and Becerik-Gerber 2011; Lu et al. 2011) However, in the case study project, the GC selected barcode for its primary advantages of cost effective deployment (both barcode tags and scanners/readers) and zero discount of performance around metals (especially rebar enclosed in concrete). Another main reason why barcode was chosen was the integration of conformance-based quality control in the production process. Taking precast component as an example, each piece of component must be scanned and checked using a scanner and tablet, the human interactions were already there. Therefore, RFID's advantages of automated data capturing and multiple tag-reading at a time were not useful in the case study project. As to on-tag data storage, all production and quality related data are stored on the cloud (Armbrust et al. 2009) and linked to the barcode ID. Therefore, a barcode ID is sufficient to associate a physical component with its digital record, which can be retrieved using a tablet App from the cloud.

5. DESIGN AND IMPLEMENTATION OF THE SCM SYSTEM

Once critical tools for the SCM integration were selected, the technology team of the project received formal trainings from BIM 360 Field support team as well as system champions from the GC in setting up, operating, maintenance, and troubleshooting. The technology team members need to become champion of the BIM 360 Field system and process so they could later on train the subcontractors. The training and system configuration process continued in the case study until main subcontractors were selected to ensure the supply chain parts for these subcontractors were properly setup. In the life cycle of the SCM design and operation, the technology team of the GC need to work with the BIM 360 Field support team to continuously customize features that are unique in a project and resolve issues encountered in the meantime.

5.1 Determining components to be tracked and quality check points

Once a subcontractor is awarded the contract, implementation starts immediately. Using the precast subcontractor as an example in the case study project, on top of the introduction of overall technology strategies and use of BIM in the project, the GC first held official workshops to give an overview of the SCM system for the project and educate the staff (the supply chain manager in particular on the subcontractor's side) regarding the setup of the system. Benefits of using the SCM system for the subcontractor were clearly conveyed so that they were more confident in using the system. The GC will then give the subcontractor's supply chain manager the project administrator authorization to the BIM 360 Field system so that he/she can manage the configuration of the system.

When setting up the system, the GC needs to collaborate with the subcontractor to establish the critical elements of the system, namely the type of components to be tracked and the quality check points. From the GC's perspective, they would want to use a precast component such as a panel, column, and beam as one unit instead of tracking each individual rebar and embed in the component. When a precast slab is composed of two separate panels produced in the subcontractor's facility, the tracking would be depending on how the slab is installed. If it is pre-assembled off-site, the GC may prefer tracking the slab as one piece. If the two panels are produced separately (at different manufacturing locations) and assembled on-site, the GC may want to track them individually. Similarly, SCM status such as "manufactured," "ready to delivery," "shipped," and "delivered on-site," for each type of component need to be determined so the GC and subcontractor's supply chain manager can evaluate whether a special checkpoint should be established for a certain type of component such as slabs with expensive tubing embeds shipped from another state. Between each two statuses, the GC also need to collaborate with the subcontractor to figure out how the owner's and AE's quality requirements can be met and what checklists and inspections should be filled out. In the case study, the technology team held regular semi-weekly meetings with the subcontractor's project manager, production manager, and supply chain manager to determine all these key elements.

5.2 Design of the data structure, workflow, and KPI

When the component type, status and quality checklists are established, the GC needs to collaborate with the subcontractor's supply chain manager to draw a map for the overall workflow for the field mobility piece of the system illustrating the main types of input workers and inspectors at the manufacturing facility should provide. Figure 3 shows the map developed for the precast subcontractor in the case study project.

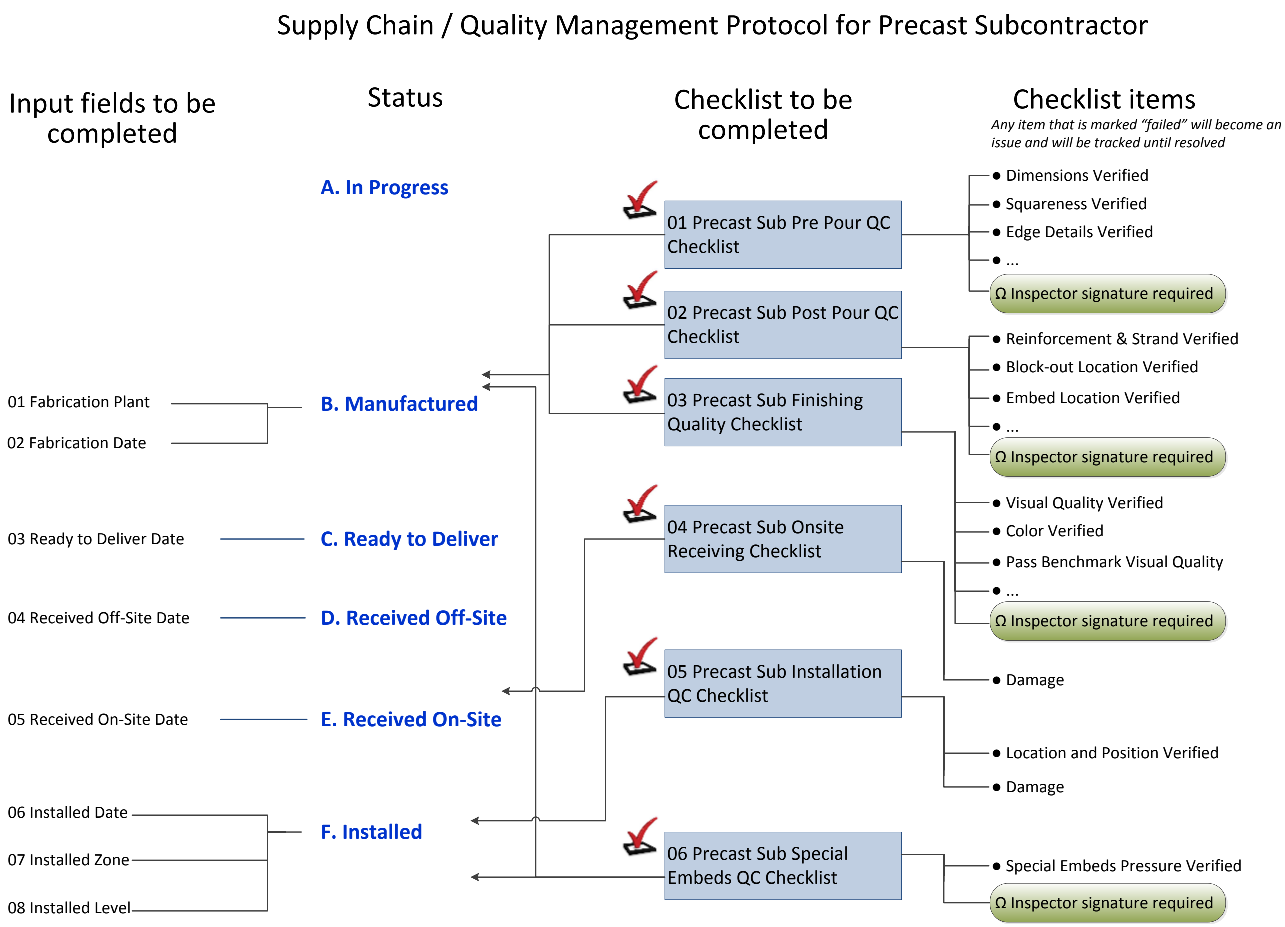

Figure 3: Overall data structure for field mobility (the precast subcontractor in the case study project)

The map shown in Figure 3 clearly demonstrates the component status, the checklists to be filled out before the change of status, and additional data inputs when changing component status. In the case study project, both GC's internal management team and the subcontractors found this map very helpful for them to understand and setup the data structure in the BIM 360 Field system. It also served as a reminder for workers and inspectors regarding what they should provide as inputs once they were in the field.

The data structure and workflow shown in Figure 3 are intended to draw an overall picture about the SCM system for a subcontractor and thus do not include scenarios when things go wrong. Specifically, once a defect is found in the field, the inspector should be able to create issues using the BIM 360 Field App on his/her tablet. Therefore the GC also needs to work with the subcontractors and the (third-party) inspectors to identify the type of issue related to the defect component, its cause, the party responsible to address the issue, and when to re-inspect the component (or just produce another one). The subcontractor's teams are mainly responsible to define these issue-related elements for each line item on a quality checklist and then obtain the GC's approval.

The tracking of SCM status and quality allow the GC to efficiently monitor and evaluate a subcontractor's performance, especially for precast and pre-assembled components. To measure this performance, the GC needs to develop KPIs such as production rate, defect rate, number of issues found per month, etc. The early definition of these KPIs can help the GC identify data types that could have been neglected otherwise when setting up the data structure.

5.3 Implementation of data structure and workflow

Once the data structure and workflow are established and confirmed by all SCM participants, the subcontractor's supply chain manager can proceed with the configuration in the BIM 360 Field system. Its web-based portal is convenient for a user to configure and customize the system anywhere as long as he/she can access Internet. Once the data structure is implemented in the system, the supply chain manager needs to further conduct two steps in the BIM 360 Field system. First, he/she needs to import all the component record to the system. It provides import function from spreadsheet so users do not have to manually input records. In the case study project, the GC specified the use of BIM tools so that the component ID, type, dimension, size, location of the project, and other type of information can be directly exported from these tools and then imported to the BIM 360 Field system with minimum modifications. The component ID and location information could be used to visually show the progress of a subcontractor in BIM, once component records with status information are transferred back to the BIM tools. The second step is linking quality checklist template to the corresponding records for conformance-based quality integration. Once these two steps are completed the SCM system is ready for tests.

5.4 Test the integrated SCM system

Testing is another crucial part of the SCM integration to the project which helps the project participants to identify things that are omitted or needed to be improved. If no prototype/mockup is requested by the owner, the GC can only test the SCM system based on simulated scenarios using subcontractors' BIM component outputs as inputs. If the owner grants the construction of certain prototype/mockup for the project, this would become an ideal test case for the SCM system. In the case study project, the GC was able to test the system using one precast mockup. Findings such as when and where to attach barcode, the number of line items to be included on a checklist, the type of dashboard needed, and the number and types of reports to send out periodically are very helpful for enhancing the performance of the system before a subcontractor officially starts production.

6. OPERATION OF THE SCM SYSTEM

Once the SCM system is up and running, the subcontractors would be taking the key role in making their part of the system functional. The GC's technology team needs to visit the subcontractor' facility at the beginning of the production to ensure the people actually using the field mobility part of the system follow the right workflow to collect data. After that, the GC checks the data collection progress on a daily basis to ensure the tracking and quality checking are done properly. Once the subcontractor is on the right track, weekly tracking according to the production schedule would be enough.

The GC can analyze KPIs based on the data collected from the field periodically or upon request. The BIM 360 Field system allows users to export component records as spreadsheet so that users can conduct sophisticated data analysis using other tools.

In the case study project, the GC used the following steps to align a subcontractor' production with the installation on-site. First, trend analysis of production rates (excluding defect components) based on the data collected from the subcontractor' facility and the job site was conducted. Second, the GC used the trend analysis to determine whether the production can keep up with the installation. If conforming, the GC would use another simulation tool to predict whether the existing production rate can accommodate the installation on the look-ahead schedule and then adjust the schedule or the subcontractor's production rate accordingly. If non-conforming, the GC would talk to the subcontractor immediately and find the reasons behind such a misalignment. Both the GC and the subcontractor would take actions to make the production match the installation on the (adjusted) look-ahead schedule.

The GC also used BIM 360 Field reporting function for billing document generation and verification. Payments to certain subcontractors in the case study project were based on the number of pre-assembled or precast components reaching to a certain status. Component records with this status can be filtered out in the BIM 360 Field reporting function so that the project accountants could know the exact number based on which they would create the payment documents. This reporting function not only enhanced transparency but also improved project cost certainty.

7. FINDINGS AND CONCLUSIONS

We propose a framework (Figure 2) in this paper to facilitate the SCM integration to projects from a GC's perspective. Using a case study and the interaction with the precast subcontractor in particular, we describe how a GC can apply lean principles, quality control methods, BIM and other techniques to SCM integration and summarize actions a GC needs to take in each step of the framework.

Examples of benefits from the SCM integration in the cast study project include: (1) the proactive and periodic reporting through email brought all SCM participants on the same page; (2) the checklists and inspection results collected from the field in real-time allowed efficient quality check for the GC, owner, and AE; and (3) project engineers and managers, the quality control manager, and superintendents reported at least 30% of time saved in retrieving the accurate production and quality data.

From the case study we obtained several findings. First, a GC needs to avoid the use of tools for the sake of their technological advancements. Expectations from different participants in the SCM system must be fully understood first and used as the foundation for selecting tools for the SCM integration to a project. Second, the implementation of the system, especially the field mobility part should have minimum impact on a subcontractor's existing workflows. The GC should work together with the subcontractors to use the SCM system to improve their work productivity and efficiency instead of drastically changing their workflows. Third, the GC should properly supervise each subcontractor's SCM portion so that they do not go overboard with tracking (i.e., tracking too many components in great detail or adding too many statuses to a type of component) or vice versa. The GC needs to carefully discuss with owners, A/E, inspectors, and the subcontractors to define the right level of detail for tracking and quality control. Fourth, on top of the uniformity in the software platform, the GC can take advantage of hardware uniformity to improve productivity in the field. For example, since the barcode scanning in the field already requires the use of tablets, other apps with functions such as reviewing of specifications, documents, and model, drawing markup, and email access can also be used in the field. Fifth, the GC should help the subcontractors to determine key data elements (such as component type and status) and naming conventions before they actually start to use the SCM system. Although these can be modified in the SCM operation phase, it would be time consuming to update the records linked to the physical components already in production. Sixth, the complexity of tools used for the SCM integration significantly affects the performance and productivity of users using the system. A more sophisticated system would require more time and resources for the subcontractors to learn and for the GC to train, assist, and supervise them. In addition errors and mistakes tend to occur more often. On the other hand, tools that are too simple cannot offer the functions and right level of customizability required by SCM integration for construction projects. The point of balance (or "sweet spot") regarding the system complexity is still heavily dependent on the participants' expectations and the GC's experience and expertise in SCM.

It is worth mentioning that internally a GC's organizational structure and dynamics between teams affect the SCM integration significantly. In this paper we use the GC as one entity and do not drill down to the roles and responsibilities inside a GC's organization. Internally, the supply chain manager from the technology team should lead the processes described in Figure 2; work with the quality assurance, procurement, and operations team to define goals of the system; work with the technology manager and project executive to demonstrate its value to the owner; and work intensively with the subcontractors to customize and implement the SCM system. In the future research, we will discuss in detail regarding roles, responsibilities, and team dynamics within a GC's organization in the SCM integration process.

REFERENCES

Armbrust, M., Fox, Griffith, R.A., Joseph, A. D. Katz, R. H. Konwinski, A. Lee, G., Patterson, D. A., Rabkin, A., Stoica, I., & Zaharia, M. (2009). "Above the clouds: A berkeley view of cloud computing". University of California, Berkeley, Tech. Rep. UCB-EECS-2009-28.

Cheng, J., & Law, K. (2010). "A service oriented framework for construction supply chain integration". *Automation in Construction,* 19(2), 245–260.

Dawood, N. (2009). “Lean enterprise web-based information system for supply chain integration: design and prototyping”. *Construction Supply Chain Management Handbook*, CRC Press, Boca Raton, FL.
Eastman, C., Teicholz, P., Sacks, R., & Liston K. (2011). “BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors”. 2nd Edition, John Wiley & Sons, Hoboken, NJ.
Ergen, E., Akinci, B., & Sacks, R. (2007). “Tracking and locating components in a precast storage yard utilizing radio frequency identification technology and GPS”. *Automation in Construction*, 16 (3), 354-367.
Li, N. & Becerik-Gerber, B. (2011). “Life-Cycle Approach for Implementing RFID Technology in Construction: Learning from academic and Industry Use Cases”. *Journal of Construction Engineering and Management*, 137(12), 1089-1098.
Lu, W., Huang, G. Q., & Li, H. (2011). “Scenarios for applying RFID technology in construction project management”. *Automation in Construction*, 20 (2), 101-106.
O’Brien, W.J., London, K. & Vrijhoef, R. (2002). “Construction supply chain modeling: a research review and interdisciplinary research agenda”. *Proceedings IGLC 10*, 1-19.
Ren, Z., Anumba, C.J., & Tah, J. (2011). “RFID-facilitated construction materials management (RFID-CMM) - a case study of water-supply project”. *Advanced Engineering Informatics*, 25(2), 198-207.
Song, J., Hass, C.T., Caldas, C., Ergen, E., & Akinci, B. (2006). “Automating the task of tracking the delivery and receipt of fabricated pipe spools in industrial projects”. *Automation in Construction*, 15(2), 166-177.
Tommelein, I. D., Walsh, K. D., & Hershauer, J. C. (2003). “Improving capital projects supply chain performance”. *Research Report PT172-11*, Construction Industry Institute, Austin, TX.
Wang, L. (2008). “Enhancing construction quality inspection and management using RFID technology”. *Automation in Construction*, 17(4), 467-479.
Yin, S., Tserng, H.P., Wang, J.C., & Tsai, S.C. (2009). “Developing a precast production management system using RFID technology”. *Automation in Construction*, 18(5), 677-691.