REAL-TIME SUPPLY CHAIN MANAGEMENT USING VIRTUAL DESIGN AND CONSTRUCTION AND LEAN

Sangwoo Cho[1] and Martin Fischer[2]

ABSTRACT

Supply chain management in construction has evolved in response to various innovative tools. Field observations and focus-group interviews with supply chain members, however, indicate a need to design an integration methodology of these tools to improve communication, reliability, visibility, and automation in the construction supply chain management. Thus the authors have developed and implemented the integration methodology of Virtual Design and Construction, lean, and real-time data capturing tools. With this integration, improvement in alignment between demand and supply, reduction in distortion of demand information, and savings in time and efforts have been achieved in a field trial for the supply chain management of the doors, frames, and hardware scope of work on a construction project, translating into a change in the behaviour of the construction supply chain management: supply chain members enable real-time, web-based, two-way communication, 4D color-coded visualizations and automatic status reports of a supply chain, and model-based Last Planner™, resulting in creating instant, consistent, visual coordination and communication between field crews and offsite personnel and bringing a high level of accountability to themselves and each aspect of the supply chain management.

KEY WORDS

Supply chain management, Virtual design and construction, Lean, Real-time data capturing tool.

INTRODUCTION

According to a series of interviews with general contractors, Door, Frame, and Hardware (DFH) installation accounts for approximately 2% of construction costs but often causes 30% of construction issues due to highly fragmented supply chains that have multiple supply chain members, phases, disciplines, and materials. Thus this research paper claims that improving the supply chain of DFH will eventually be a key success factor in improving supply chains on building project. In an "action research" environment where the first author has participated in three projects and two focus-group interviews, three motivating cases below have been documented and analyzed to support this claim. Research hypotheses will follow in the next section.

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MOTIVATING CASE #1: FRAGMENTED, PUSH-DRIVEN COMMUNICATION IN SCM

A DFH project manager in a construction project in Santa Cruz, CA, commented: "Closer communication between suppliers, job teams, and DFH project managers is the best prevention of future problems with supply chain effectiveness." In current practice of the supply chain management (SCM), the communication among stakeholders is fragmented. And the communication is even push-driven from upstream to downstream actors along with material flow (Figure 1) This fragmented, push-driven communication in the SCM results in higher possibility of misalignment between demand and supply (Figure 2) because supplier's control on production and delivery is not based on updated work plans from the field which best reflect current progress of installation. This misalignment, in turn, creates an unexpected increase in inventory or work-in-process, potentially translating into overruns of cost and time (Arbulu and Ballard 2004) such as additional costs because of the additional storage space and the additional manpower required for maintaining the inventory and space.

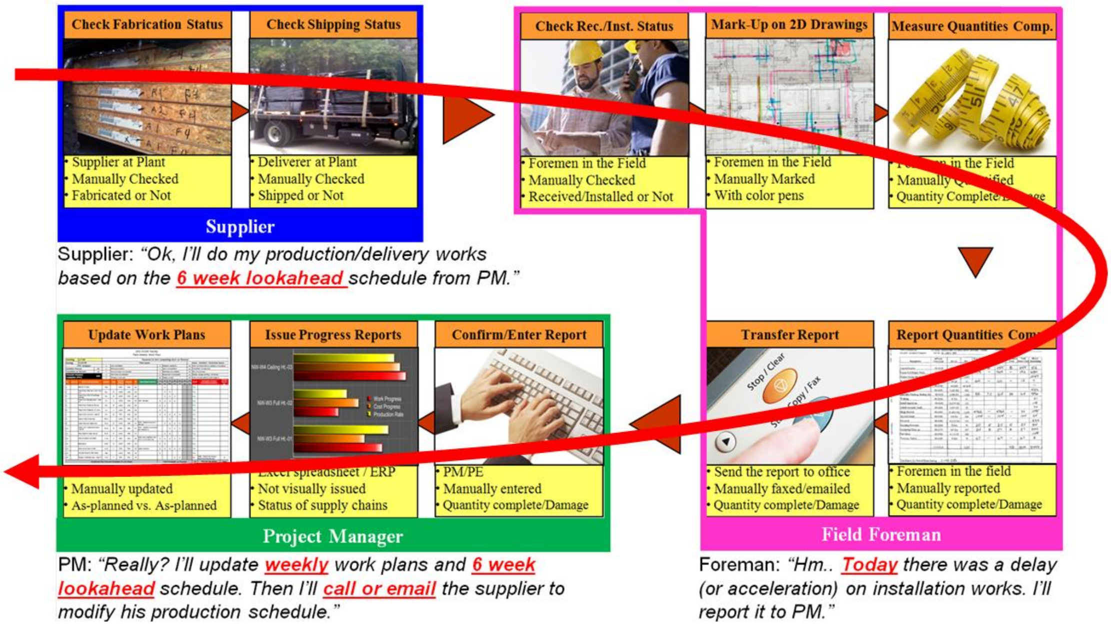

Figure 1: Fragmented, Push-Driven Communication along with Material Flow from Supplier to Field Team and to Office Project Manager

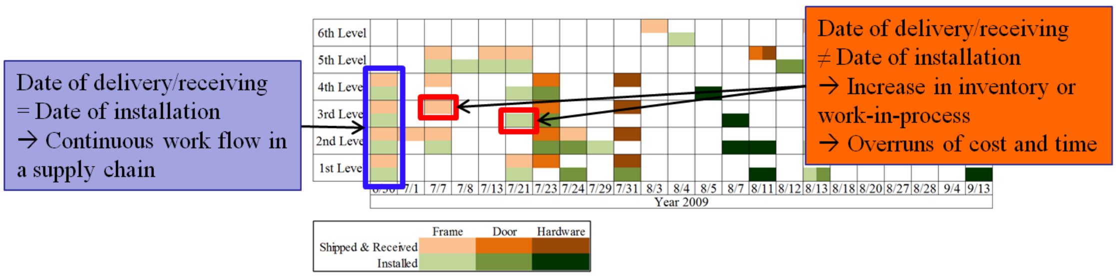

Figure 2: Pattern Analysis of a DFH Project Showing that Misalignment between Supply (i.e., Date of Delivery/Receiving) and Demand (i.e., Date of Installation) Increases Inventory and Work-In-Process

MOTIVATING CASE #2: LOW RELIABILITY IN SCM

According to the study on the current SCM in Figure 1, project managers communicate with suppliers with 6-week look-ahead schedules for placing orders to support construction operations. The look-ahead schedules consist of weekly work plans. Figure 3, however, shows that updating process on the work plans has a low reliability because it is based on manual-takeoff information of quantities completed captured in the field using a measuring tape or even simply visual inspection. Superintendents or project managers are unlikely to go to site to check whether or not these quantities have been really completed. Low reliability of the work plans results in distortion of demand information in the ordering process and then creates the bullwhip effect (Lee et al. 2004) which, across a supply chain, inserts additional contingencies in amount of materials ordered. This distortion of demand information is one of the main root causes of misalignment between demand and supply in construction.

Figure 3: Low Reliability in Updating Process of Work Plans which are Tools of Communication with Suppliers in SCM

MOTIVATING CASE #3: LOW VISIBILITY IN SCM

Many tasks in the construction SCM are manual- and paper-based. Thus the authors observed that there is an issue in communicating variability of demand with suppliers. Hand-marked 2D plans cannot be shared easily and quickly and paper reports of quantities completed are not shared with suppliers. Figure 4 shows that project managers need to manually enter the status from field into their spreadsheet and then updated weekly work plans based upon this spreadsheet. These additional works augment decision latency and eventually batch sizes of materials to be ordered, leading to distortion of demand information (Chen and Lee, 2009; Lee et al., 2004)

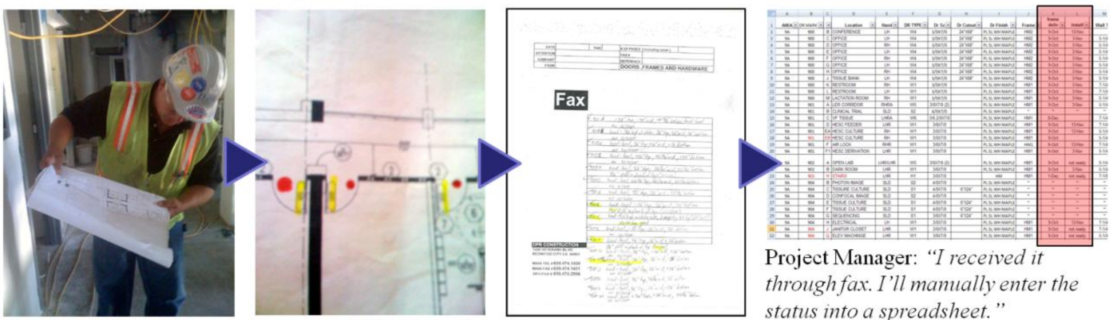

Figure 4: Hand-Marked Plans and Paper Log-Based Work Plans which are not Sharable Creates Negative Impacts on Communicating Where and How Much Material Is Needed

RESEARCH HYPOTHESES

The motivating cases indicate that current SCM in construction needs tools to improve communication, reliability, visibility, and automation. There have been practical researches and system tools to improve these factors one by one.

Arbulu and Ballard (2004) point out that the web-based Last Planner™ can increase workflow reliability and reduce demand variability. And this web-based Last Planner™ can be used for communication among supply chain members.

Fischer (2003) and Koo and Fischer (2000) highlight benefits of Virtual Design and Construction (VDC) in achieving improvement of reliability and visibility through accurate model-based quantity takeoffs and through 3D/4D virtual models.

Lee et al. (2004) indicate that better communication tools for exchange of inventory status information and ordering process can help reduce distortion of demand information and in turn improve alignment between demand and supply.

Many previous researches regarding use of RFID/Barcode in construction suggest that these real-time data capturing tools can improve visibility through ID-based progress checking and automation through automatic data input/output/sharing (Mueller and Tinnefeld 2007, Lee and Ozer 2007).

Recently there have been researchers (Sorensen et al. 2009, Chin et al. 2008) testing a joint solution of VDC and RFID for progress management where two factors, visibility and automation, have been improved.

Despite these tools partially being used in the construction industry, there is still a substantial need to have an integrated solution of these tools (i.e., VDC, lean, and real-time data capturing tools) to jointly improve the four factors (i.e., communication, reliability, visibility, and automation). With this improvement, the authors formulate a hypothesis that the proposed integrated system can achieve in the construction SCM (Figure 5):

1. Improvement in alignment between demand and supply
    a. Days of inventory turnaround on site
    b. Days of work-in-process on site
    c. Rate of just-in-time delivery
    d. Days of job delay due to non-availability of needed elements

2. Reduction in distortion of demand information
    a. Latency of decision making and information sharing
3. Savings in time and effort
    a. Time savings in recording, documenting, communicating, and reporting
    b. The number of manual, unreliable steps replaced with automatic, reliable steps

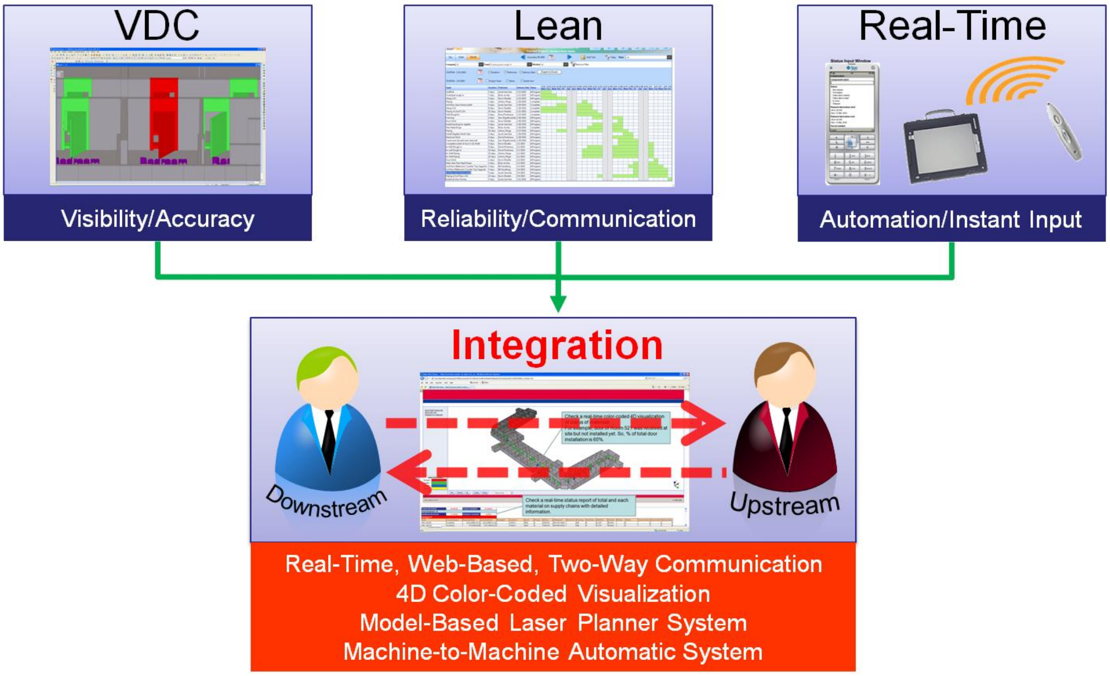

Figure 5: The Proposed Integrated System of VDC, lean, and Real-Time Data Capturing Tools

SYSTEM DEVELOPMENT

With a great deal of help from end-users (i.e., field foremen, suppliers, and project managers) and software developers, the integrated system has been developed and tuned-up through simulations in a controlled environment (Figure 6). Each status of materials in a supply chain is scanned, 4D color-coded, quantified, and then reported. Then both time logs from real-time data capturing tools and quantities completed from VDC models are combined to create as-built progress of a supply chain which is to be compared to as-planned work plans in the web-based Last Planner™ to calculate PPC (Percentage of Plan Completion) and accordingly update daily/weekly work plans.

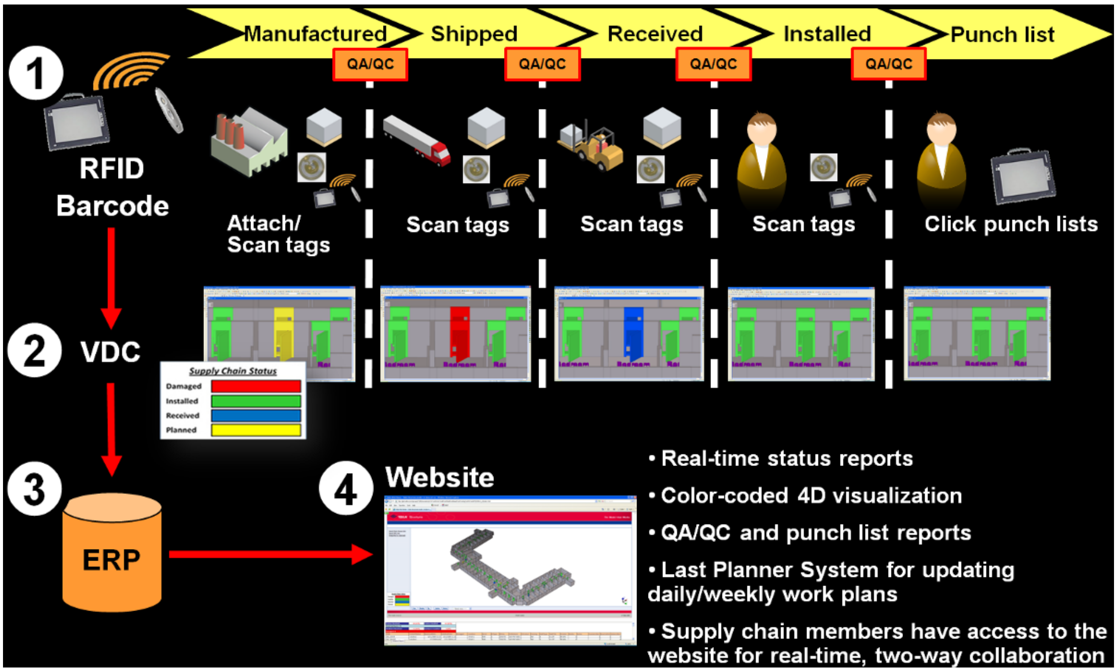

Figure 6: Overview Diagram of the Integrated System from Real-Time Data Capturing Tools to VDC and then to Last Planner™

Through swimlane mapping and time study on both current and integrated SCM systems, time-consuming, unreliable steps could be deleted or replaced with automatic, reliable steps. Among them, two major steps are introduced in Figure 7.

Current SCM	New SCM
At the time components are received or installed, field foreman must manually review plans, update status, and then issue a paper report (120 seconds/material)	Field foreman uses barcode scanning to instantly access material info and update status, and then output is automatically 4D color-coded and reported to project managers and suppliers (56 seconds/material)
In a supply chain, any QA/QC issues are marked on plans and must be re-entered into daily reports (hours or even days later) (1020 seconds/material)	QA/QC issues entered into tablet PC instantly generate electronic reports and 4D visualization for reordering (128 seconds/material)

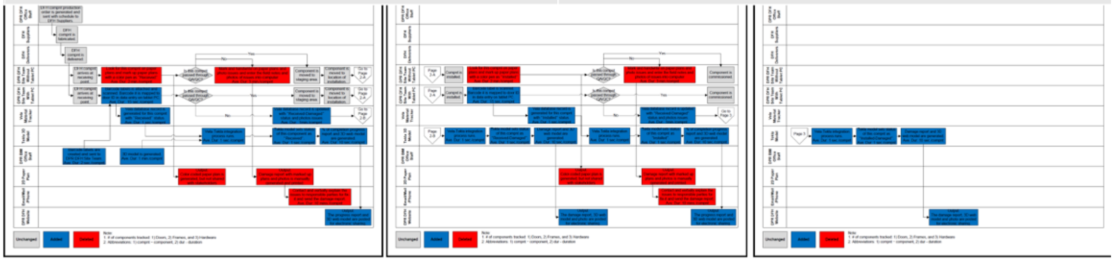

Figure 7: Swimlane Map and Time Study on Current and Integrated SCM Systems

SYSTEM IMPLEMENTATION

One pilot project was selected for testing the integrated SCM system. Project descriptions are as follows:

Project: University of California in Santa Cruz - Porter College B (six-story, 102,751SF)

Supply chain: Manufactured – Shipped – Received – Installed – Punch list

The number of materials in the supply chain: 234 doors, 234 frames, and 2203 hardware (Contract $800,000)

Period of implementation: June 2009 – September 2009

Through barcode scanning, current status of each material in the supply chain was captured (Figure 8) and transferred to the database of the VDC for publishing web-based 4D color-coded visualizations and detailed status reports based upon the model-based quantities completed (Figure 9). The supply chain members (i.e., suppliers, field teams, project managers, and owner) had access to the project website to see the status reports and visualizations.

Figure 8: Barcode Scanning and SCM Status Transferring from Field to VDC Database

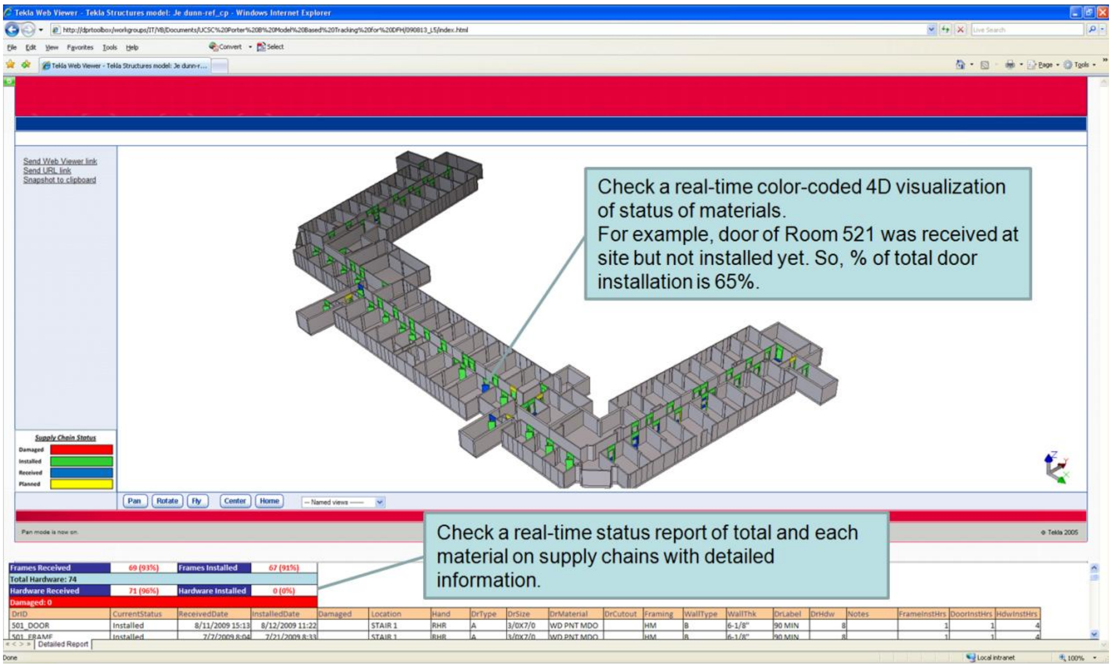

Figure 9: 4D Color-Coded Visualization and Detailed Status Reports on the Project Website

The model-based quantities completed and the time logs from the barcode scanning are transferred to the web-based Last Planner™ where PPC is calculated based on as-planned and as-built quantities and durations. This model-based, real-time PPC enables automatic micro-management on last planners' commitment by instantly detecting mismatch between as-planned plans and as-built progress, leading to continuous update of work plans for better alignment between demand and supply (Figure 10).

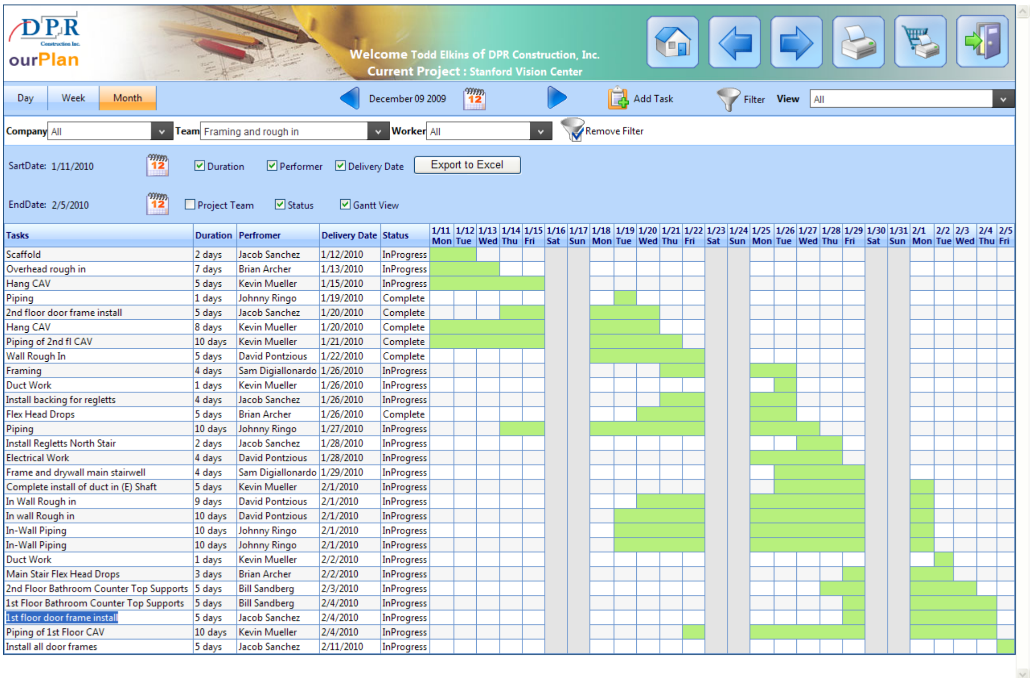

Figure 10: Web-based, Model-based, Real-time Last Planner™ (Image courtesy DPR Construction, Redwood City, CA)

Through the implementation of the integrated SCM system on this pilot project, quantitative and qualitative results are obtained as follows:

Better alignment between demand and supply and less distortion of demand information: Rather than saying “We think we are 75% complete”, the supply chain members could say “We know we are exactly 75% complete and which 75% is actually complete”. Better visibility and web-based information sharing increased reliability of the SCM, enabling better alignment between demand and supply and less distortion of demand information.

Time savings: Through the time studies on the swimlane maps of the current SCM system vs. the integrated SCM system, the authors documented that 70% savings (=28 hours saved) of time and efforts of the field foremen in recording, documenting, communicating, and reporting were achieved (Figure 11).

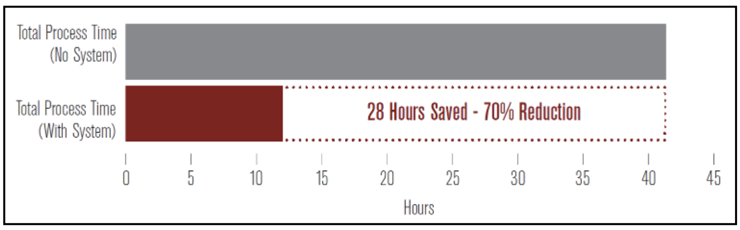

Figure 11: Comparison of Total Process Durations with No System and with the Integrated System

Reduction in reorder rate: A rate of zero unnecessary reorder was achieved, mainly due to the improved visibility of the SCM. There was no unnecessary change order, leading to less distortion of demand information. The typical 2% DFH job cost related to unnecessary reorders did not exist in this project.

Testimonials from end-users: After the implementation, the authors conducted and documented another round of interviews with end-users as shown below.

Overall Satisfaction Score: 5 (highest)

✓ *"With the new system, we accomplished everything in less time than ever before."*

✓ *"Much more accurate picture of what can actually be installed with the number of people on the project helped for future planning."*

✓ *"Now we have immediate visibility so I can tell right away – eliminates confusion."*

✓ *"It enabled us to communicate status of materials with stakeholders in a better way."*

✓ *"With the old process, I had to fax huge amounts of paper works (e.g. daily status reports) and make countless numbers of calls for status updates. We have gained substantial time savings with the new system."*

✓ *"All the project participants can check the website for status check from anywhere anytime."*

✓ *"With the new system we can measure and foresee in a more reliable way what can be installed within the planned timeframe."*

CONCLUSIONS AND FUTURE RESEARCH

The integrated system of VDC, lean, and real-time data capturing tools is developed and implemented for 1) improvement in alignment between demand and supply, 2) reduction in distortion of demand information, and 3) savings in time and efforts in the field, translating into a change in the behaviour of the construction SCM: dramatic reduction in decision latency from days to hours and even minutes with clear visibility of the supply chains. In addition, this integrated system caused positive cultural impacts to the supply chain members in the pilot project. They have been able to create instant, consistent, visual coordination and communication between field crews and offsite personnel and bring a high level of accountability to themselves and each aspect of the SCM.

Next steps of the research plan are underway in order to develop a map of causes and effects in the construction SCM and study on interdependencies of the causes and degrees of the effects. Through this mapping and study, the authors can identify the causes and effects which negatively impact aspects of the construction SCM and figure out how the proposed integrated system can be tuned up to minimize the negative causes and effects.

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