In part 1 of this Case Study, Boldt pumped grout through 2 holes in the frame called “grout ports,” located 76 mm (3”) below the header, one on each doorjamb. A grouting crew first fills the doorjambs halfway. Once this grout has set, the crew then fills the remaining halves and the header. Unfortunately, this procedure had problems. During placement, grout leaked through the cracks between the frame and the wall, blowing out the foam backer rods and caulking. As frames were already installed when they began grouting, any leak prevention system had to be applied to the outside of the frame. At first, Boldt tried to use the latex caulking and security sealant as a barrier, however both the caulking and sealant kept blowing out. To prevent further blowout, Boldt devised a “Plywood Fix” (according to Boldt, other contractors use similar fixes). They cut two large U-shaped pieces of plywood sized to fit directly against the seam between the door frame and precast wall (Figure 2). They built C-clamps out of plywood and used them to hold the two U-shaped pieces together against the door frame. Workers added wooden shims between the C-clamps and the U-shaped pieces to tighten the fit. After pumping the grout and allowing it to set, they removed the Plywood Fix. Sometimes, the plywood’s removal damaged the caulking, so Jacques had to re-caulk the frames. However, after developing experience in applying the Plywood Fix, workers managed to remove it without damaging the caulking, so Jacques did not have to re-caulk every frame. The Plywood Fix was unwieldy and time-consuming. It took about 10 minutes to install and about 10 minutes to remove and relocate. When we applied the “Five WHYs” to unravel aspects of the Plywood Fix, it became apparent that problems were more deeply rooted in the structure of work. This case study is a means to understand what happened and to determine systematic means to eliminate the need for “Plywood Fixes” on future projects.”

**APPLICATION OF THE “FIVE WHYS”**

The “Five WHYs” is a quality management technique of problem solving that tries to find the root cause of a problem. Once a problem occurs, workers should ask and answer why it occurred at least 5 times in succession until they identify an actionable root cause. The strategy for fixing the system is to eliminate the root cause to avoid repeat occurrence (Wilson et al. 1993). The “Five WHYs” is an integral part of the Toyota Production System (Ohno 1988 p. 17) that became known as “Lean Production” in the U.S. It is a useful technique in our Lean Construction tool set as well. The following paragraphs begin with a discussion of a “Why?” followed by details regarding local and global fixes that address the “Why?”

**WHY #1: Why did caulking and foam backer rods blow out?** Caulking and backer rods blew out because of the hydrostatic pressure developed by wet grout during the grouting process.

**Security Sealant Fix:** This fix applies security sealant on both the inside and outside edges of the frames to prevent grout blowout. It implements Venture’s original caulking specifications. The objective of the fix is to prevent blowout when the workers grout the door frames.

**WHY #2: Why did grout leak through the cracks?** Grout leaked through the cracks due to the high pump pressure and thin grout mixture. With those two factors, the cracks were not tight enough to hold back the grout. This lack of tightness is the reason why workers introduced backer rods to provide support when caulking over wide cracks. Since backer rods and caulking combined could not hold back the grout, the grouting crew introduced the Plywood Fix.

**On-site Weather Stripping Fix:** Boldt could try to tighten the seal between the frame and the wall. Some kind
of weather stripping material might be glued to run along the perimeter of the frame prior to installation to replace the backer rods. Tightening the anchor bolts would compress the weather stripping, thereby providing a tight seal. However, security sealant would still have to be applied to the prison cell side of the frame to prevent tampering.

**WHY #3: Why was grouting of the hollow metal door frame needed?**

We do not know the origin of the grouting requirement but speculate that grout adds to security by (1) protecting anchor bolts, (2) providing a bond between frames and walls while making the frame heavier should an inmate try to push the frame out, (3) filling the hollow frame and thereby preventing inmates from hiding objects in it, and (4) making it more difficult to disable any electrical lock mechanisms.

**Concrete Lip Fix:** One way to eliminate the need to grout is to prefabricate walls with a concrete lip that protrudes on the prison cell side of the frame (Figure 3). Then, inmates would see only a recessed door and concrete walls since the lip blocks access to the frame completely. Once the frame is anchored against the lip, workers could apply latex caulking or weather stripping on the hallway side of the frame. The gap between the concrete lip and the frame might also be bridged with security sealant to prevent inmates from storing contraband in the seam.

When asked if this fix was feasible, Spancrete noted that introducing a 51 mm (2”) lip is relatively simple and it would not add much cost to the precast concrete walls. Fabricating such a lip requires adding a block to the wooden forms, increasing the amount of concrete and meshing used, and shifting a piece of reinforcing bar to strengthen the lip. Spancrete would also have to keep the lip from being damaged during transport and installation. In addition, Boldt should confirm if Venture and the owner are willing to let the frames remain hollow in this situation.

**Heavy Gauge Steel Door Frame Fix:** Another method to eliminate the need for grouting is to replace the 14- and 16-gauge hollow metal door frames with heavier 10- or 12-gauge frames. Using a heavier gauge steel might make the frame too heavy for an inmate to deform or push out. However, this fix requires that security sealant is strong enough to prevent inmates from tampering with anchor bolts, hiding objects in frames, disabling electrical locks, etc.

**WHY #4: Why were there cracks between the door frames and precast panels?** First, door frame installers need to have a 3 mm (1/8”) or so opening between the frame and the wall to slide the frame into the panel opening and plumb it. Second, this opening will vary in size along the frame as a result of dimensional tolerances (stochastic variation relative to the design dimensions of a product) during fabrication and placement of the concrete walls and metal frames. Cracks are to be expected when surfaces touch each other in any assembly of parts because it may be difficult to manufacture each part with a smooth surface. Smoothness is a relative concept and achieving it comes at a cost. In addition, materials change in dimensions over time (e.g., shrinkage cracks, deflection and settlement cracks, and cracks resulting from wear). They may also expand or shrink with tempera-
ture changes throughout the day. The construction industry has developed many kinds of materials and techniques to fill cracks, to cover them up, to make them water- or air-tight, to provide structural integrity to the assembly, or to meet other functional requirements.

Tolerance Fix: Tolerances are specified by contract. They represent acceptable variation. Nevertheless, if not specified and managed properly, they may compound problems as design and construction progress. Variation not only in production rates (Tommelein et al. 1999), but also in geometry (Milberg and Tommelein 2003) has detrimental impact on those downstream in the supply chain.

On this project, Venture developed design drawings that showed rough openings in the walls. Using those rough openings, Spancrete developed precast wall shop drawings. The recommended tolerance for openings in precast walls is 6 mm (1/4") (Freedman 1996 p. 162) (Note that product tolerances mentioned are assumed to refer to one standard deviation removed from the mean, specified dimensions. Also note that all unit conversions in the figure and text are approximate.). As Spancrete builds walls within a tolerance of 3mm (1/8") and due to field requirements of providing a 3mm (1/8") gap for installers, Spancrete’s rule of thumb is to increase the dimensions given by the architect by 6 mm (1/4") on each side of the door opening. Spancrete thus plans for openings that are 6 mm (1/4") taller and 12 mm (1/2") wider than Venture’s specified design. Spancrete’s shop drawings reflect these modifications.

A few months after Spancrete’s shop drawings had been approved by Boldt and Venture, and fabrication of precast walls had started, Venture developed a bid package that specified the frames within a door schedule. LaForce submitted a bid to supply the frames using the door bid package and the door openings shown in Venture’s

FIG. 4. Tolerances on Hollow Metal Door Frame and Precast Concrete Wall Panel
Midwest Wholesale Hardware is the premier wholesale distributor of Adams Rite products. We have recently added many new items to inventory including: MS1950, 4591, 4593, 4900, MS1500, 71R1, 71R2, 8600EL, 8800EL, and 4611. Go to midwestwholesale.com for detailed cut sheets.
Why not cast the frame in the opening between the wall and window frames cast-in-place as well as utilities and furniture already installed. The Module Fix radically changes the existing process of building prisons as the contractor would simply purchase the completed prison cells and then lift them into place. This results in higher materials procurement costs and different on-site skill and equipment needs, but it reduces labor risks and associated costs, and it also results in greater quality consistency.

Consideration of Fixes

Table 1 lists the project participants involved in the various fixes that were discussed in this paper and additional ones described by Tsao et al. (2000b). As shown, all project participants are involved in at least one fix. Local fixes are controlled by a single project participant and are feasible within the existing contractual arrangements whereas global fixes are not. Many local fixes fall under the category of “productivity improvement” (e.g., Oglesby et al. 1989) but few fixes are, in fact, local.

A company’s ability to recognize and implement a fix is dependent on contractual agreements. For instance, had Spancrete also been responsible for installing the frames, they would have had an incentive to develop a more global fix. The issue thus is: Who owns/controls the supply chain? In this situation, partly because Boldt holds a design-build contract, and partly because Boldt is the construction manager who self-performs a considerable portion of the work, Boldt owns/controls a significant part of the supply chain.

As mentioned, we worked with Spancrete to evaluate the feasibility of the Concrete Lip Fix and the Precast Fix. We also heard later that Redgran-

| WHY #5: Why are door frames and panels fabricated separately? These two parts are fabricated separately because they require different materials, knowledge, skills, and fabrication tools. Company specialization has further led to this division of labor. Through such fragmentation, the A/E/C industry loses valuable opportunities for integration. |

Precast Fix: Why not cast the frame directly into the walls (i.e., use the frame as part of the formwork)? When Boldt asked Spancrete if they could implement this fix, Spancrete was confident that they could. In fact, Spancrete mentioned that the cost to implement this fix is negligible because the time they normally spent blocking out the door openings would be spent instead on positioning the door frames into their wall forms. The feasibility of this fix depends on field quality issues since a primary concern is making sure walls and therefore doors are plumb so that they open properly. In addition, Spancrete needs to work out how to make this fix work on levels with precast, prestressed hollow core floor slabs that are thin and would not allow the same wall installation flexibility as levels with a slab on grade. Spancrete is also concerned about receiving, handling, and shipping liabilities: without additional compensation, they do not want to be held responsible for door frames damaged by other parties.

Module Fix: The Module Fix moves construction off-site. Companies such as Oldcastle Rotondo of Rehoboth, MA, Tindall Corporation of Petersburg, VA, and Rotondo Weirich of Lederach, PA, fabricate single-cell and 2-cell prison modules. These modules consist of 5 or 6 sides and come with door and window frames cast-in-place as well as utilities and furniture already installed. The Module Fix radically changes the existing process of building prisons as the contractor would simply purchase the completed prison cells and then lift them into place. This results in higher materials procurement costs and different on-site skill and equipment needs, but it reduces labor risks and associated costs, and it also results in greater quality consistency.

Consideration of Fixes

Table 1 lists the project participants involved in the various fixes that were discussed in this paper and additional ones described by Tsao et al. (2000b). As shown, all project participants are involved in at least one fix. Local fixes are controlled by a single project participant and are feasible within the existing contractual arrangements whereas global fixes are not. Many local fixes fall under the category of “productivity improvement” (e.g., Oglesby et al. 1989) but few fixes are, in fact, local.

A company’s ability to recognize and implement a fix is dependent on contractual agreements. For instance, had Spancrete also been responsible for installing the frames, they would have had an incentive to develop a more global fix. The issue thus is: Who owns/controls the supply chain? In this situation, partly because Boldt holds a design-build contract, and partly because Boldt is the construction manager who self-performs a considerable portion of the work, Boldt owns/controls a significant part of the supply chain.

As mentioned, we worked with Spancrete to evaluate the feasibility of the Concrete Lip Fix and the Precast Fix. We also heard later that Redgran-

| WHY #5: Why are door frames and panels fabricated separately? These two parts are fabricated separately because they require different materials, knowledge, skills, and fabrication tools. Company specialization has further led to this division of labor. Through such fragmentation, the A/E/C industry loses valuable opportunities for integration. |

Precast Fix: Why not cast the frame directly into the walls (i.e., use the frame as part of the formwork)? When Boldt asked Spancrete if they could implement this fix, Spancrete was confident that they could. In fact, Spancrete mentioned that the cost to implement this fix is negligible because the time they normally spent blocking out the door openings would be spent instead on positioning the door frames into their wall forms. The feasibility of this fix depends on field quality issues since a primary concern is making sure walls and therefore doors are plumb so that they open properly. In addition, Spancrete needs to work out how to make this fix work on levels with precast, prestressed hollow core floor slabs that are thin and would not allow the same wall installation flexibility as levels with a slab on grade. Spancrete is also concerned about receiving, handling, and shipping liabilities: without additional compensation, they do not want to be held responsible for door frames damaged by other parties.

Module Fix: The Module Fix moves construction off-site. Companies such as Oldcastle Rotondo of Rehoboth, MA, Tindall Corporation of Petersburg, VA, and Rotondo Weirich of Lederach, PA, fabricate single-cell and 2-cell prison modules. These modules consist of 5 or 6 sides and come with door and window frames cast-in-place as well as utilities and furniture already installed. The Module Fix radically changes the existing process of building prisons as the contractor would simply purchase the completed prison cells and then lift them into place. This results in higher materials procurement costs and different on-site skill and equipment needs, but it reduces labor risks and associated costs, and it also results in greater quality consistency.

Consideration of Fixes

Table 1 lists the project participants involved in the various fixes that were discussed in this paper and additional ones described by Tsao et al. (2000b). As shown, all project participants are involved in at least one fix. Local fixes are controlled by a single project participant and are feasible within the existing contractual arrangements whereas global fixes are not. Many local fixes fall under the category of “productivity improvement” (e.g., Oglesby et al. 1989) but few fixes are, in fact, local.

A company’s ability to recognize and implement a fix is dependent on contractual agreements. For instance, had Spancrete also been responsible for installing the frames, they would have had an incentive to develop a more global fix. The issue thus is: Who owns/controls the supply chain? In this situation, partly because Boldt holds a design-build contract, and partly because Boldt is the construction manager who self-performs a considerable portion of the work, Boldt owns/controls a significant part of the supply chain.

As mentioned, we worked with Spancrete to evaluate the feasibility of the Concrete Lip Fix and the Precast Fix. We also heard later that Redgran-
<table>
<thead>
<tr>
<th>FIXES</th>
<th>Venter Architects</th>
<th>Boldt Construction</th>
<th>Spancrete</th>
<th>LaForce</th>
<th>Central City</th>
<th>Jaques Caulki</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prevent Caulking Blowout</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grout Pump Fix *</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Security Sealant Fix</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grout Fix *</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foam fix*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrostatic Pressure Fix *</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prevent Grout Leakage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plywood Fix (Actual Fix)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bungee Cord Fix *</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On-site Weather Stripping Fix</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Off-site Weather Stripping Fix</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uneven Leg Channel Fix*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eliminate Grouting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-Grouted Frame Fix *</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stacked Pre-Grouted Frame Fix *</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concrete Lip Fix</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy Gauge Steel Frame Fix</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weld Plate Fix *</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manage Cracks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field Sequencing Fix *</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tolerance Fix</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combine Components</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precast Fix</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Module Fix</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perform Fix</td>
<td>☐</td>
<td></td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Work Affected by Fix</td>
<td>☐</td>
<td></td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Approve Fix</td>
<td>☐</td>
<td></td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

Table 1. Fix-Responsibility Matrix (* indicates Fixes discussed in Tsao et al. 2000b)
ite workers eventually determined how to install security sealant on both sides of the frames to eliminate the need for the Plywood Fix. As a result, after using the Plywood Fix primarily in Housing Buildings E and F, workers used the Security Sealant Fix instead in Housing Buildings G and H.

From Fixes to Work Structures

When confronted with problems of an existing system, it is natural to try and develop “fixes” to solve the problems. Consequently, a good way to address problems within a project that has an established product design is to consider fixes to the production system. Then, project participants should consider the feasibility of the fixes to highlight those that have the best potential for successful implementation. With the best fixes in hand, project participants should find good combinations of fixes to form alternative Work Structures. In general, local fixes are easier to combine to form alternative Work Structures, while global fixes may be so complex that they can form an alternative Work Structure in and of their own.

In this case, workers eventually succeeded with the Security Sealant Fix and thereby eliminated many fixes from further consideration. With Boldt’s input, we selected a handful of the most promising fixes to be combined into two alternative Work Structures. The first alternative combines the Security Sealant Fix with the Grout Pump Fix. The Grout Pump Fix replaces a company-owned air-pressure powered grout pump operating at 30 MPa (4,350 psi) that costs $1,200 per month in rent to the project with a hand-operated grout pump operating at 5 MPa (725 psi) that costs $500 to purchase and can last several years depending on use (e.g., Kenrich 2002). Boldt tried this low-risk alternative on its next project: it was simple to test and could not significantly impact the project if it failed. After learning to use the hand-operated grout pump, Boldt successfully adopted this alternative Work Structure.

The second alternative is the Precast Fix. Recognizing its potential but due to issues brought up earlier, Boldt is continuing to assess its technical feasibility. In addition, Boldt might need to test the soundness of this Work Structure in order to convince Venture that it is a sufficient if not a superior alternative.

Work Structuring should be first addressed early in the AEC project development process before any major decisions in product and process designs have been made.

Integrated Product-Process Design and Design-Build

Work structuring could naturally drive a design-build project, but this is not the way today’s design-build projects are conceived. A State project manager noted that Wisconsin’s decision to use design-build at Redgranite was driven by the demand for project delivery speed—there has been “overcrowding in the correctional system for a number of years”—however design-build is “not a typical way of doing business with [the State]” (Ryan 2000). The State’s chief architect further noted that “the state’s primary use for design/build is to quicken a project’s timetable in order to squeeze it into the upcoming state budget” and that “the state would be more willing to use design/build on simple projects like... correctional facilities [because] you can describe what you want with a simple building much more easily than you can with a complex building.”

The Daily Reporter, a newspaper that covers Wisconsin construction, rewarded the State’s experiment in design-build by naming Redgranite as the “Top Design/Build Project of 2000” (Thompson 2000). It selected Redgranite as an exemplary project because Boldt “finished [the project] on time and within budget” while hiring many local workers in the process.

Based upon a statistical analysis of 351 U.S. general building projects, researchers found that design-build offers more speed and certainty in cost and schedule performance in comparison to design-bid-build (Champagne 1997, Konchar and Sanvido 1998, and Sanvido and Konchar 1998). Reinforcing this finding, Boldt noted that the use of design-build shaved 6 to 9 months off Redgranite’s schedule (Thompson 2000). However, this presented case study revealed that despite the existence of a design-build contract, Boldt and Venture broke up the system of walls and door frames in the same way they would had Boldt held
THE COMPLETE IVES PRODUCT LINE
IN STOCK AT BOYLE & CHASE

FREE ADVERTISER INFORMATION AT: www.thru.to/dhi
DOORS AND HARDWARE • JULY 2006

A company’s ability to recognize and implement a fix is dependent on contractual agreements.

A design-bid-build contract—Venture designed the components and Boldt installed them.

The need for the Plywood Fix indicates a lack of product-process design integration. However, installers do not necessarily complain about (deficient) product design because (1) contractually speaking, the original design is given to them and must be executed as contractually agreed upon, (2) at the time of installation they feel it is too late to get changes made, (3) they worry that by providing a design alternative, they will be considered non-responsive to the bid request, (4) they do not want to be liable if their suggested design fails, (5) they will lose an opportunity for potentially lucrative changes later, (6) they may have more important problems to address such as developing bargaining tactics and determining which battles to fight, or (7) site problems may be considered theirs to resolve and complaining might reflect poorly on their skill and pride (“tricks of the trade”) so they believe workarounds are what they are supposed to do. Workarounds are of course costly and time consuming, yet they are an accepted way to perform work. Thus, although design-build “offers the owner a single point of responsibility for design and construction services” (Sanvido and Konchar 1998 p. 18), it only provides an opportunity for collaboration. In contrast, Work Structuring efforts develop a methodology for collaboration by aligning project participants and shaping the work flow in order to improve overall performance in the delivery system of a capital project.

Wisconsin practitioners have been questioning what it means to use design-build. Snow (2000) suggested that design-build might be “anything the owner thinks it is” while Schultz (2000b) found all contractors that he interviewed had different interpretations of design-build. Doyle (2000a and 2000b) noted that since practitioners have different definitions for design-build, design-build as a concept is hard to define and thus difficult to quantify and measure. Furthermore, design-build takes on many variations (e.g., projects led by contractors, design-build teams, designers, developers, or joint ventures), so there is no such thing as a standard methodology to implement it (Doyle 2000a and Schultz 2000a). These factors are not endemic to Wisconsin—they are found in numerous other regions that employ design-build. Thus, although design-build serves as a contracting approach and has convinced states to move away from design-bid-build selection of project participants, it provides only an opportunity for collaboration and, as Paulson (1976) pointed out, “[its] name alone, however, does not guarantee results.” Instead, work structuring should be developed to provide a framework for collaboration.

Work Structuring Revisited

We advocate the use of an explicit Work Structuring approach to provide a structured methodology that guides project participants towards achieving integrated product-process design. Molenaar and Songer (1998) found that “the percent of design completion at the request for proposal (RFP) phase has no statistically significant effect on project success... Too much design can be constraining and limit the advantage of creativity and constructability in design-build.” They further noted that “an RFP that clearly defines the project scope but leaves room for contractor input will be most successful.” Along the same lines, Work Structuring should be first addressed early in the AEC project development process before any major decisions in product and process designs have been made. For example, project participants may meet at the project onset to develop a “Schematic Design in a Day” to investigate a range of alternative Work Structures (Miles 1998). In addition, if project participants had access to information about the Work Structures used on similar past projects, then the “Five WHYs” could be employed to identify ways to improve upon their performance.

Some may argue that the cost of the system of walls and doors is small in relation to the overall project, so it is wasteful to investigate improvements to its delivery. However, as mentioned, the system of walls and doors is critical in prison construction because it generates value for the owner. Moreover, in addition to the benefit of reducing the project’s dura-
SABL™
STAND ALONE BATTERY LOCK

HIGH TRAFFIC ACCESS CONTROL FOR
HOSPITALS & EDUCATIONAL FACILITIES

Based on award winning & popular
DK-26 keypad programming
Fits into standard ANSI 2-3/4” backset
Fully weatherproof keypad with true
10 digit operation
55 user codes + 2 passage & 2 lockout
REX input and remote release relay
Four attractive architectural finishes
Available in a variety of keyways
Optional privacy function

1-800-MAGLOCK
www.securitron.com

SECURITRON®
World Leader in Electric Locking Solutions

MagnaCare
LIFETIME REPLACEMENT WARRANTY
We believe making work structuring explicit can help practitioners overcome these constraints and adopt better ways of designing and building projects.

project participants systematically address Work Structuring issues at varying levels of detail during coordination meetings so that several systems solutions will be developed and considered. During these meetings, a different person could be appointed each time to make Work Structuring issues transparent for the group. This Work Structuring facilitator would be responsible for identifying and documenting any trade-offs that emerged between the project’s supply chain-, product-, process-, and operations designs. This transparency could help the group better understand the implications of their design decisions. In addition, having different facilitators engages more project participants in the Work Structuring effort and is likely to foster a more collaborative environment in the project development process. Alternatively, the owner could ask one of its representatives to be the facilitator.

Is the Plywood Fix representative of today’s construction practices? We believe it does reflect today’s reliance on on-site craft skills to mitigate problems that should not have been created in the first place. The companies involved in this case study are well regarded in their fields, so their practices are ‘typical’ if not better than the industry average. Engineering News Record (ENR) lists Boldt as #109 of the 2001 Top 400 Contractors (ENR 2002) and Venture as #97 of the Top Midwest Design Firms (Midwest 2002). Boldt’s and Venture’s combined experience in prison construction was used when they designed and built Redgranite in a fashion similar to before. The owner, designers, and wall fabricator balanced their needs and resources to develop the product design. The panel erectors, door frame installers, grouters, and caulkers negotiated their traditional work procedures to develop the operations design. However, since all project participants rarely have the opportunity to consider the structure of work together and early enough to decide what would work best for the system, the product design was developed with little consideration for the process design. As a result, project participants were more product-oriented than system-oriented, so the system of walls and door frames at Redgranite was far from optimal.

Work structuring includes elements from various practices in the AEC industry, such as constructability analysis, value engineering, and productivity improvement studies. However, despite the extensive literature on these subjects, we are unaware of any documents that present these practices formally to achieve systematic implementation. Like design-build, they have difficulty developing solutions beyond contractual agreements, work traditions, and trade boundaries because they try to preserve standard work breakdowns and traditional roles of supply chain participants. As a result, these practices fail to recognize opportunities for systematic improvements that arise from the definition of Work Structuring proposed in this paper.

Work Structuring aimed at project-level performance may have been employed by others on previous projects, possibly by Engineer-Procure-Construct companies. However, even then it is likely those projects structured work in an ad hoc fashion because we have yet to see the theoretical concepts of Work Structuring formulated for application in the AEC industry and discussed in technical journals. Should Work Structuring be well-established in practice, then our role as researchers is to document the instances of practice to support and validate its emerging theoretical principles (Laufer 1997). After describing and validating Work Structuring theory, we should articulate techniques for effective Work Structuring. However, we suspect that most projects do not systematically structure work, so we hope that our research effort in documenting the presented case study will convince AEC practitioners to consider Work Structuring on their projects, and educators to introduce it in their teaching.

Conclusions

The hollow metal door frame case study illustrated a typical problem encountered in AEC practice today, where a contracting mentality hampers thinking about system-wide pro-
duction-based solutions. We revealed how poorly-made decisions resulted in lost opportunities for achieving systematic improvements. On this project, the architect decided on the Work Structure by designing the system of walls and doors. The wall fabricator and door frame manufacturer together might have developed a better system design, had they not been restrained contractually by each getting a piece of the work from the construction manager and provided they could resolve design liability issues.

This case study leads to the following conclusions about Work Structuring and integrated product-process design practice: (1) The use of design-build project delivery does not ensure integrated product-process design. Although Redgranite was praised as an outstanding design-build project, we identified lost opportunities to improve the design and construction of one of its significant components. (2) Traditional WBS practice prevents project participants from seeing opportunities for systemic change. The architect is accustomed to designing walls and door frames separately. The construction manager is accustomed to procuring walls and door frames separately. The company that makes walls is different from the company that makes doors. As a result, project participants failed to see the walls and door frames as a single enclosure system that generates significant value for the owner. (3) Local optimization can be detrimental to global optimization. As latex caulking is cheaper than security sealant, the construction manager first asked to change the caulking requirements to reduce materials costs. The construction manager thereby unintentionally contributed to grout blowout problems. (4) Project participants fail
to learn across projects; they rely on ‘received traditions’ (Schmenner 1993 p. 399). Installers may not see that process design problems can be linked to inadequacies in product design. Thus, they do not provide feedback to designers to encourage modifications of the product design to better support process design.

To summarize, this case study has described problems the construction crews faced, examined solutions they came up with, and explored system design decisions that shaped operations design. We illustrated the kind of reasoning that is needed to engage in Work Structuring, applied the “Five WHYS” to get to root causes of problems within existing Work Structures, and demonstrated how project participants can develop alternative Work Structures. We provided some theoretical underpinnings of Work Structuring and advocated the use of Work Structuring to serve as a methodology for achieving integrated product-process design. Over 30 years ago, a contractor noted “the need for removing the legal, social, and labor restraints presently burdening the construction industry” (Kellogg 1971). We believe making work structuring explicit can help practitioners overcome these constraints and adopt better ways of designing and building projects.

Acknowledgements:
This research was funded by grant SBR-9811052 from the National Science Foundation, whose support is gratefully acknowledged. Any opinions, findings, conclusions, or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the National Science Foundation. The authors would also like to thank Paul Reiser of Boldt Construction, the carpenters of Redgranite, Chad Mehlberg of LaForce Doors, Rick Rountree of Kenrich Products, Inc., and Joe White, John Schnell, and Doug Oswald of Spancrete Industries, Inc. for their help with this case study.

References:


Work Structuring... from page 44


