For Pickett Regional Training Institute Phase II
Blackstone, VA

SENIOR THESIS FINAL REPORT

Figure 1: Site Aerial - Courtesy of Barton Malow

Submitted 4/4/12
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Senior Thesis: AE 481/482

Fort Pickett Regional Training Institute Phase II

Blackstone, VA

Project Information

Function	Billeting Buildings
Project Cost	$28 Million
Total Stories	2
Size	116,400 SF
Construction Dates	10/25/10-12/31/11
Delivery Method	Design-Build

Project Team

Owner	Virginia Army National Guard
Project Administrator	Army Corps of Engineers
Design/Builder	Barton Malow Company
Structural	Desai/Nasar Consulting
Civil	Mindel, Scott, & Associates
Electrical	ETS Engineers
Mechanical/Plumbing	Sellinger Associates

Special Thanks To:

Designer & Builder

Owner

Owner's Representative

Architecture

- The three billeting buildings are placed around the perimeter of the ceremonial quadrangle drawing focus to the administration building.
- The billeting buildings utilize identical designs and material associated with modern-day office buildings.

Construction

- The three billeting buildings were constructed in a phased approach consisting of six area (3 buildings with 2 floors) where each area lagged the previous area by one week.
- This lag was believed to minimize the learning curve, increase efficiency, and maintain crew sizes.

Electrical

- Each building features an electrical room that houses an 800A switchboard at 277/480V/3PH/4W that services a 277/480 lighting panel and power distribution panels for mechanical loads .
- The electrical rooms have transformers serving 120/208V panelboards servicing receptacles, washers, dryers, 208V heat pumps , and all 120V mechanical equipment.

Mechanical

- Features a central closed water loop heat pump system.
- Heat pumps are located throughout the buildings and control 3-5 rooms per heat pump, which allows for a closer match between actual heating /cooling temperature and user desirability.

Structural

- Each building is supported by spread and continuous footings with a 4" slab on grade .
- The second floor is composed of hollow-core planks with a 2" concrete topping slab.
- The structure consists of cold formed metal stud bearing walls, roof trusses, and SIPs.

Executive Summary

The Senior Thesis Final Report serves to discuss the research and conclusions of four analyses conducted on Phase II of the Fort Pickett Regional Training Institute. The project entails the design and construction of three billeting buildings for the Virginia Army National Guard that total 116,400 SF. The four analyses aim to target problematic schedule concerns through the use of modularized construction, prefabrication techniques, scheduling practices, and innovative technology.

Analysis #1: Modularization of Bathroom Units

The first analysis looked to minimize the difference in time and work between the construction of the bathrooms and bedrooms in the field. In order to bridge this gap, the use of modularized bathroom units was investigated to shift the work from the field to a manufacturing facility. The analyses resulted in an eight week acceleration of the fit-out schedule and an estimated $213,903 in savings. Additionally, the pods were found to display superior quality in comparison to typical work performed in the field, an item that was of constant concern on the project.

Analysis #2: Implementation of Short Interval Production Schedules

The second analysis investigated the use of short interval production schedules (SIPS) on the project, in order to help mitigate the risk involved with erecting the precast hollow-core planks. The SIPS was believed to improve the productivity and flow of work from building to building. The analysis showed a shortening of the work sequence by 11 days and saved $117,524.

Analysis #3: Feasibility of Precast Exterior Façade Panels

The third analysis aimed to reduce the building enclosure schedule by replacing the field constructed CMU veneer with precast concrete panels that are constructed off-site. In order to alter the veneer, the design needed to be altered, which in reality would need to be considered by the impacted parties. Additionally, the panels were tested to investigate the structural and mechanical implications of the use of the precast panels. After conducting a thorough analysis, the panels were believed to be well in the best interest of the project team by reducing the enclosure schedule by 10 weeks and saving $1,094,129.

Analysis #4: Integration of Material Tracking Technologies

The fourth analysis aimed to enhance the coordination within the material management of the precast hollow-core planks. This activity acted as the most critical schedule item, making the planks a key area of focus. To combat the risk associated with the planks, material tracking technology was investigated for its potential benefit on the Fort Pickett project. After conducting a complete analysis, the material tracking system cost an estimated $9,300, an insignificant figure compared to the future costs associated with rectifying a potential delay in the schedule from mishandled or wrongly manufactured precast floor planks.

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Virginia Army National Guard

U.S. Army Corps of Engineers

PACE Industry Members

My Family and Friends

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Project Overview

Project Introduction

On February 27, 2010, the Virginia Army National Guard contracted Barton Malow to construct and design three barracks totaling 116,400 SF at the Fort Pickett Regional Training Institute in Blackstone, VA. The $28M contract was awarded as an option upon successful completion of Phase I of the Regional Training Institute. The three billeting buildings are being constructed in order to replace the dilapidated housing constructed during the World War II era. In order to facilitate operations, the Army Corps of Engineers served as the owner's representative, a role that is responsible for overseeing day to day operations of the project. The project was bid as a Design-Build delivery system, making integration between Barton Malow's design and construction teams critical for success.

Upon near completion of Phase I of the project, which included an auditorium, administration building, and offices, Barton Malow was provided notice to proceed with Phase II of the project. The phasing of the two phases created a complex construction approach, but also contributed to the current success of the project by allowing the team to accelerate the schedule. The three billeting buildings, as seen in Fig. 2 below, are composed of two floors that feature identical floor layouts. The barracks feature a simple floor plan, where a central corridor stretches the length of the buildings with rooms located along the two sides of the corridor. The project also features the incorporation of a few new, innovative construction techniques, such as a precast hollow-core plank floor system and a structurally insulated panel roofing system.

The project's repetitive construction nature, as well as its incorporation of prefabricated materials, created an innovative implementation strategy on the Regional Training Institute. Although most of the project team had little exposure to the practices attempted to be employed, the team excelled and successfully handed the building over prior to the January 13, 2012 turnover date.

Figure 2: RTI Campus - Courtesy of Barton Malow

Site Plan and Existing Conditions

Due to the campus's isolated location within the military base, as well as the magnitude of the site, space is not a constraining factor for construction, which can be seen in Fig. 3 below. The construction manager's and subcontractors' trailers were strategically placed north of the campus to allow easy access for visitors, as well as remain in close proximity to the military personnel occupying the Headquarters and Administration Building constructed in Phase I. In addition to the expansive area, streets completely surround the site and run in both directions making deliveries, parking, and site access incredibly easy in comparison to most construction environments. Although sidewalks extend from nearby parking lots, pedestrian traffic is very limited and not a primary safety concern for the project team.

Figure 3: Site Plan

The site is surrounded by a 6' chain linked fence and uses minimal security techniques, since the Military Base is protected by checkpoints and only allows authorized personnel on to the site. Throughout the course of the project, portable toilets were located at both the north and the south parts of the site. Temporary power was located near the south entrance of the site, where it tapped into an existing line running south of the site. Recycling and waste hoppers remained in consistent areas throughout the life of the project, near the south entrance and in the center of the campus.

The jobsite was planned to maximize the space, as well as take advantage of the two entrances, although the south entrance was the primary entrance used. Prior to entering the site, workers' parking was located adjacent to the entrance. This was beneficial to Barton Malow, in order to reduce inefficient traveling times for breaks and lunch. It also made it advantageous to the workers, because tools could be transported over a short distance, reducing the need for vehicles to enter the site to deliver equipment and tools. Across the street from the site in the north were the CM's and subcontractors' trailers. These were placed here to allow easy access from visitors, as well as to isolate themselves from the jobsite.

In order for Barton Malow to reach LEED goals, the handling of waste and recyclables was an item of key concern when constructing the billeting buildings. Within the general conditions, Barton Malow budgeted $40,000 to accommodate the disposal of waste and recyclables, but it was up to the project team to manage the proper disposal of materials. Within the LEED NC 2.2 checklist, Barton Malow strived to divert 75% of construction waste from disposal. This was critical, earning two points towards the projected LEED Silver rating.

To get a better understanding of the project's site, refer to the existing conditions site plan in Appendix A.

Local Conditions

Fort Pickett is located just outside of Blackstone, VA and around 60 miles southwest of Richmond, VA, which can be seen in Fig. 4. The military base is located on swampy land, which was previously deemed as unsuitable for construction, but viewed as ideal training grounds for the Virginia Army National Guard and other Federal agencies. The site of the project was once a forested area, but has now been cleared for construction.

Figure 4: Geographic Location - Courtesy of Google Maps

The RTI enacted construction methods typically used within the geographical region, as well as remained within common practices utilized by the Army Corps of Engineers. Although a steel structure was utilized on the billeting buildings, the system differed from traditional methods. As described in the systems summary section, the structural system mirrored residential construction by using cold formed steel studs as the primary structure of the building. This type of construction minimized specialized steel crews and focused more on framing crews for the construction of the buildings. In addition, the design was created to meet the simplistic, standardized approach of construction within the armed forces, which was reinforced by the buildings' façade. The façade featured split faced CMU placed by hand in horizontal bands displaying the colors of the Military. Although prefabricated CMU panels could have been a more efficient approach, the VAARNG chose to proceed with the traditional method of placing each block by hand for aesthetic purposes.

The site is located in the southeastern region of Virginia's Piedmont Physiographic Province, which is characterized by igneous and metamorphic rocks underlying irregular plains and hills. The soil in this region is typically a combination of organic matter and bedrock residuum. The United States Department of Agriculture Soil Conversation Service's survey of the site indicated that the soils are mostly composed of fine sandy loams with moderate infiltration rates. The soils are well drained and have intermediate water retention capacities. A separate survey was conducted on July 26, 2007 by MM&A personnel that consisted of two soil borings. The soils encountered during this investigation ranged from sands and sandy clays grading with depth into saprolitic clays and quartz gravels.

Regarding the site hydrogeology, groundwater in the region is principally recharged by infiltration of precipitation into unconfined water table aquifers. Most of the unconfined groundwater flows relatively short distances and discharges into nearby streams, while some groundwater continues to flow downward to recharge deeper aquifers. During a July 26, 2007 limited subsurface investigation, depths to groundwater were estimated to be between 12 and 16 feet.

Client Information

The Virginia Army National Guard (VAARNG) serves as the acting Owner of the Regional Training Institute at Fort Pickett Military Base. The Army National Guard is composed of acting forces from states, territories, and the District of Columbia across the country and is a fixture of the Army, along with the Active Army and the Army Reserve. The Army National Guard acts as a protector to both the State and Federal governments and primarily acts in times of emergencies, such as storms, natural disasters, and civil disturbances. The Army National Guard is composed of civilians who serve on a part time-basis.

Figure 5: Logo - Courtesy of VAARNG

The billeting buildings have been in discussion for a number of years, but recently were approved for funding. The three billeting buildings are being constructed to replace the currently dilapidated barracks that were constructed during World War II. Many of the current billeting building at Fort Pickett are no longer suitable for living and are filled with dangerous materials, such as lead paint and asbestos.

In order to receive funding to construct the billeting buildings, legislation was passed within Congress, which made the total requested funds to be set in stone. For this reason, the budget was set in stone and cannot afford to overspend on the project. To help ensure that the financial aspects, as well as the quality, schedule, and safety issues were managed appropriately, the Army Corps of Engineers (COE) was hired to serve as the owner's representative. In addition to serving as the Owner's Representative, the COE also served as the inspectors for all components of the building. By participating in the construction operation on a daily basis, it was beneficial to receive early input from a quality control and inspection aspect of the work; this eliminated future problems, since appropriate standards of work were established from the start of an activity. To further control the budget, the COE utilized a cost loaded schedule to ensure that activities were fully acceptable by quantity, as well as quality standards before sending payment to Barton Malow for their work.

The billeting buildings required no special sequencing or phasing, but for the purpose of construction, Barton Malow proceeded with a phased approach. This was believed to be in the best interest to Barton Malow, since it minimized the learning curve, maintained balanced crews, and allowed the punch list process to be staggered, an item of great benefit to the Quality Control Manager and Project Engineer on site. The plan proposed was to hand-over a building at a time, so that the VAARNG has the opportunity to spread its resources over a greater amount of time. In addition to providing a phased turn-over, Barton Malow was working with the VAARNG and COE on a daily basis to ensure that the building meets and exceeds the standards proposed in the RFP.

Project Delivery System

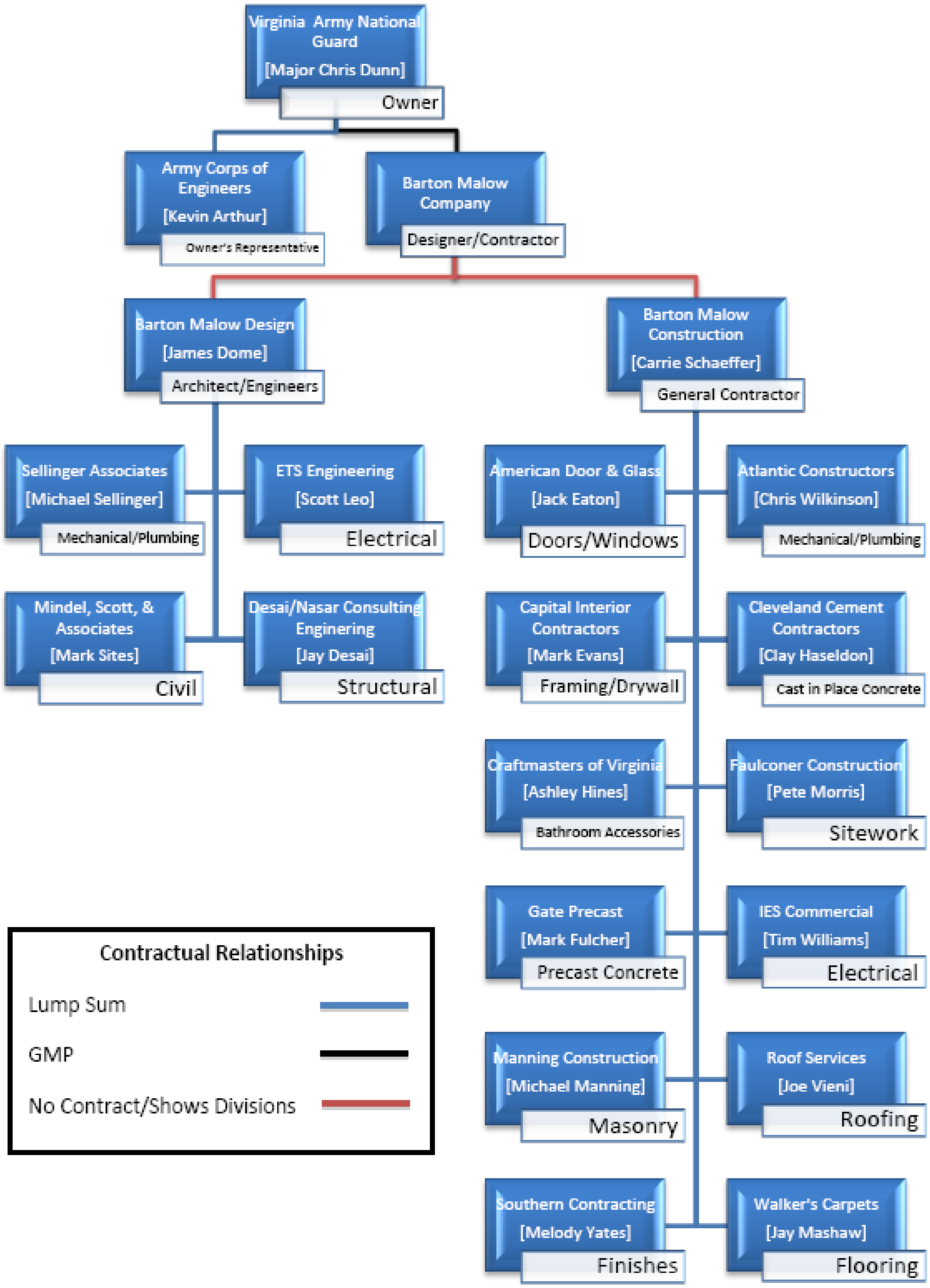


Figure 6: Project Delivery System

Phase II of the Fort Pickett Regional Training Institute Project utilized a Design-Build delivery system with Barton Malow serving as the Designer/Builder. In addition, since it is a Department of Defense project, the Army Corps of Engineers served as the Owner's Representative to facilitate construction processes.

Since the project is a Department of Defense project, the delivery system was very unique to the typical private project. To begin the process, the Virginia Army National Guard filled out a Needs Assessment to the Military Contractor's Office to obtain support for funding. From there, the Military Contractor's Office reviewed the information and made a decision to proceed forward and request funds from Congress. Upon approval, a Construction Cost Limitation (CCL) was established by Congress, where the CCL contained the funds for representation, design, and construction services. From there, the Virginia Army National Guard brought aboard the Army Corps of Engineers (COE) to act as an Owner's Representative under a lump sum fee. The COE then began to perform research and conduct meetings with the Owner to get a better understanding of the needs of the Client. Once the needs of the Owner were clearly represented in the form of an RFP, the RFP was solicited on a website for companies to bid. The project was procured as a hard bid in the form of a Design-Build delivery system for two phases, but with the second phase being an option. At the end of the bidding process, in September of 2008, the lowest bidder, Barton Malow, was identified and awarded the project barring any complications, such as bonding. Upon successful completion of Phase I, Barton Malow was awarded Phase II for the amount of $28,177,099 in the form of a GMP. Within the GMP, Barton Malow built in a 3% fee at $850,000 with no shared savings clauses built in.

Barton Malow consists of a design and construction division, making the Design-Build approach an ideal opportunity for the company to succeed. Barton Malow had the advantage of acting as one entity, where other contractors were forced to collaborate and negotiate fees, budgets, and responsibilities with outside designers. Within Barton Malow Design, James Dome served as the lead individual and the Architect of Record. Although Barton Malow Design has some Engineers on staff, they received consultation from a number of Engineers, which can be seen in Figure 6 on the previous page.

Barton Malow Construction was responsible for the management and construction of the building process using a number of different Subcontractors. As seen in Fig. 6 on the previous page, twelve primary Subcontractors were responsible for the work, with each Subcontractor procured under a hard bid approach. Once the lowest bidder was identified, the contracts were then awarded using lump sum contracts. Due to the poor state of the economy, the work was awarded with negligible fees, although the GMP allowed for higher numbers, since the Subcontractors' work was awarded much later than the initial contract was awarded for from the Virginia Army National Guard. As a result, Barton Malow was able to capitalize on the opportunity and collect a greater fee than initially anticipated.

Regarding insurance, Barton Malow bonded the project for the full contract value. Barton Malow also maintained General Liability and Builder's Risk Insurance, where Barton Malow budgeted for $181,419 and $41,000 respectively to insure the required amounts specified in the RFP by the Virginia Army National Guard. In addition, Barton Malow's CCIP Program required that all subcontractors hold Worker's Compensation and Employer's Liability Insurance. Upon failure of the Subcontractor to acquire the specified insurance, Barton Malow held the right to provide the necessary insurance for them at the Subcontractors' expense. To further insure themself, Barton Malow also required all Subcontractors to submit a performance and payment bond, in the event of failure to meet obligations set forth in the contract. This ensured that Barton Malow was alleviated from any liability from problems associated with the work of the responsible Subcontractor.

As mentioned earlier, the Design-Build delivery method was the ideal delivery system for the project at hand. Using a Design-Build approach, the Owner was able to minimize responsible parties involved and use only one contract. Not only did this system benefit the Owner, but it was incredibly advantageous to Barton Malow, since it had the resources to conduct the design and construction services in-house. Although this was only Barton Malow's second project in the Federal field, their outstanding record from Phase I made them clear favorites to be awarded Phase II as well. Regarding the contract, the GMP was the most logical contract type, in order to ensure that there were minimal cost overruns, since the CCL was set in stone by Congress. Although, the Virginia Army National Guard had awarded the project under the CCL to allow for minimal cost overruns and potential change orders, there was very limited room for error, which made the use of a GMP the most appropriate contract choice.

Project Team Staffing Plan

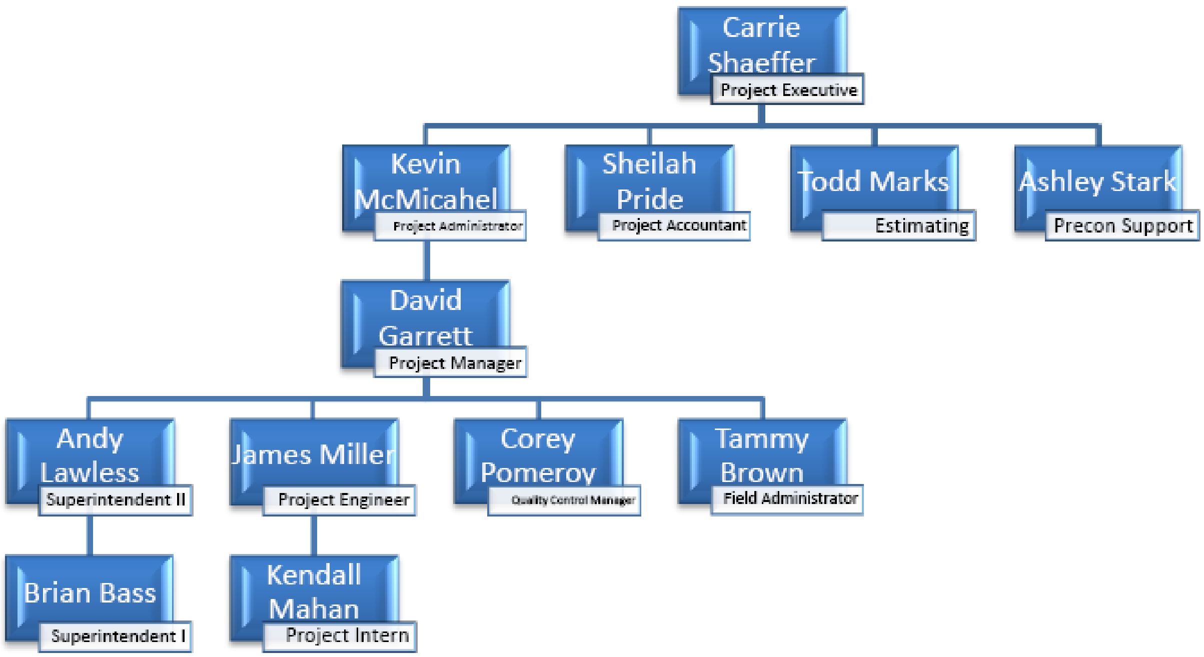


Figure 7: Staffing Plan

Due to the successful turnover of Phase I, Barton Malow decided to employ a nearly identical staffing structure to that of Phase I with the addition of another Superintendent and Project Intern. For Phase II, Andy Lawless, Superintendent II, was brought onto site to add valuable experience to the project team, as well as provide opportunities to other members of the team to explore new roles. For the size of the project, the team was slightly overstaffed, but this allowed others to gain experience in new positions by creating a mentoring atmosphere.

Following the trend of a typical Barton Malow project team, the staff was led by Carrie Shaeffer, the Project Executive. She primarily worked out of the office, but was in charge of overseeing the project from the instance the RFP is posted to the day the project is turned over to the Owner. Kevin McMichael served as the Project Administrator, a similar role to the Project Executive, but was more focused on a smaller group of projects, typically 3-5. His role was primarily based out of the office, but made frequent trips to ensure that operations were running properly. In addition to these players on the project team based out of the office, the team also consisted of a Preconstruction Support, Estimator, and Accountant.

The leader on site was David Garrett, the Project Manager. He was ultimately responsible for the success of the project and handled the day-to-day operations of the site. In addition to the Project Manager, the project staffs two Superintendents, Project Engineer, Quality Control Manager, Field Administrator, and Project Intern. The members of this team were responsible for their own individual tasks, but all share a focus and responsibility to deliver the project on time and ahead of schedule. Each member brought their own level of experience, but because of their collaborative work environment, every member continued to develop and became a greater asset to the company.

One position that was unique to this project was the Quality Control Manager. Following the guidelines of the RFP and any federal project, a Quality Control Manager was required to be on site to facilitate quality control between the CM team and the Army Corps of Engineers. This unique position consisted of recording daily reports, toolbox talks, inspections, and punch list items.

Project Schedule Summary

Upon successful completion of Phase I, the Virginia Army National Guard (VAARNG) decided to award Barton Malow Phase II of the project, giving them notice to proceed on February 27, 2010. Due to the unique situation with a phased Design-Build delivery system with an option for the second phase, the project schedule is very different than a traditional schedule. A detailed project schedule can be seen in Appendix B, which includes Phase I and Phase II.

Since the project was hard bid to include both phases with an option to proceed with Phase II, an initial design needed to be created to appropriately bid the project. The project was bid using 30% design documents, which means that at the notice to proceed with Phase II, the design needed to be finalized to reach 100% design documents. It can also be noted that most of the site MEP work was performed in Phase I, which allowed Barton Malow to expedite the site work. Within the Design Phase, Barton Malow obtained payment and performance insurance, conducted geotechnical reports, calculated building estimates, and created/issued design drawings for the VAARNG to approve for construction. The Procurement Phase consisted of establishing a schedule with the Army Corps of Engineers (COE), as well as the handling of contracts and submittals with Subcontractors. The duration of this phase stretched into the later portion of the project, since the procurement steps extend as far as the fabrication and delivery of the materials to the site.

The Construction Phase involved a phased construction sequence between the three billeting buildings, Buildings 500, 600, and 700. Due to the unique layout of the campus, the three billeting buildings were constructed in a phased approach consisting of six areas. The lead floor was the ground floor of Building 700, followed by the ground floor of Building 500, and so on, until it reached the second floor of Building 600. The lag maintained an approximate one week separation on the schedule, in order to fluidly move workers from one building to the next. This was believed to be an ideal strategy to eliminate any potential hindrance from an often-detrimental learning curve. Contrary to an obvious strategy of moving from building to building based on the next building in line, the first two buildings to begin work were the identical buildings across the campus from one another, so that the learning curve could be further minimized.

Project Cost Summary

In order to get a better understanding of the costs associated with the buildings, it was critical to conduct a number of cost analyses, including a cost overview and building systems overview. The project cost overview can be seen below in Fig. 8, which includes a number of different figures. Since Phase II consists of both the construction of the billeting buildings and demolition, there are two different line items with general conditions included and not included for both. These construction costs also include the 3% contractor's fee, but do not take into account contingency, insurance, etc. The last line item shows the total project cost or the GMP cost. Each line item also includes a cost per square foot cost value.

Project Cost Overview (116,400 SF)		
	Actual Cost	**Cost/SF**
Construction Cost (Billeting Buildings)		
Actual (Without General Conditions)	$22,031,725	$189
Actual (With General Conditions)	$23,750,812	$204
Construction Cost (Billeting Buildings & Demolition)		
Actual (Without General Conditions)	$22,789,225	$196
Actual (With General Conditions)	$24,724,716	$212
Total Project Cost		
Actual GMP Cost	$28,177,099	$242

Figure 8: Project Cost Overview

The next cost analysis conducted was the building systems overview, which can be observed in Fig. 9 on the following page. The table breaks down the actual cost, cost per square foot, and percentage of building cost associated with all of the major building systems. Due to the high energy efficiency associated with the mechanical system, the initial cost was elevated, but it is believed to be in the best interest of the Owner in regards to the life cycle cost of the building. The mechanical/plumbing systems comprised nearly 20% of the total building cost. Another staggering figure was the drywall/metal framing line item, which made-up over 11% of the building cost. Although this is a significant percentage of the building cost, the metal studs served as load bearing walls, so the elevated percentage was expected.

Building Systems Overview			
	Actual Cost	Cost/SF	% of Building Cost
Acoustical Ceiling	$381,202	$3.27	16.1
Concrete Cast-in-Place	$1,243,212	$10.68	5.2
Demolition	$757,500	$6.51	3.2
Drywall/Metal Framing	$2,634,376	$22.63	11.1
Electrical	$2,808,994	$24.13	11.8
Fire Protection	$359,055	$3.08	1.5
Masonry	$2,490,660	$21.40	10.0
Mechanical/Plumbing	$4,689,430	$40.29	19.7
Painting	$264,155	$2.27	1.1
Precast Concrete	$657,224	$5.65	2.8
Resilient Flooring	$613,504	$5.27	2.6
Roof Deck/SIPS Panels	$762,424	$6.55	3.2
Roofing	$1,705,486	$14.65	7.2
Sitework	$1,522,575	$9.15	6.4
Structural Steel Framing	$944,350	$8.11	4.0

Figure 9: Building Systems Overview

General Conditions Estimate

In order to gain a further understanding of the expenses occurred by Barton Malow while working on the Fort Pickett Regional Training Institute, a General Conditions estimate was conducted using the aid of RSMeans 2012. An estimate of the General Conditions can be observed in Appendix C, where the estimate is organized by CSI Masterformat. Using the values calculated from the estimate, it was then possible to group the items into their respected categories, including project staff, bonding/insurance, general services, general expenses, and temporary facilities/utilities. The categories were then adjusted using a combination of location, time, and burden factors, which can be seen in Fig. 10. The time factor was calculated by taking a national inflation value and adjusting it to reflect the time at the midpoint of construction. Burden was another factor that was incorporated and was used for the project staff to cover costs related to business meals, traveling, and employee relocation. After compiling the results, the general conditions for the Fort Pickett Regional Training Institute were an estimated $3,199,054.58 or 11.3% of the total project cost.

General Conditions					
	Location (Petersburg, VA)	Time	Burden	Unadjusted GC Costs	Adjusted GC Costs
Project Staff	0.849	1.085	1.300	$1,622,250	$1,944,159
Bonding & Insurance	0.849	1.085		$411,386	$379,245
General Services	0.849	1.085		$708,440	$653,091
General Expenses	0.849	1.085		$155,572	$143,417
Temporary Facilities & Utilities	0.849	1.085		$85,848	$79,141
			Total	$2,986,495	$3,199,054

Figure 10: General Conditions

The project staff category consisted of the field personnel present on site and did not include office overhead, such as estimating, accounting, and the upper management. This category composed 61% of the total General Conditions, which can be seen in Fig. 11. This category is probably the most likely to deviate, since there is no way of knowing which members of the management team will be present the entire way through construction. It is common practice for Superintendents to leave earlier than the Project Managers and Engineers, since there presence is not required for most closeout activities. There are also unforeseen conditions relating to turnover within the company, relocations, or overstaffing to keep personnel employed that were not initially intended to be a part of that project team. The general conditions estimate conducted reflects all of the employees' presence the entire way through the construction project, except for the intern, in order to ensure that the project is properly funded.

Within the bonding and insurance category, Barton Malow bonded the project at its full contract value as specified by the U.S. Army Corps of Engineers. By bonding the project for its contract value, it ensured that the VAARNG would have their buildings delivered to them as intended with or without Barton Malow serving as the CM. Barton Malow also picked up General and Liability Insurance, as well as Builder's Risk Insurance. Together these items composed 12% of the General Conditions and ensured the company against any potential incidents that could occur throughout the course of construction.

General services include a number of different services provided by outside companies, such as material testing, equipment testing, inspections, borings, commissioning, surveying, scheduling, periodic cleaning, and final cleaning. These services made-up 20% of the total cost of the project or around $650K. Many of these estimates were calculated from a percentage of the total cost of the job, but others such as cleaning were determined using a reasonable duration for their services.

General expenses were composed of items utilized during the course of construction, such as dumpsters, safety equipment, weather protection, temporary fencing, temporary roads, and other necessary items. This category was responsible for only 5% of the construction costs and served as one of the safest and cheapest categories required for construction. These items could all be priced successfully through a book or vendor, which leaves little uncertainty for budgeting purposes.

The last and one of the most difficult items to estimate was the temporary facilities and utilities, since it was tough to estimate utility prices and the duration of necessary items on a job site. These items included the construction management trailer, equipment, furniture, storage units, portable toilets, and temporary utilities. Like the project staffing category, the actual cost of these items is directly related to the duration of construction. If the project is delayed then the use of these items will need to be extended, resulting in heightened costs in comparison to what was budgeted. For this reason, it is highly beneficial to the project team to complete the work as soon as possible.

Percentage of General Conditions by Category		
	Project Cost	**Percentage of GC Cost**
Project Staff	$1,944,160	61%
Bonding & Insurance	$379,245	12%
General Services	$653,091	20%
General Expenses	$143,417	5%
Temporary Facilities & Utilities	$79,141	2%

Figure 11: Percentage of General Conditions by Category

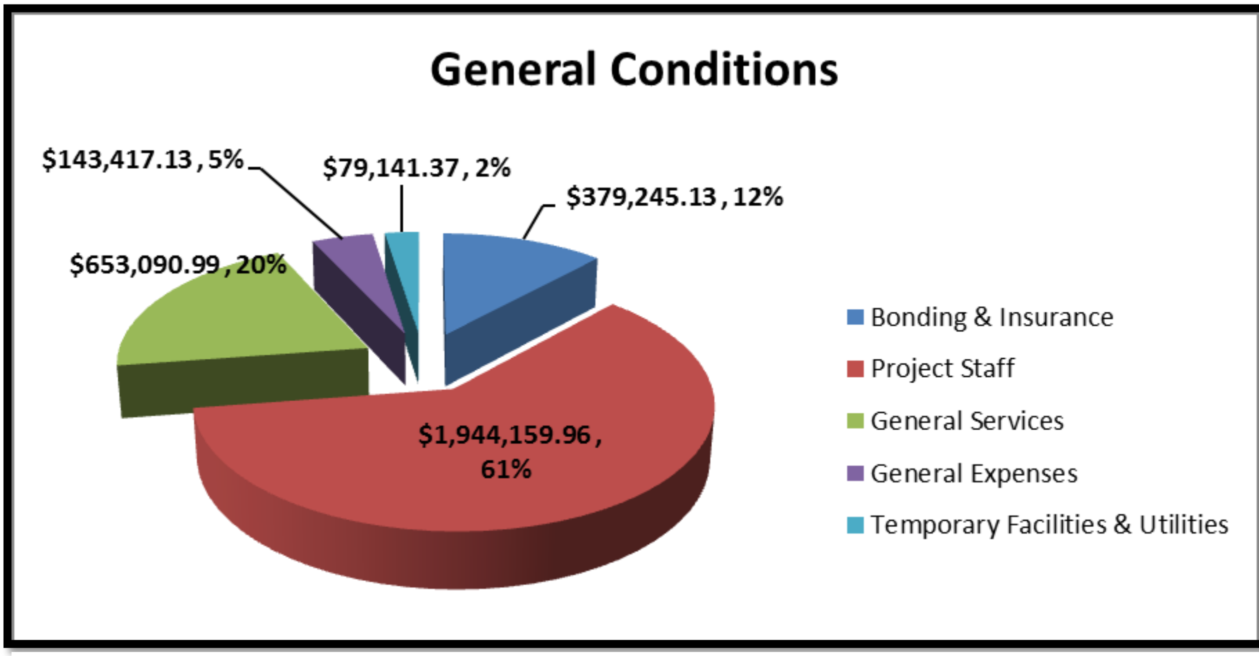


Figure 12: General Conditions by Percentage

To convey a better depiction of the cost breakdown within the General Conditions, Fig. 12 above shows each category and its respected percentage and costs. Altogether, the General Conditions values estimated represent a reasonable estimate for a typical project at 11.3% of the total contract value. The driving factor is most notably the project staff and for that reason in order for Barton Malow to gain as much fee as possible for the project, it is dire that the team completes its work on schedule, if not faster. Although Barton Malow is utilizing a GMP contract, an accelerated schedule still results in the early removal of temporary facilities, temporary utilities, and project personnel, which in turn results in higher profits for the company. Although General Condition’s estimates are composed of a level of variability, it is believed that the values estimates are very accurate for the Fort Pickett Regional Training Institute.

Architecture

Layout and Design

The architectural design of the buildings follows the practical, simplistic ideology of the United States Military. Form follows function as the buildings were designed to maximize living capacity, while minimizing cost. The design features a classic axial layout to reinforce the architectural line of the buildings and draw focus to the educational buildings. The three billeting buildings are placed around the perimeter of a square to create the ceremonial quadrangle. The open space will function as a parade ground, as well as reinforce the overall campus design.

The two story billeting buildings utilize identical floor plans and a corridor that stretches from one end of the building to the other. Corridors are oversized in anticipation of heavy traffic with exits located at each end of the buildings. Living suites are equipped with an operable window, sink, open closet, and a bathroom to be shared between two suites. This design is consistent throughout, with the exception of a few private rooms for higher ranking personnel. Centrally located on each floor is a laundry, lounge, communication, and mechanical room.

The interior materials used are consistent to modern-day office buildings. The colors are light and airy to accentuate the volume and operational experience. To build on the simplistic approach taken in the design, the buildings are consumed by standard military colors, such as tan, navy green, black, gray, white, and red. Various colors are used throughout the buildings to emphasize areas of importance and develop a hierarchy of space. Ceiling heights also vary to add importance to selected areas.

Building Façade

A rusticated masonry exterior skin was integrated using a variety of masonry units. The various colors meet the requirements identified by the Virginia National Guard. Multiple textures accented by detailed banding in the masonry are used to reinforce human scale and add a visual aesthetic to the facility. Vertical elements were implemented to break ups its linear nature, moreover drawing attention to the entrances and reinforcing the overall axial plan of the campus. The façade is composed of a variety of CMU textures and colors, including split-faced and smooth. The only break from the use of CMU’s on the exterior came from the precast concrete window sills. Windows are typical aluminum framed with glass panes. Further information regarding the façade is restricted, due to possible threats.

Roofing

The roofing system is a prefinished military green colored 24 gauge standing seam metal roofing with slip joints at the walls. Beneath the metal roofing is a Blue Skin, which acts as an air, water, and vapor barrier. The roofing is anchored to 6 5/8" Structural Insulated Panels (SIP) that are composed of 7/16" thick OSB panels on both faces and filled with R-40 foam insulation. The metal roofing also uses snow guards to prevent injuries from winter hazards to nearby bystanders.

Sustainability

The LEED Silver design utilizes a combination of advanced HVAC and lighting systems throughout the buildings. The buildings are equipped with several heat pumps throughout the buildings, so that the inside environment can be controlled more effectively to the desired conditions. The campus utilizes a centralized glycol system to cool the glycol in the heat pumps throughout the buildings. The mechanical system is enhanced with an ERV to retain energy from the exhaust air. The ERV wheel recovers air exiting the building and conductively transfers the energy to the incoming air. In addition, each room is equipped with occupancy sensors to ensure that energy is not wasted. Many of the materials on site were also tracked, guaranteeing proper disposal and recycling of material leaving the site.

Building Systems Summary

Demolition

In accordance to the project contract, Barton Malow is to demolish a number of buildings that are later to be specified. In order to meet restrictions attached to the project funding, a specified amount of occupiable square footage is to be demolished in equivalence to the square footage being constructed. The buildings that are in discussion for demolition were constructed during the World War II era and are no longer suitable for occupancy. The buildings are composed of hazardous materials, such as lead paint and asbestos insulation. Although the buildings are not on the site of the Regional Training Institute, the buildings are to be demolished following the construction of the billeting buildings.

Structural Steel Frame

The project consists of three, two level stand-alone structures. The structural steel frame differed from traditional methods, primarily using cold formed steel metal studs to support the buildings, similar to dormitories or residential construction. The cold formed steel bearing walls consisted of 14 and 16 gage studs placed at 16" on center, which can be seen in Fig. 13 below. Unlike traditional steel structures, metal decking was not used for the floor support system, and instead hollow-core planks were used. The planks rested on the cold formed steel metal stud wall panels, as well as W12x26 structural steel wide flange beams that served as headers across the large doorway openings. The roofs for all buildings are supported by pre-engineered cold formed steel roof trusses, which are supported on cold formed bearing wall panels and W10 x22 structural steel wide flange beams. The roof trusses, as well as a few structural members that served as headers were the only part of the steel structure that required the use of a crane throughout the course of the project. In order to lift these items, two cranes were utilized, including a 75 ton and 100 ton crawler crane. In addition, a cold-formed steel load bearing shear wall system is used to resist wind and earthquake loads, directing lateral forces from the roof level, through the rigid level floor supports, and into the foundations. The exterior wall enclosure is composed of cold formed steel framing, serving as a back-up to a split-faced CMU veneer and other wall finish materials.

Figure 13: Metal Stud Bearing Walls - Courtesy of Barton Malow

Cast- in-Place Concrete

Figure 14: Slab on Grade - Courtesy of Barton Malow

Cast-in-place concrete was used on a number of different aspects of the buildings, specifically the foundations and the floor topping slabs. All of the buildings are supported on continuous footings and spread footings at column locations bearing on native soil. In addition, all of the buildings have a 4" minimum slab on grade that is reinforced with welded wire fabric/fiber mesh over a vapor barrier bearing on 4" of compact granular fill. As mentioned previously, precast hollow core planks served as the structural floor, but the planks were topped with 2" of cast in place concrete to eliminate the plank joints, as well as give the floor greater structural integrity. All of the concrete poured on site was placed using a pump truck, which can be seen above in Fig. 14. Wood formwork was used for the slab on grade and topping slab pours.

Precast Concrete

The supported floors for all buildings consist of 8" thick precast hollow-core plank. The hollow-core planks were connected together by sliding the ends together, reinforcing the joint, grouting the joint, and then placing a 2" concrete topping slab on top that was reinforced with welded wire fabric. The hollow-core planks are supported on cold formed steel bearing wall panels, which can be seen in Fig. 10 to the right. The hollow-core planks were placed using the 75 ton and 100 ton crawler cranes that were also used for the trusses. In order to expedite the setting process, the cranes were located on opposite sides of the buildings and then alternated lifts along the length of the building.

Figure 15: Hollow-core Planks - Courtesy of Barton Malow

Mechanical System

Figure 16: Heat Pump

The mechanical system is composed of a central closed water loop heat pump system, which is incorporated into the rest of the campus. To handle the additional load, a 240 KW electrical boiler, associated pumps, and a 200 ton closed cell fluid cooler were added to the mechanical room of a neighboring building. Underground HDPE piping routes the ethylene glycol fluid to the campus, where each building will be provided with base mounted VFD pumps. One of the pumps will be on 100% standby at all times, but will be coordinated by a lead/lag cycle to equalize wear. The pumps are controlled through VFD's to maintain a preset pressure differential across the piping system and will reduce flow at times when building occupancies are low to save energy. The corridor ceiling space is occupied by high efficiency horizontally placed heat pumps. The heat pumps are supplied with environmentally friendly refrigerant R 410a. The fans are driven by high efficiency ECM motors. The compressors are two-stage to match the capacity to the load. They have supply and return ductwork with outdoor ventilation air ducted directly to the return air side. The heat pumps are provided with two way control valves to work in conjunction with the VFD pumps to reduce energy using during part load conditions. In general, three to five rooms will be supplied from one heat pump, which reduces maintenance work load, allows for closer match between actual heating/cooling load and heat pump capacity, and greatly reduces congestion in the ceiling plenum. Energy recovery ventilators are used to pre-treat outdoor air with toilet room exhaust through an enthalpy heat wheel, which allows negligible amounts of air crossover. This saves substantial energy and reduces the design heating and cooling loads.

Electrical System

The primary electrical distribution is supplied by the Southside Electrical Utility, where primary power will run to transformers located on pads 33 ft. behind each building. The transformers feeding the service are 5000KVA. The electrical rooms are accessible from the exterior of each building and feature an 800A switchboard at 277/480V/3PH/4W that services a 277/480V lighting panel, and power distribution panels for mechanical loads located in the first and second floor electrical rooms. The electrical rooms have transformers serving 120/208V panel boards servicing the receptacles, washers, dryers, 208V heat pumps, and all 120V mechanical equipment throughout the buildings. In order to become more environmentally friendly, occupancy sensors were placed in every room to minimize the amount of energy wasted in typical buildings.

Masonry

A rusticated masonry exterior skin was integrated using a variety of masonry units. The various colors meet the requirements identified by the Virginia Army National Guard. Multiple textures accented by detailed banding in the masonry are used to reinforce human scale and add a visual aesthetic to the facility. Vertical elements were implemented to break ups its linear nature, moreover drawing attention to the entrances and reinforcing the overall axial plan of the campus. The façade is composed of a variety of CMU textures and colors, including split-faced and smooth block, which can be seen in Fig. 17. The 8" and 4" CMU block is supported by the structural steel bearing walls around the exterior of the building. Hydraulic scaffolding was utilized throughout the masonry construction process to expedite the placing of block.

Figure 17: CMU Facade

Analysis 1: Modularized Bathroom Units

Problem Identification

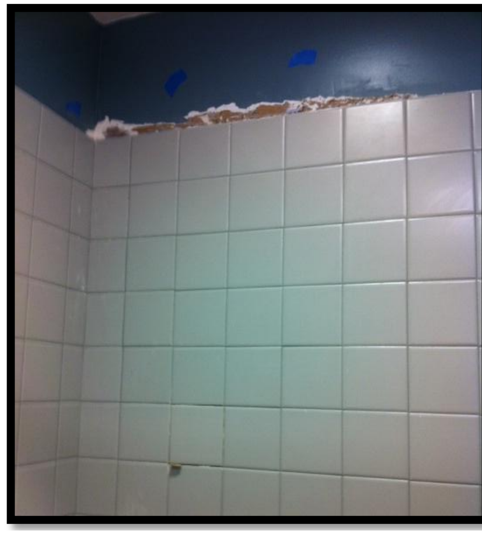


Figure 18: Problematic Grout/GWB Joint

Although the Fort Pickett Regional Training Institute features a simplistic design layout, the project was hindered by its ability to accelerate the construction of the bathrooms. The RTI's floor layouts feature a repetition of two bedrooms with a common bathroom, a design approach that minimizes the costly bathroom fixtures, as well as constrains the MEP work and tile finishes to a concentrated area. Although the design is favorable from a cost standpoint, the bathrooms remain a problematic area, due to their level of detail and work within such a limited area. The bathrooms consist of a built-in shower, toilet, tile finishes, and MEP conduit for the mentioned fixtures, as well as the sinks located on the common wall between the bedrooms and bathrooms. In addition, the project team had a constant battle with the drywall and tile Subcontractors to provide quality work, particularly at the grout and drywall joints, which can be seen above in Fig. 18. The tile subcontractor was forced to remove excess grout after the joint had been finished, which created excess work to fix the problem and a conflict to allocate the financial responsibility to correct the work. A constant problem faced by the project team was the amount of work involved with the construction of the bathrooms in comparison to the bedrooms. The rooms were able to be constructed with ease, leaving the completion of the bathrooms as the main schedule driver.

Research Goals

To perform research on the application of modularization within the construction industry through case studies, research papers, and interviews with industry professionals. To derive an implementation strategy, including manufacturing, transportation, erection, and installation of the units. To determine the feasibility of utilizing modularized units on the Regional Training Institute, including a schedule and cost analysis of the proposed system.

Background Information

The idea of modularization for construction purposes continues to gain momentum in the construction industry, although the practices remain relatively new. Modularized units or pods are pre-built rooms, typically kitchens or bathrooms, which are best thought of as plug and play appliances. The units are manufactured off-site in a controlled work environment as ready for occupancy with completed plumbing, electrical fixtures, tile, fixtures, and other kitchen/bathroom accessories. The concept is incredibly advantageous to any project in regards to quality and schedule, but the value can greatly depend from project to project. The use of modularized units is favorable for building designs that feature repetitive layouts, which is exactly what the billeting buildings at Fort Pickett demonstrate. In addition, the use of pods requires a dedication to coordination and earlier involvement in the design phase from all of the involved parties. Since the Regional Training Institute project utilizes a design-build delivery system, coordination can be greatly facilitated.

Figure 19: Modularized Units or Pods (Mensh)

Due to the potential that modularized units possess for accelerating project schedules, this analysis of modularized units serves as a benchmark for the construction industry and a tool for future considerations of using modularization on future projects. The research addresses how to deal with projects that possess unrealistic project schedules and activity durations. Projects that are forced into tight construction windows have the opportunity to learn from this analysis, where a plan for implementation has been outlined, as well as a feasibility study for its use on the Fort Pickett Regional Training Institute project.

Project Constraints

Although the Regional Training Institute campus is composed of three nearly identical buildings, there are a few differences that cause dilemmas in the deployment of modularized bathroom units. The largest constraint is the slight variation in floor layouts on the first floor. Building 600's first floor features a number of group bathrooms, in order to maximize the occupancy of the living spaces and is intended for lower ranked military personnel. The two different bathroom designs can be seen in Fig. 20 on the following page. In addition to the differing bathroom pods on the first floor, the pods on the first floor will be supported by slab-on-grade concrete, which creates increased coordination for MEP risers during the concrete slab pour. Additionally, to keep the floor of the pods at an elevation consistent to the bedrooms, a ½" depression of the pods will need to be formed prior to the concrete pours. Another item to consider is the excess materials from the pods. An additional partition wall will be needed for the wall to connect to the corridor wall, as well as a ¼" metal sheet and ¼" cement board layer for the pod floors. Last but not least, because of the cost savings tied with using cold formed metal stud walls and precast hollow-core planks for the second floor, the sequencing will need to be slightly altered. The exterior walls are load bearing, so the pods will need to be placed inside the room prior to setting the hollow-core planks. Additionally, accessibility to the plumbing connections of the second floor pods creates sequencing problems, so the second floor pods will need to be hooked up before pushing the first floor pods into place and framing the partition walls around them.

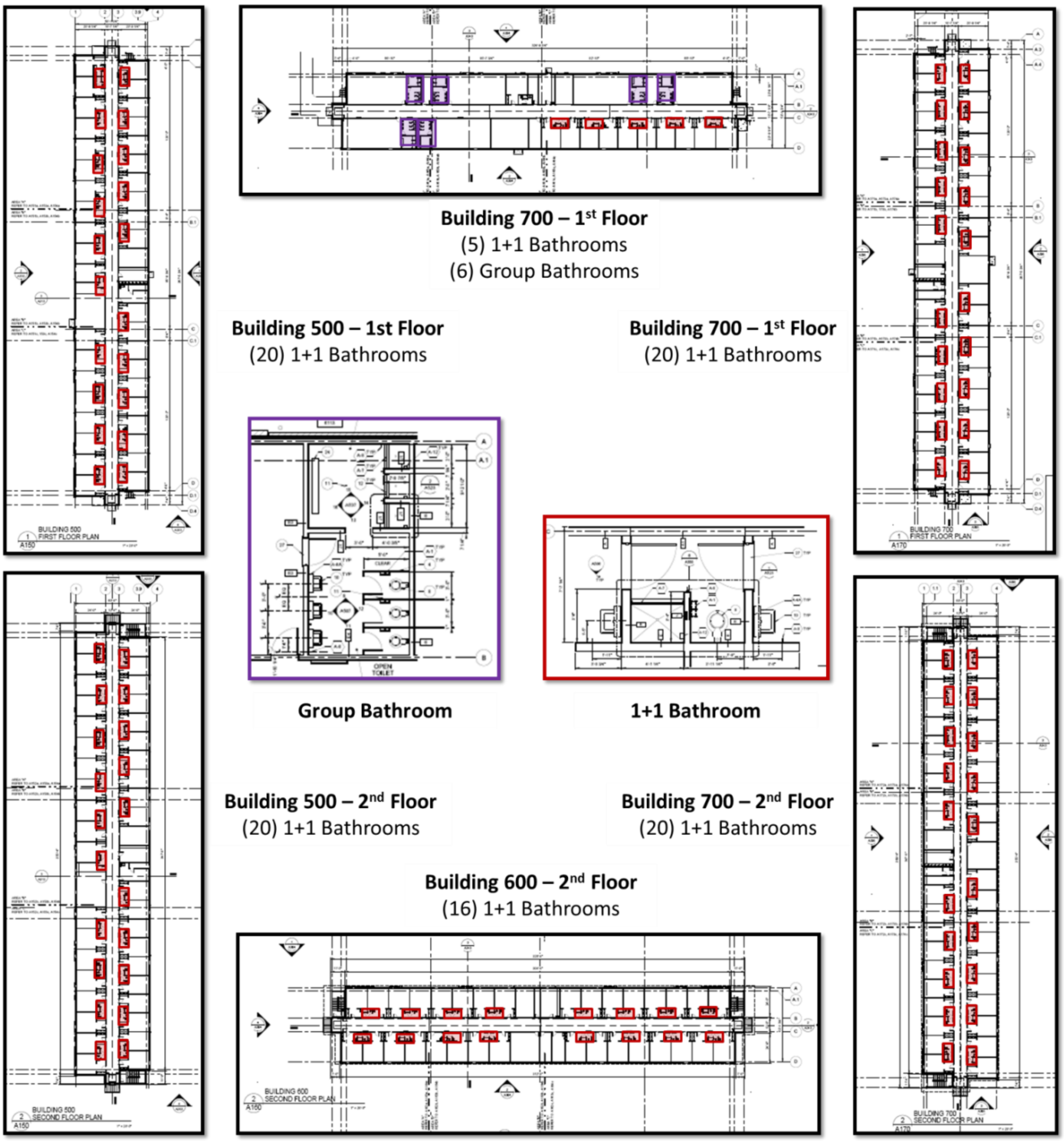


Figure 20: Regional Training Institute Bathrooms

Procurement

The use of pods has the potential to greatly accelerate the construction schedule, but it must be realized that for this to be a possibility, there must be a considerable amount of planning between the designers, manufacturers, and contractors. The project uses a design-build delivery method, which is incredibly beneficial for coordination, but it is absolutely dire to procure a pod manufacturer and get them on board as soon as possible. Since the contract is composed of two phases with the barracks being constructed during Phase II, 30% design documents needed to be submitted to the U.S. Army Corps of Engineers upon bidding Phase I for both phases. Although the project's schedule is flexible with the multiple phase construction approach, the design would be best proposed during the bidding process with the intention of using bathroom pods for the barracks. The best strategy would be to use bridging documents from Barton Malow, where the pod manufacturer would be responsible for completing the architectural drawings between the final design development and 50% construction documents. This step would occur upon successful completion of Phase I and the Army Corp of Engineers award of Phase II to Barton Malow.

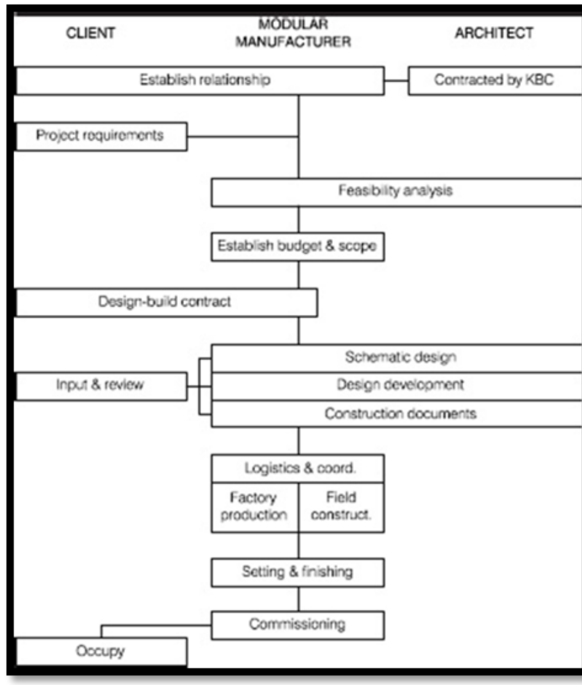


Figure 21: Flow Chart for Design-Build ("Scribd")

Design

At this point, it is critical to coordinate the implementation strategy for using bathroom pods. In order to effectively use pods in the building design, the following members would need to be included in design discussions:

- Barton Malow Construction
- Barton Malow Design
- POD Manufacturer
- U.S. Army Corps of Engineers – Owner Representative
- Virginia Army National Guard - Owner
- Atlantic Contractors - Mechanical/Plumbing Contractor
- IES - Electrical Contractor
- Cleveland Concrete – Concrete Contractor

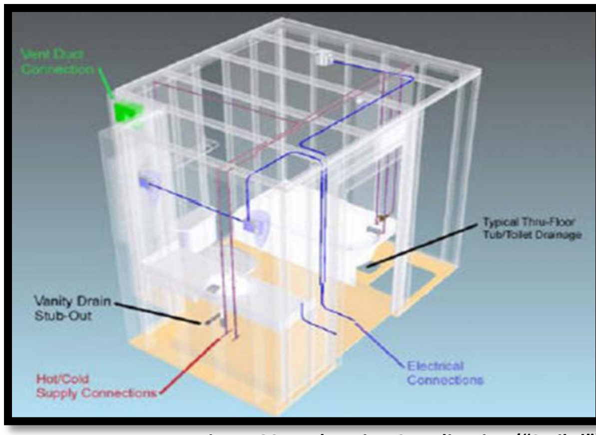


Figure 22: Pod Design Coordination ("Scribd")

The design team would play the largest role by coordinating the building systems with the manufacturer of the modularized bathrooms units. To aid in this process, the use of Barton Malow's Revit/BIM models would greatly increase coordination between the different parties. Although there are a number of different modeling software available, Revit contains the greatest ability for coordination between the different parties. The model allows for prototypes and mockups to be generated to investigate problematic areas prior to construction and can even be used for estimating purposes. Revit even expedites the shop drawing process by taking the shop drawings directly out of the file. Barton Malow's NavisWorks 4D model even allows the project team to simulate the sequencing and setting of the pods into their desired spaces.

One of the first items to coordinate is the concrete slab-on-grade floor. In order for the pods to be able to be set on the slab, coordination must exist between the concrete contractor and the structural engineers. Pods can produce a significant point load on slab-on-grade systems, so special design adjustments may need to occur. In order to eliminate changes in elevation, the use of concrete depressions using formwork could be utilized on the slab-on-grade and second floor topping slabs, which would again change the structural design of the slabs. In addition, the concrete pour must be coordinated with the MEP subcontractors, so that the proper MEP rough-ins are in place.


Figure 23: MEP Connections – Courtesy of Barton Malow

The MEP subcontractors must also consider the connection points between the MEP work performed on-site and in the manufacturing facility. Most bathroom pods require a hot and cold connection, three drainage connections, two electrical connections, and one HVAC connection (Mensh). It is critical that the connection points are coordinated properly to ensure that the units can be installed without any problems in the field. Fig. 23 to the left depicts the current MEP connections from the 4D model, which can be planned properly using Barton Malow's current design model.

Another area of focus is the design of the connections of the pods to the building structure. The pods can be custom designed to fit any desired building layout, so Barton Malow Design would need to establish pod dimensions with the manufacturer. Once a pod design is established, it would then be necessary to detail the connections of the pods to the stud wall. As seen below in Fig. 24 and Fig. 25, the wall to ceiling and wall to floor connections are detailed respectively.

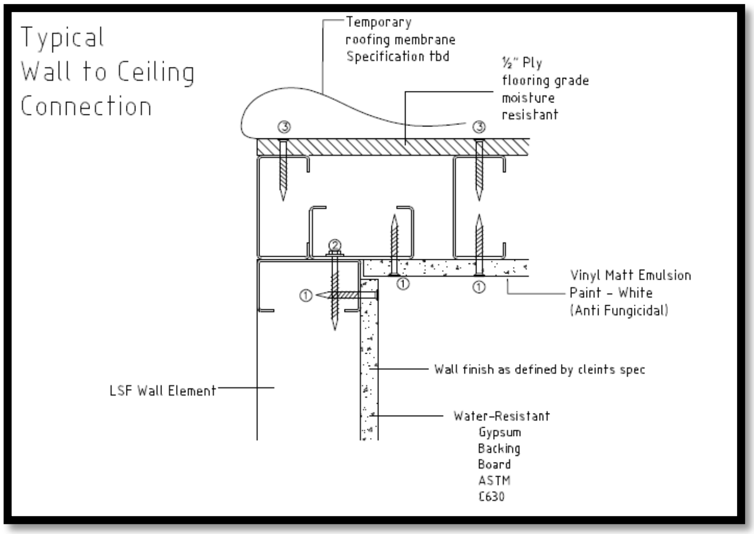


Figure 24: Typical Wall to Ceiling Connection (Mensh)

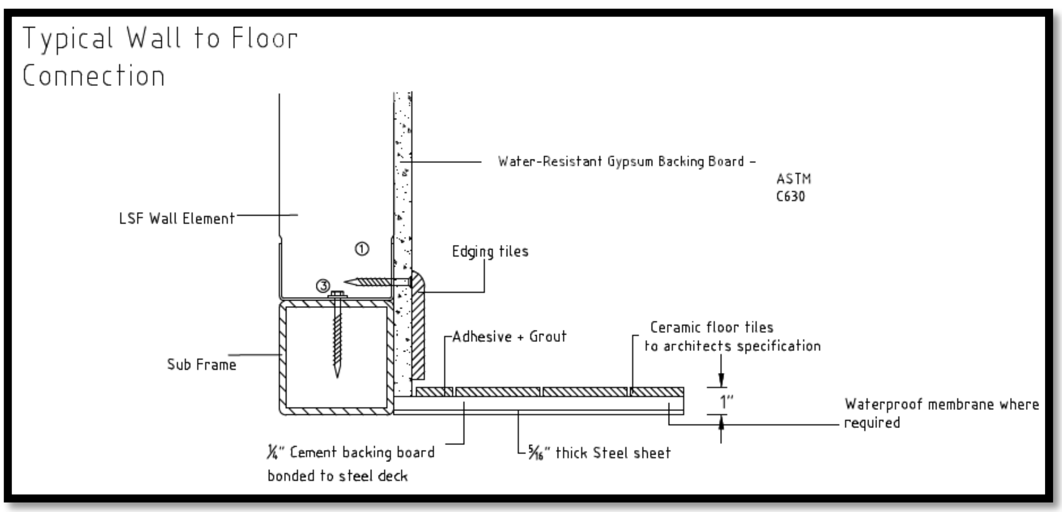


Figure 25: Typical Wall to Floor Connection (Mensh)

Manufacturing

The purpose of incorporating pods into the building designs is to shift the work from the field into a manufacturing facility, ultimately reducing the construction schedule. Although the driver for switching to modularized units is schedule acceleration, there are a number of other advantages of manufacturing the pods in a factory setting. First and foremost, the pods are built with a level of fit and finish that is unachievable in the field. The builders are full-time tradesmen and quality control supervisors, which promotes continuous improvement by identifying inefficiencies and employing corrective practices directly into the manufacturing line. Workers in the manufacturing facility typically have a higher skill level and cooperation. Many manufacturing plants utilize union labor, which results in more dedicated and consistent work.

Figure 26: Manufacturing Facility (Mensh)

Modularized construction constitutes lean construction by utilizing just-in-time delivery methods and reducing waste by 1000% in comparison to field construction (Mensh). Materials are delivered as needed, opposed to sitting around job sites where they risk being damaged. Materials are scheduled to arrive as they need them and are delivered directly to strategic locations to maximize worker efficiency. The facility works as an assembly line where people have the opportunity to master activities that they are comfortable with.

Constructing the pods in a factory setting allows for greater efficiency through repetitive activities. In traditional field construction practices, inconsistencies in measurements and installations create deviations in future work from the construction documents. A stud wall may be out of plum, or sheetrock may not have been hung straight, which leads to further problems and additional time allocated to custom sizing material to fit in to place. With modularized construction, every pod is made with repetitive processes. This allows workers to make the same measurements, cuts, and installs every time. Materials can be prepped and stored upon installation, which is not often possible in the field, due to limited space.

Figure 27: Operating Machinery (Mensh)

Factory settings also contain the necessary tools to complete the task-at-hand. Factories have greater proximities of the work needed to complete to the locations of necessary tools. In the field, it is not uncommon for disputes to erupt over stolen and misplaced tools. Factories are designed to allow accessibility of heavy equipment, convenient machinery locations, and proper tools. By having the available resources to complete work, construction processes can be greatly expedited. The figure on the left shows a worker operating a piece of machinery with no obstructions.

Factories feature a much better work environment, which promotes better work efficiency. An uncontrolled work environment could potentially deal with detrimental weather conditions, which could reduce efficiency, as well as lead to safety incidents and injuries. In addition to the removal of weather related safety issues, the construction of pods are performed in a controlled facility with adequate light, adequate work space, and fewer trade personnel, which together promotes better safety and less incidents on site ("Scribd"). Manufacturing facilities also include improved auxiliary services, such as bathrooms, break-rooms, lunch-rooms, and locker-rooms.

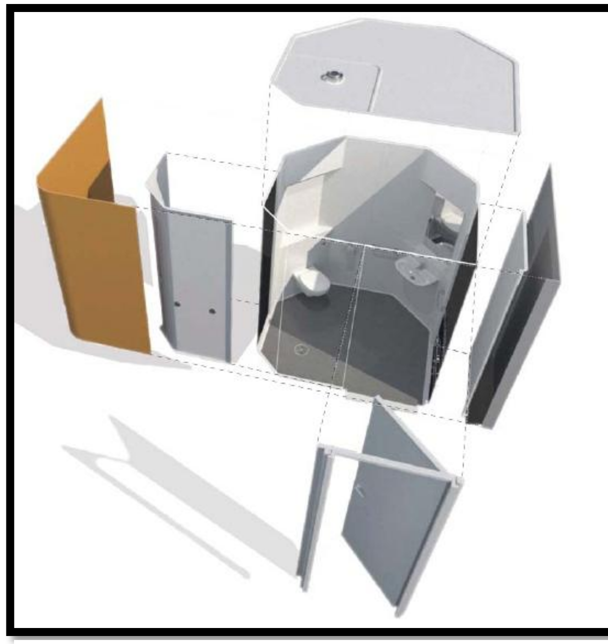


Figure 28: Pod ("Scribd")

An item that is often overlooked on the job-site is security, a risk that is minimized when working in a manufacturing facility. Opposed to job-sites where materials, tools, and equipment are often vandalized or stolen, these facilities are protected from outside visitors and are typically monitored closely.

Quality Control

Modularized bathroom units demonstrate a level of quality that is not obtainable in traditional field constructed bathrooms. The improved physical access to the work creates a much greater level of quality in the inspection taking place. The higher level of lighting allows the inspectors to see minute flaws in the modules, which can be fixed at the plant instead of in the field. Another item that is often overlooked is the proximity of the supervisors to the work taking place. In the field, it is often difficult for workers to locate a foremen or supervisor to clarify an issue, but in the manufacturing plant, workers have the ability to resolve any issue in the plant in a timely manner.

Pod manufacturers perform quality control tests that are often overlooked in the field, which ensures that the client is receiving a quality product. Before leaving the shop, a number of mandatory tests are performed to ensure that there are no issues with the pod prior to shipping. Fig. 29 shows the rigorous test performed in the shop to deliver a higher quality usable space.

Type of Test	Description
Leak Testing of Mains Cold Water System (Set and Test Pressure Regulators)	A pressure test required to identify any potential leaks within the mains cold water supply system, period held and pressure.
Leak Testing of Domestic Hot Water Supply System (Set and Test Pressure Regulators)	A pressure test required to identify any potential leaks within the domestic hot water supply system, period held and pressure.
Leak and Functional Testing of the Waste Pipes, Traps, etc.	A functional water test to ensure actual drainage and detect for leaks. Period air test 50mm or 75 mm complete system.
Setting of Toilet Level Flushing	A functional test to ensure that the manufacturers' recommendation for cistern flush volumes and performance are met.
WHB overflows	A functional and visual test in accordance with requirements to ensure all overflows functional correctly.
Shower Flow Rate Setting	A functional and visual test in accordance with requirements to ensure that the flow rate of the shower head is set correctly.
Shower Temperature Setting	A functional test to ensure that the thermostatic temperature of the shower is set in accordance with requirement. Max temperature if required.
Functional Electrical Appliance Testing	A functional test to ensure that all fitted electrical appliances work correctly.
Electrical System Conformity and Safety Testing	A prescribed test in accordance with IEE Regulations (or code equivalent) to ensure safety performance. Insulation, continuity, polarity checks, visual and dimensional check that all service outlets are to drg's, labeled and capped.

Figure 29: Quality Control Tests (Mensh)

Delivery

Upon successfully passing inspection from the manufacturer and Army Corps of Engineers, the units are then ready for cleaning and packaging. The pods are wrapped in weatherproof packaging and covered in foam protection to ensure that they are not damaged during shipment. Deliveries can be made at the convenience of the project, creating a just-in-time delivery method, opposed to having them occupy space around the site where they can be damaged and take up valuable time from moving them around. The units can be prearranged to be delivered simultaneously, floor by floor, or at whatever is the most favorable strategy for the project team. The transportation service is typically built into the pod manufacturer's contract, which makes coordination with their shipping department important to guarantee just-in-time delivery practices.

The maximum size of modules that can be shipped is governed by state laws for semi-trailers. City and county governments may also impose additional restrictions. The laws may entail the requirement of special permits, maximum trailer dimensions, the use of specific roads, maximum weights, and limited times of day to travel. In general, the maximum module weight is 44,000 lbs., so it is important to take this into consideration ("Scribd").

The first thing to look at is the most effective route for the delivery of the pods. Kullman's manufacturing facility is located in Lebanon, NJ, so the most efficient path would be to utilize Interstate 95, since it has flexible transportation guidelines. The suggested route can be seen below in Fig. 30. Using Interstate 95 as the main transportation route results in a 370 mile trip at approximately 7 hours. This means that in order for the pods to arrive on-site for just-in-time deliveries, the trucks would need to leave the manufacturing facility around 12AM. Transporting the pods through the night also reduces potential traffic problems.

Figure 30: Pod Delivery Route (Google Maps)

Once the route is established, it is then possible to determine the maximum truck dimensions. Dave Mensh, Head of Davis Construction’s Residential Group, stated that one of the most critical items to consider is the size of the pods in comparison to the maximum transportation restrictions. He expressed that it was important to ensure that the pods or the sections of the pods are constructed so that they remain within the dimensions of a covered truck bed. He said that if the pods are designed not to fit within a covered trailer, then the shipping costs escalate to nearly 10x more. In addition, this creates more potential for damaging the pods due to improper securing of the pods on the truck and leads to greater problems from the acquisition of permits. At this point, the financial benefit of utilizing pods over field construction is typically negated (Mensh).

The following figure shows the maximum dimensions of a truck bed for transportation with the numbers not in parentheses being the restrictions for transportation without permits. To Fort Pickett’s benefit, the pod dimensions are 8’ 7 ½” x 7’ 10 ¼” x 8’ 2”, which fits below the most stringent restrictions of the four states, Virginia’s requirements without a permit.

State	Width	Height	Length	State	Width	Height	Length
Alabama	12' (16')	* (16')	76' (150')	Montana	12'-6" (18')	* (17')	* (120')
Alaska	10' (22')	*	100' (*)	Nebraska	12' (*)	14'-6" (*)	85' (*)
Arizona	11' (14')	* (16')	* (120')	Nevada	8'-6" (17')	* (16')	105' (*)
Arkansas	12' (20')	15' (17')	90' (*)	New Hampshire	12' (16')	13'-6" (16')	80' (100')
Califonia	12' (16')	* (17')	85' (135')	New Jersey	14' (18')	14' (16')	100' (120')
Colorado	11' (17')	13' (16')	85' (130')	New Mexico	* (20')	* (18')	* (190')
Connecticut	12' (16')	14' (*)	80' (120')	New York	12' (14')	14' (*)	80' (*)
Delaware	12' (15')	15' (17'-6")	85' (120')	North Carolina	12' (15')	14'-5" (*)	100' (*)
District of Columbia	12' (*)	13'-6" (*)	80' (*)	North Dakota	14'-6" (18')	* (18')	75' (120')
Flordia	12' (18')	14'-6" (18')	95' (*)	Ohio	14' (*)	14'-10" (*)	90' (*)
Georgia	12' (16')	15'-6" (*)	75' (*)	Oklahoma	12' (16')	* (17')	80' (*)
Idaho	12' (16')	14'-6" (16')	100' (120')	Oregon	9' (16')	*	95' (*)
Illinois	* (18')	* (18')	* (175')	Pennsylvania	13' (16')	14'-6" (*)	90' (160')
Indiana	12'-4" (16')	14'-6" (17')	90' (180')	Rhode Island	12' (*)	14' (*)	80' (*)
Iowa	8' (16'-6")	14'-4" (20')	85' (120')	South Carolina	12' (*)	13'-6" (16')	(125')
Kansas	* (16'-6")	* (17')	* (126')	South Dakota	10' (*)	14'-6" (*)	*
Kentucky	10'-6" (16')	14' (*)	75' (125')	Tennessee	10' (16')	15' (*)	75' (120')
Louisana	10' (18')	* (16-'5")	75' (125')	Texas	14' (20')	17' (18'-11")	110' (125')
Maine	8'-6" (18')	8'-6" (*)	80' (125')	Utah	10' (17')	16' (17'-6")	105' (120')
Maryland	13' (16')	14'-6" (16')	85' (120')	Vermont	15' (*)	14' (*)	100' (*)
Massachuetts	12' (14')	13'-9" (15')	80' (130')	Virginia	10' (*)	15' (*)	75' (150')
Michigan	12' (16')	14'-6" (15')	90' (150')	Washington	12' (16')	14' (16')	*
Minnesota	12'-6" (16')	*	95' (*)	West Virgina	10'-6" (16')	15' (*)	75' (*)
Mississippi	12' (16'-6")	* (17')	53' (*)	Wisconsin	14' (16')	*	80' (110')
Missouri	12'-4" (16')	15'-6" (17'-6")	90' (150')	Wyoming	* (18')	* (17')	* (110')

Figure 31: State Delivery Restrictions (“Scribd”)

Figure 32: Delivery of Pods (Mensh)

In order to provide the most financially beneficial plan for the project, it is in the best interest of the project team to only modularize the smaller 1+1 bathrooms and construct the group bathrooms in the field. Modularizing the larger bathrooms creates transportation and construction problems that are not in the best interest of the team to inherit. For the purpose of Fort Pickett's Regional Training Institute project, there are 101 total pods that need to be shipped. The first shipment for level one of the three building consists of 45 bathroom pods, and level two consists of 56 bathroom pods. Fig. 33 below diagrams the shipping method using the most cost effective transportation method, a single drop trailer. The trailer is capable of carrying 6 pods per delivery, resulting in 17 total trucks to deliver all 101 pods to the site.

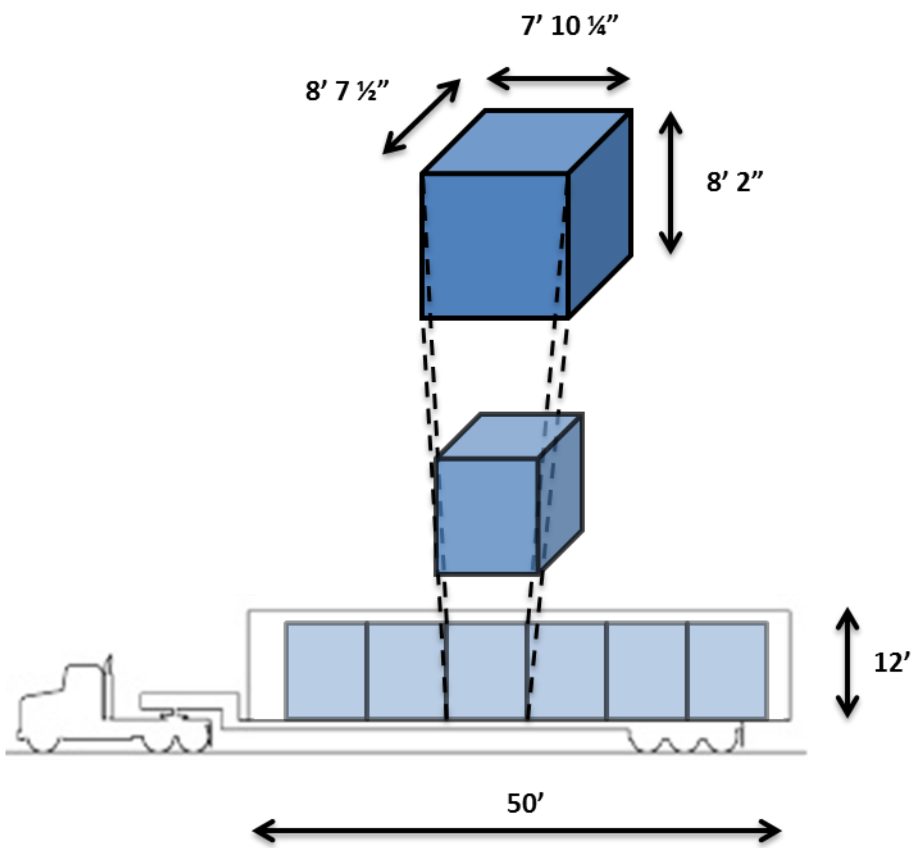


Figure 33: Shipping Diagram

Using FairTran, I was able to find relative shipping costs for the pods in the Central Atlantic region. Using a reefer truck for long haul distances, the shipping costs were $2.11 per mile ("FairTran"). Fig. 34 below shows the cost breakdown for shipping the pods from the manufacturing facility to the job-site.

Shipping Breakdown			
Trucks	**Rate/Mile**	**Miles**	**Total Cost**
17	$2.11	370	**$13,272**

Figure 34: Shipping Costs ("FairTran")

According to Kullman Offsite Construction, the use of modularized construction practices generally has a 5% reduction in overall transportation demand, resulting in 5% savings ("Scribd"). This is a result of transporting only necessary items and eliminating material waste sent to the site. Therefore, the use of modularized bathroom units on the Fort Pickett project results in a savings of $664.

Placement into Buildings

One of the more critical items to discuss during the planning stage is at what point to place the pods in the building. In order to have them inserted into the building structures, it is more favorable to have the mechanical, electrical, and plumbing rough-ins completed, so that the units can be connected as they are delivered. This must be coordinated in advance with the appropriate contractors. In regards to equipment, the pod manufacturers typically provide special equipment that can be utilized to successfully move the units into place. The two main methods of moving the pods inside are the use of a lull or crane, which can be seen below in Fig. 35 and Fig. 36.

Figure 36: Placement with Crane (Mensh)

Figure 35: Placement with Lull (Mensh)

When considering the Regional Training Institute's floor layout, the use of a crane is the most feasible method, specifically since the structure of the building is cold formed metal stud walls. Although the use of a crane is more expensive, the load bearing walls need to be completed prior to dropping the pods in so that the units are not damaged during the structural wall erection process. In addition, the load bearing walls in the barracks are the perimeter walls, as well as the corridor walls, which happen to be the walls that double as the bathroom walls to be used for connections. This means that once the load bearing walls are erected, there is no way that the pods can be pushed into the building and must be dropped in over the walls using a 25 ton mobile crane.

The other critical item to consider is the erection of the hollow-core planks for the first floor pods and the roof trusses for the second floor pods. To account for these overhead items, the pods will need to be placed on their desired floors prior to the erection of the overhead structural systems, something that will be noted in the proposed fit-out schedule. Once the pods are placed into the building using special equipment provided by the pod manufacturer, as seen in Fig. 37 to the left, they are positioned into each room and remain there until the plumbing risers and cored holes are completed. The partition walls and MEP work can be performed around the pods until they are ready to be pushed into their final locations.

Figure 37: Pod Being Moved into Temporary Locations

To provide a better understanding of the site logistics associated with the pod installation process, Fig. 38 to right and Appendix D show a site plan of the placement of the bathroom pods in Building 700. The deliveries are unobstructed and can be made through the center of the campus. The pods can be erected with a just-in-time delivery method. According to Dave Mensh, a typical 2 man crew can place 12 pods per day on average, which means that each floor will take no longer than 2 days.

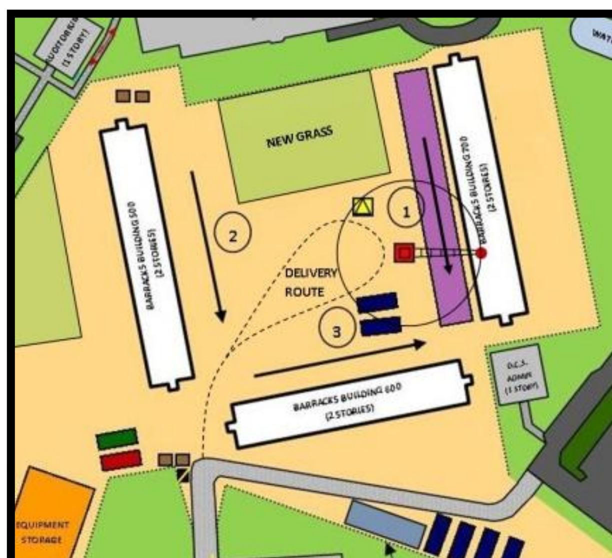


Figure 38: Pod Install Site Plan

Installation

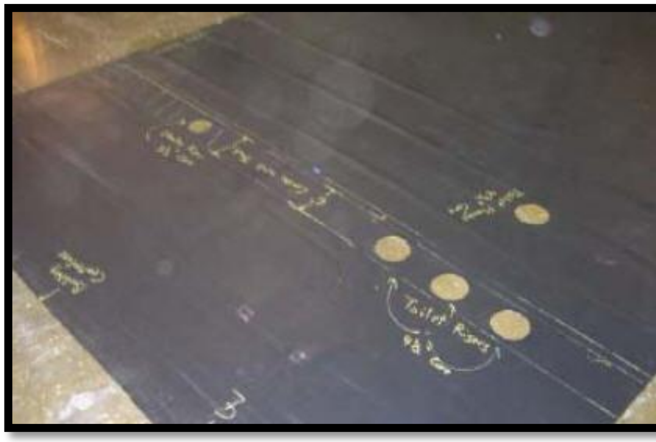


Figure 39: MEP Hole Template (Mensh)

Once the pods have been placed within the building, it is then possible to begin hooking up the final connections. The first step in the installation process is for the responsible contractors to drill cores for the MEP conduit. These holes are drilled using a template provided by the pod manufacturer, which eliminates errors and saves a great deal of time. The second step is dealing with the MEP risers, which is made up of vent risers, waste risers, water supply, and vent shafts. This construction is completed the same way as traditional construction methods and follows the MEP drawings. The waste pipes are hung in place beneath the cored holes, but are not yet connected to bathroom in the floor above.

The next step in the process would be to remove the packaging and place the pods into place using special equipment to roll them into their final location, which can be seen below in Fig. 40 and Fig. 41**.** Depending on the specifications from Barton Malow Design and the manufacturer, the pods could be designed to be integrated into the buildings wall structure or slid adjacent to the pre-built, fire rated wall. For the purpose of the RTI, the pod would have to be slid adjacent against the common wall shared by the bathroom and corridor, since it would complicate the structural design and integrity of the building's safety. Since this common wall must be constructed in the field, a partition wall will be used on the pod design to allow finishes to be applied.

Figure 40: Holes for MEP Risers (Mensh)

Figure 41: Moving Pods into Place (Mensh)

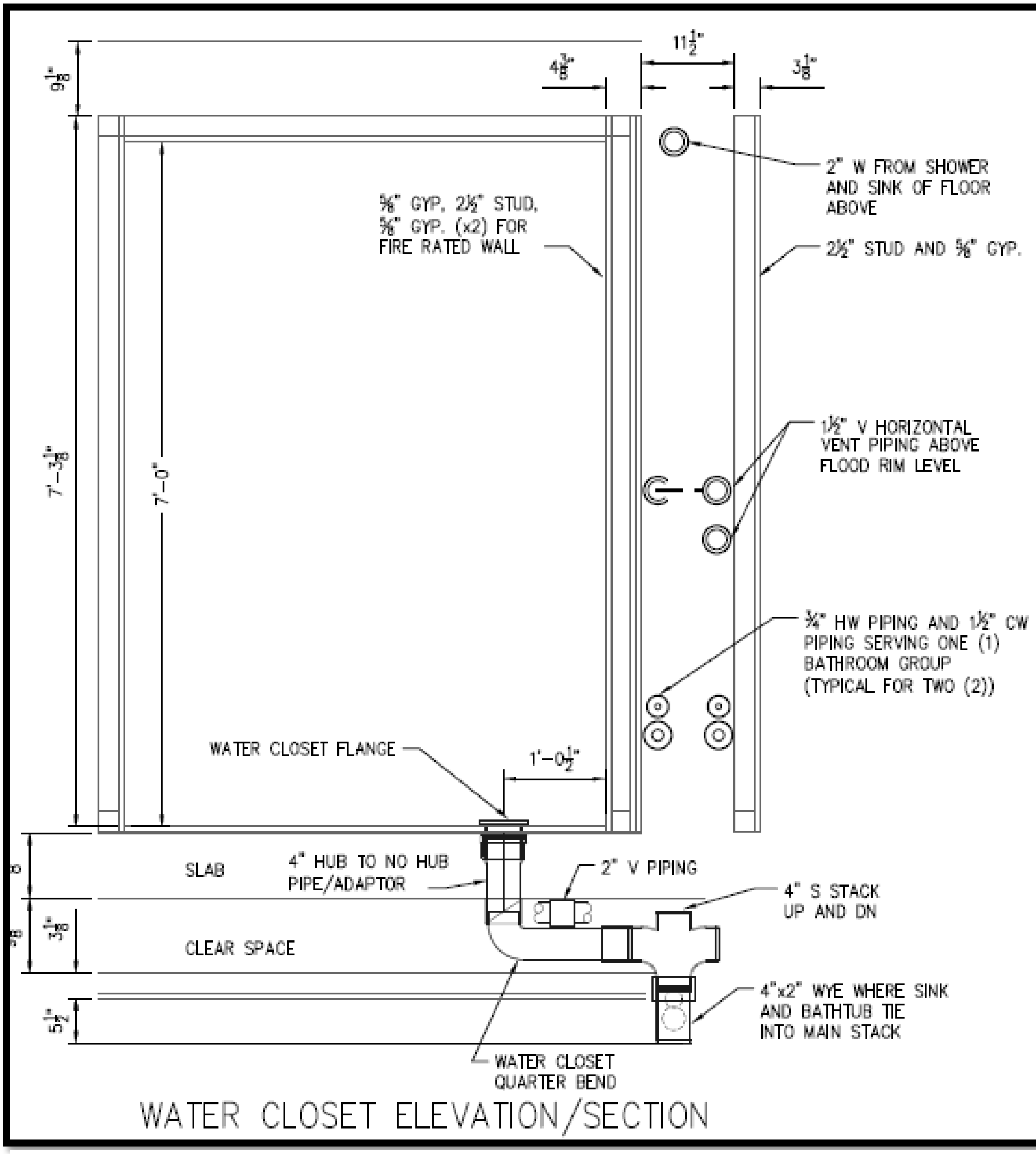


Figure 42: Typical Plumbing Connections (Mensh)

Once the pods are in their final location, they can be hooked up and tested for use. Fig. 42 shows a typical drawing of the necessary connections in order to successfully install the pods. The pods are typically installed from the top floor down to make the plumbing connection points more accessible from the floor below. Fig. 43 on the following page shows the plumbing connections being made for the pods on the floor above. Once the plumbing connections are made, the electrical and HVAC hookups can then be connected.

Figure 43: Plumbing Hookups (Mensh)

To finish the installation process, the pods need to be framed into the building. The exterior of the pods can be covered with sheetrock for the non-structural walls. The pods can also be secured to the floor using traditional framing nails or tapcon masonry screws. The pods to be used for the RTI consist of a fully finished bathroom interior, but the outside of the pod walls will need to be finished in the field. The main purpose for this decision is the sinks located on the exterior walls of the pods and to provide consistency in the quality of the work. Finishing the outside of the pod walls could create problems with differing levels of finish quality, so this can be avoided by performing this work in the field. Additionally, to ensure that the sinks are not damaged, the sinks will be installed in the field along with the exterior pod finishes.

Figure 44: Framing the Pods into the Building (Mensh)

Finished Products

The following pictures are a number of modularized bathroom units completed by Davis Construction:

Figure 46: Hilton Hotels (Mensh)

Figure 45: Holiday Inn (Mensh)

Schedule Analysis

The main driver for utilizing modularized bathroom units is to accelerate a project schedule, a benefit that is attempting to be obtained on the Fort Pickett Regional Training Institute project. According to Davis Construction, "Davis has experienced a construction schedule by as much as 20%." The reasoning for this is the major shift of work from the field to the manufacturing facility. Dave Mensch from Davis Construction stated that where built in place bathrooms take 30+ days from start to finish to construct, it only takes the site trades one hour to hook up the pods.

In order to evaluate how much work can be shifted off-site into Kullman's manufacturing facility, takeoffs were performed in Appendix E. These values were then used to estimate the percentage of the work associated with the 101 bathroom pods in comparison to the entire building, since the project's schedule was only broken into buildings and not areas. The estimated schedule reductions can be seen on the following page in 47. Although the group bathrooms were determined to be in the best interest of the project to be constructed in the field, the cement board and ceramic tile activities were able to be almost completely removed from the project schedule. The other huge schedule savings were associated with the doors, fixtures, electrical, and plumbing work. Where the pods did not make a tremendous impact was with the mechanical work, since the duct runs remained above the pods. The only mechanical activity that could be shifted into the factory was the installation of the grilles.

Estimated Schedule Reduction				
	Percentage Reduced	Old Duration	New Duration	Days Saved
Cement Board	90%	21	3	18
Ceramic Tile	90%	15	3	12
Plumbing Fixtures	50%	22	11	11
Door Frames	50%	25	13	12
Doors/Hardware	50%	15	8	7
Plumbing Rough-in	50%	25	13	12
Plumbing Piping Installation	50%	25	13	12
Metal Stud Wall Framing	30%	25	18	7
Insulate Walls	30%	11	8	3
Hang Drywall	30%	18	12	6
Finish Drywall	30%	59	42	17
Paint	30%	53	37	16
Electrical Rough-in	30%	52	37	15
Light Fixtures	20%	7	6	1
Power and Lighting Wiring	20%	30	24	6
HVAC Ductwork	5%	43	41	2

Figure 47: Estimated Schedule Reductions

Once the new durations had been calculated, it was then possible to use the existing fit-out schedule found in Appendix F to generate a new project schedule, which can be seen in Appendix G. Since all three buildings utilize nearly identical schedules with a one week lag from one building to the next, a schedule was created for Building 700. The schedule highlights activities that were introduced to the schedule in red, shortened activities in blue, and impacted activities in green. The new activities consisted of placing the pods in the buildings and then later moving them to their desired areas. The placement of the pods on the first level is scheduled to take place two days prior to the erection of the hollow-core plank floor system and at the end of the erection of the load bearing walls. By placing an average of 12 pods per day, the crew can place 24 pods per the given duration, where the buildings only have a maximum of 20 pods per floor. With a similar situation, the pods on the second level are erected two days prior to the erection of the roof trusses. Once the pods are placed in the building, the fit-out activities can begin around the pods. When the necessary partition walls and MEP work has been completed, the pods can be pushed into place, noted as the second group of pod activities on the proposed schedule. Both activities were determined to have minimal impact with the other work taking place, since the pod manufacturer crews are responsible for setting the pods and placing them appropriately.

The only other activity that needed to be considered when constructing the new schedule was the newly introduced concrete work. As mentioned earlier in the analysis, concrete depressions are needed to keep the pod floors at an equivalent height to the bedrooms. This means that additional work in the form of formwork must be introduced to the concrete activities. Using the detailed estimate from Appendix H, the depressions will take an additional two days per floor using one crew or one day using two crews. Since the additional work is so minimal, there is no need to change the actual schedule, since additional workers could be used to remain on the current core and shell schedule. Additionally, some work will be saved from having to pour less concrete. Where this additional work does need to be considered is in the cost analysis.

After considering the new durations, activities, and sequences, the schedule was found to save just over 8 weeks. The schedule acceleration results for the use of modularized bathrooms units can be observed below in Fig. 48.

Fit-Out Schedule Acceleration			
	Fit-Out Start Date	Fit-Out Finish Date	Duration (Days)
Bathrooms Built in Field	2/8/11	10/17/11	180
Bathroom Pods	2/8/11	8/19/11	139
		Total	41

Figure 48: Fit-Out Schedule Acceleration

Cost Analysis

The use of bathroom pods serves to accelerate the project schedule, but for the most part has had trouble making tremendous savings from a cost standpoint. Favorable conditions arise where repetitive designs and be replicated, allowing for great schedule gains and a reduction in project overhead on-site. If adequate time can be salvaged, the pods can not only be found to be desirable from a scheduling perspective, but as well as from a financial perspective.

The first item to consider within the cost analysis is the cost impacts due to using concrete slab depressions for the pods. Fig. 49 on the following page summarizes the results from the detailed cost estimate, which can be observed in Appendix H. The items highlighted in red are project cost savings through a reduction in material quantities, but the black items are additional costs. Although using the ½” depressions reduces the amount of concrete needed, the additional formwork creates a much greater cost impact. As a result, the depressions cost an additional $16,877 to the concrete work.

Cost Impact to Concrete Work			
	Quantity	Cost/Quantity	Total Cost
First Floor Bathrooms			
Concrete Depressions	45	$230	$10,350
Normal Weight Concrete	45	$18	$810
Placement	45	$5	$225
Finishing	45	$41	$1,845
Second Floor Bathrooms			
Concrete Depressions	56	$236	$13,215
Lightweight Concrete	56	$22	$1,232
Placement	56	$5	$280
Finishing	56	$41	$2,296
		Total Additional Cost	**$16,877**

Figure 49: Cost Impact to Concrete Work

The next item to consider is the cost of construction of the bathrooms themselves. After conducting a detailed estimate of the bathrooms using RSMeans, which can be seen in Appendix H, the bathrooms were found to cost $13,152 per bathroom. In addition, the estimate showed that 37% of the cost was allocated towards the labor and 63% of the cost towards the materials. The use of pods has the advantage of shifting work from the field to the factory, and although Dave Mensh stated that the savings from materials is typically nil, the labor used in factories is typically 25% cheaper in comparison to the field. As a result, the labor costs can be reduced $122,816 in the factory compared to the field. Another item to consider is cost of the additional materials, including cement board, metal studs, and metal floor plates. Referencing Appendix H, the cost of the additional materials was estimated to cost the project an additional $156,348. Shown in Fig. 50 below, the overall cost impact of constructing the pods in the plant will cost an additional $33,532.

Cost Impact to Bathrooms		
	Cost/Bathroom	Total Cost
Bathrooms Built in Field		
Labor	$4,866	$491,466
Material	$8,286	$836,886
Total	**$13,152**	**$1,328,352**
Bathroom Pods		
Labor (25% Savings)	$3,650	$368,650
Material	$8,286	$836,886
Additional Material	$1,548	$156,348
Total	**$12,628**	**$1,361,884**
Total Additional Cost	**$1,216**	**$33,532**

Figure 50: Cost Impact to Bathrooms

The last item to consider is the cost impact to install the pods in comparison to constructing them in the field. In order to move materials around the job site, a lull was rented for most of the project duration. By reducing the overall project schedule, this rental cost can be shortened by $42,800. In order to place the pods, a 25 ton crane will need to be rented with a two man crew to the set the pods. Overall, the cost impact of installation was a $15,619 savings, which can be seen below in Fig. 51.

Cost Impact to Installation			
	Cost	Cost/Quantity	Total Cost
Bathrooms Built in Field			
Lull	$5,350	8 Weeks	$42,800
		Total	$42,800
Bathroom Pods			
Crane (25 Ton)	$1,625	11 Days	$17,875
Pod Install Crew (2 Laborers)	$846	11 Days	$9,306
		Total	$27,181
		Total Cost Savings	$15,619

Figure 51: Cost Impact to Installation

Although the cost of construction is slightly higher using pods, the ability to accelerate the project schedule and save on general conditions results in an overall savings, which can be seen in Fig. 52 below. After investigating all of the influenced work from the use of the pods, the project has the ability to save an estimated $213,903.

Cost Impact of Using Pods		
	Unadjusted Cost	Adjusted Cost (Time=1.085) (Location=0.849)
Bathrooms Built in Field		
Cost of Construction	$1,328,352	$1,223,631
Lull	$42,800	$39,426
Deliveries	$13,272	$13,272
	Total	$1,276,329
Bathroom Pods		
Cost of Construction	$1,361,884	$1,254,520
Concrete Depressions	$16,877	$15,547
Crane	$17,875	$16,466
Pod Install Crew	$9,306	$8,572
Deliveries	$12,608	$11,614
General Condition Savings	$265,200	$244,293
	Total	$1,062,426
	Total Cost Savings	$213,903

Figure 52: Cost Impact of Using Pods

Recommendation & Conclusions

Although the use of bathroom pods has only been found to be favorable under select project types, the Fort Pickett Regional Training Institute project acts as an ideal candidate for implementation. Modularization aims to relocate the work off-site into a controlled work environment that ultimately results in a higher quality product and accelerated project schedule on-site. Pods also provide the opportunity to gain LEED points through the use of different construction strategies and materials.

As expected, the project schedule was able to be reduced by eight weeks, which means that the Barton Malow can distribute the project team to other necessary projects two months sooner. This schedule acceleration also greatly benefits the Virginia Army National Guard by allowing them to occupy the buildings at a more convenient time.

Modularization is typically tough to accumulate a cost savings, but due to the repetitive nature of the design and the quantity of the pods, the project was estimated to save $213,903. In addition to this savings, Barton Malow is also able to shorten the construction loans, open up more bonding capacity for other work, and reduce the chance of vandalism and theft on-site. After reviewing all of the influenced areas of construction, it is very much in the interest of Barton Malow and the Virginia Army National Guard to implement the use of modularized bathroom units on the Regional Training Institute.

Analysis 2: Implementation of Short Interval Production Schedules (SIPS)

Problem Identification


Figure 53: Hollow-core Planks

The Fort Pickett Regional Training Institute is composed of three billeting buildings, which creates an ideal opportunity for phasing, but a heightened concern for scheduling and crew balancing. With so many precast and prefabricated elements being utilized throughout the construction process, there must be greater coordination and planning to ensure that the schedule remains on pace. Although there are a number of critical activities, none play as an important of a factor as the precast-hollow core planks. Following the erection of the first floor's load bearing walls, the precast hollow-core planks are to be set, which makes the entire schedule dependent on a timely activity duration. Without the planks in place, the topping slab cannot be poured, the second floor's load bearing walls cannot be erected, and the building enclosure cannot begin.

Research Goals

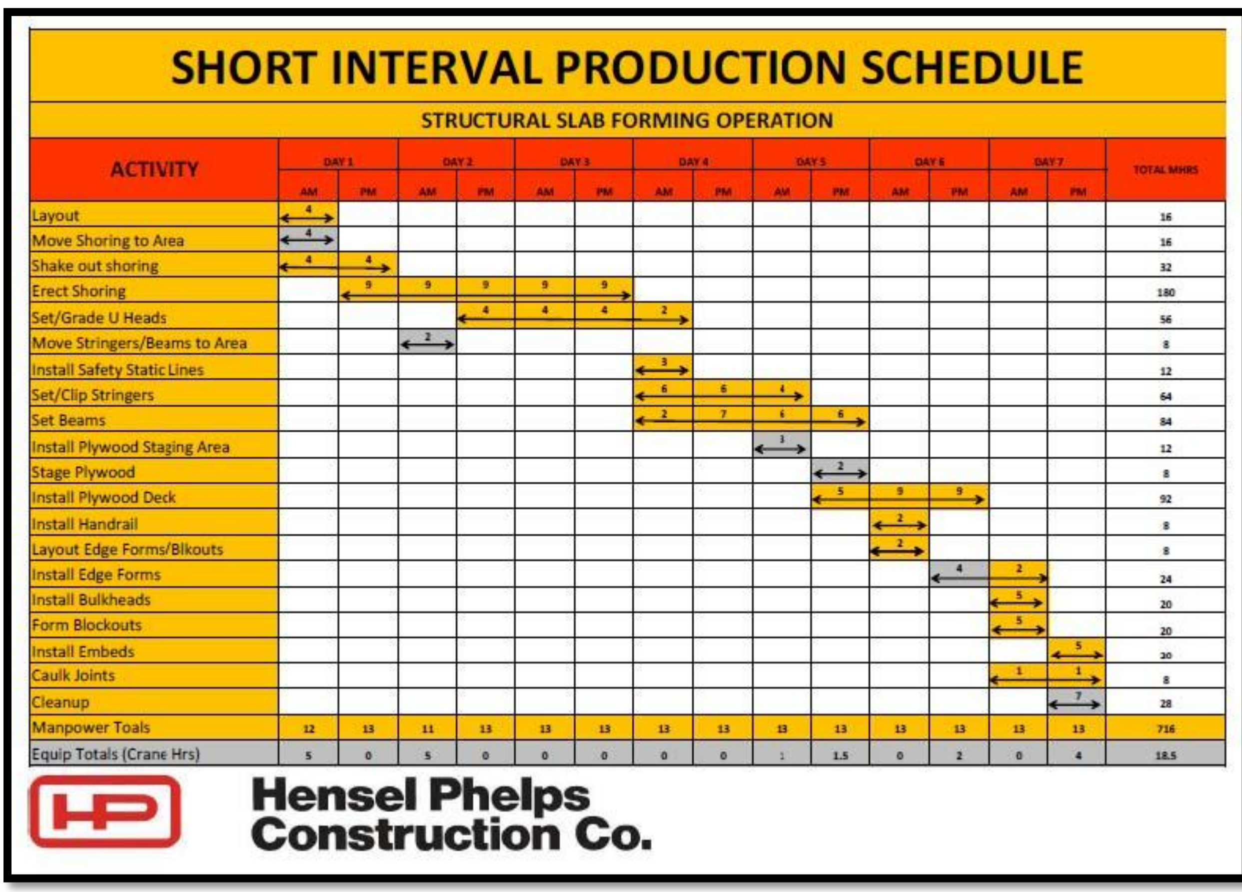
To investigate the use of SIPS on past construction projects, specifically the Pentagon Renovation by Hensel Phelps. To develop an implementation strategy for precast hollow-core planks on the Fort Pickett project with consideration to the current project schedule, manpower, and constraints. To conduct a feasibility study and analyze the financial, coordination, and schedule impacts associated with utilizing SIPS on the RTI project.

Background Information

In order mitigate the scheduling and crew balancing problems with the precast hollow-core planks, short interval production scheduling (SIPS) will be implemented on the Fort Pickett project. SIPS take a project schedule and break the task into smaller and more detailed items, which can include crews, crew sizes, and durations. The SIPS are manufactured using input from the construction management team and responsible Subcontractor's foremen, which creates a more accurate depiction of the time to be allotted for tasks. Utilizing SIPS has the potential to greatly increase coordination on the project by designating work areas and providing a better detailed schedule of work. This gives the workers a clear depiction of exactly where they are to be at any given part of the day, eliminating inefficiencies and stoppages in work.

Traditional SIPS

Within the idea of short interval production scheduling, there are two different methods, traditional and non-traditional. Traditional SIPS typically deal with one process, which encompasses only one or two contractors. The schedule is man and material loaded and displays shorter durations, since the schedule is composed of less work. Traditional SIPS aim to help level manpower and material usage, but are not always perfect in doing so. They are best used for assembly line or repetitive sequences, such as installing precast wall panels or floor planks. Although the schedule is structured much deeper than a typical project schedule, traditional SIPS do not maintain consistent time segments, which require a slightly greater dedication to management than the non-traditional method. Shown below in Fig. 54 is a traditional weekly SIPS schedule of structural slab forming provided by Hensel Phelps. The activities are displayed on the left side of the schedule with their respective man and equipment hours shown under the days. The number in each activity box represents the manpower allocated for the given time segment. The right column represents the total manpower needed for a given activity. The two bottom rows show the total manpower and total equipment required each day.



SHORT INTERVAL PRODUCTION SCHEDULE

STRUCTURAL SLAB FORMING OPERATION

ACTIVITY	DAY 1		DAY 2		DAY 3		DAY 4		DAY 5		DAY 6		DAY 7		TOTAL MHRS
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	
Layout	4														16
Move Shoring to Area	4														16
Shake out shoring	4	4													32
Erect Shoring		9	9	9	9	9									180
Set/Grade U Heads				4	4	4	2								56
Move Stringers/Beams to Area			2												8
Install Safety Static Lines							3								12
Set/Clip Stringers							6	6	4						64
Set Beams							2	7	6	6					84
Install Plywood Staging Area									3						12
Stage Plywood										2					8
Install Plywood Deck										5	9	9			92
Install Handrail											2				8
Layout Edge Forms/Blkouts											2				8
Install Edge Forms												4	2		24
Install Bulkheads													5		20
Form Blockouts													5		20
Install Embeds														5	30
Caulk Joints													1	1	8
Cleanup														7	28
Manpower Toals	12	13	11	13	13	13	13	13	13	13	13	13	13	13	716
Equip Totals (Crane Hrs)	5	0	5	0	0	0	0	0	1	1.5	0	2	0	4	18.5

Hensel Phelps Construction Co.

Figure 54: Traditional Weekly SIPS (Sandeen)

In addition to the weekly SIPS displayed above, SIPS can be broken down into further detail by outlining individual days. Although this method is incredibly detailed, if the SIPS is being applied to a favorable repetitive process, the schedule should be able to be replicated for every area of the project site. The following image, Fig. 55, shows a traditional daily SIPS with the day detailed by activity from the project's typical 6:00 AM - 3:00 PM work day.

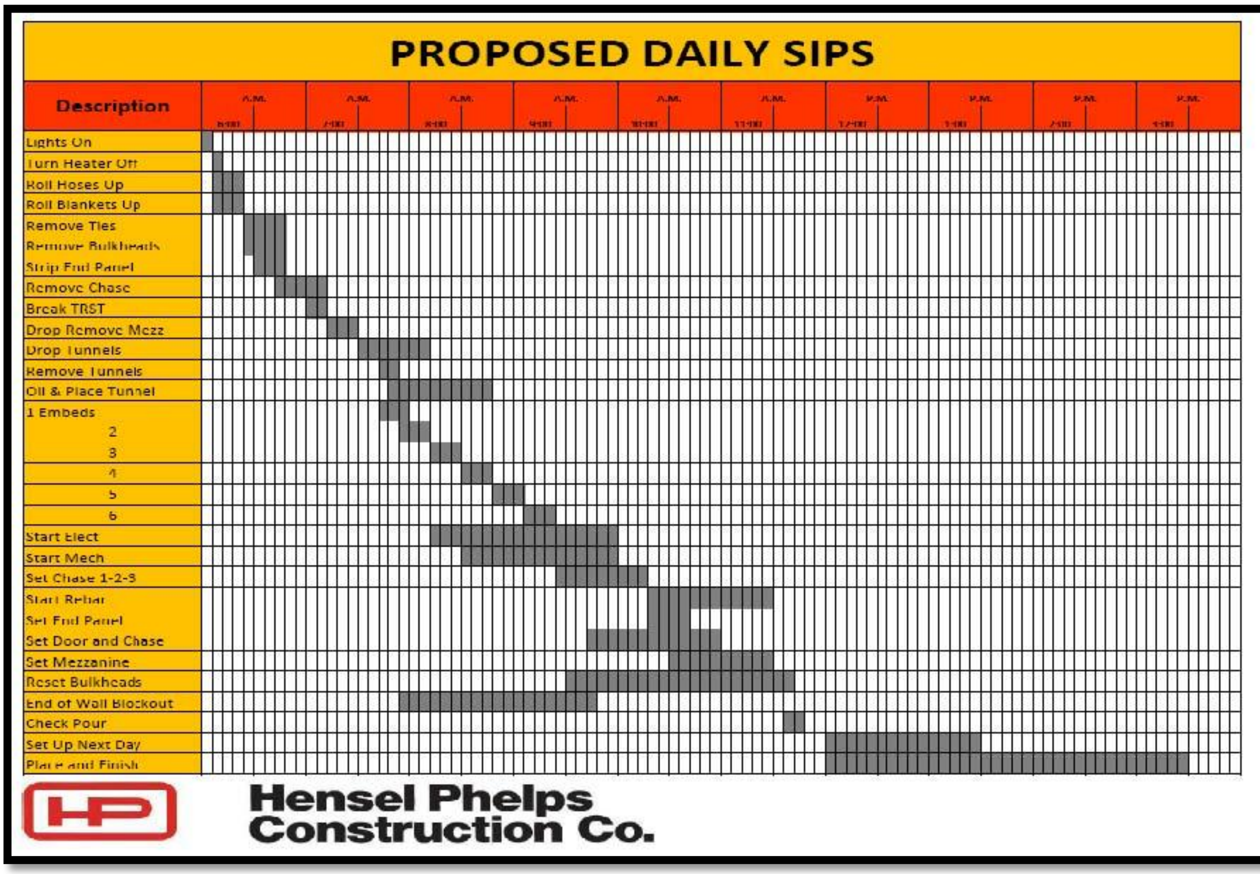


Figure 55: Traditional Daily SIPS (Sandeen)

Non-Traditional SIPS

Although SIPS have been used for some time now, a recent break from the traditional method has begun to gain momentum in the construction industry. Non-traditional SIPS demonstrate a much more detailed and complex scheduling practice by involving many trades and activities with a designated area. Due to the greater work activities associated with non-traditional SIPS, these schedules tend to demonstrate longer over all durations. Differing from traditional SIPS, they use consistent and incremental schedule time blocks, acting as similar to a parade of trades or train. These schedules are extremely concerned with getting the activity completed on time before moving on to the next area, since a disruption in work could completely bring the flow of work to a standstill. Because of the flow of work and number of activities that can be included in a non-traditional SIPS, they act as ideal candidates for finish work activities.

Shown in Fig. 56, a non-traditional SIPS was manufactured for the Pentagon Renovation project, which will be addressed later in a case study analysis. The schedule is broken down into designated areas with time blocks allocated to each area on any given day. The blocks are shown with different colors and number, which depict the different crews and contractors at that given time and place. By referencing the key below the schedule, each block can be matched up with its respective crew (Sandeen).

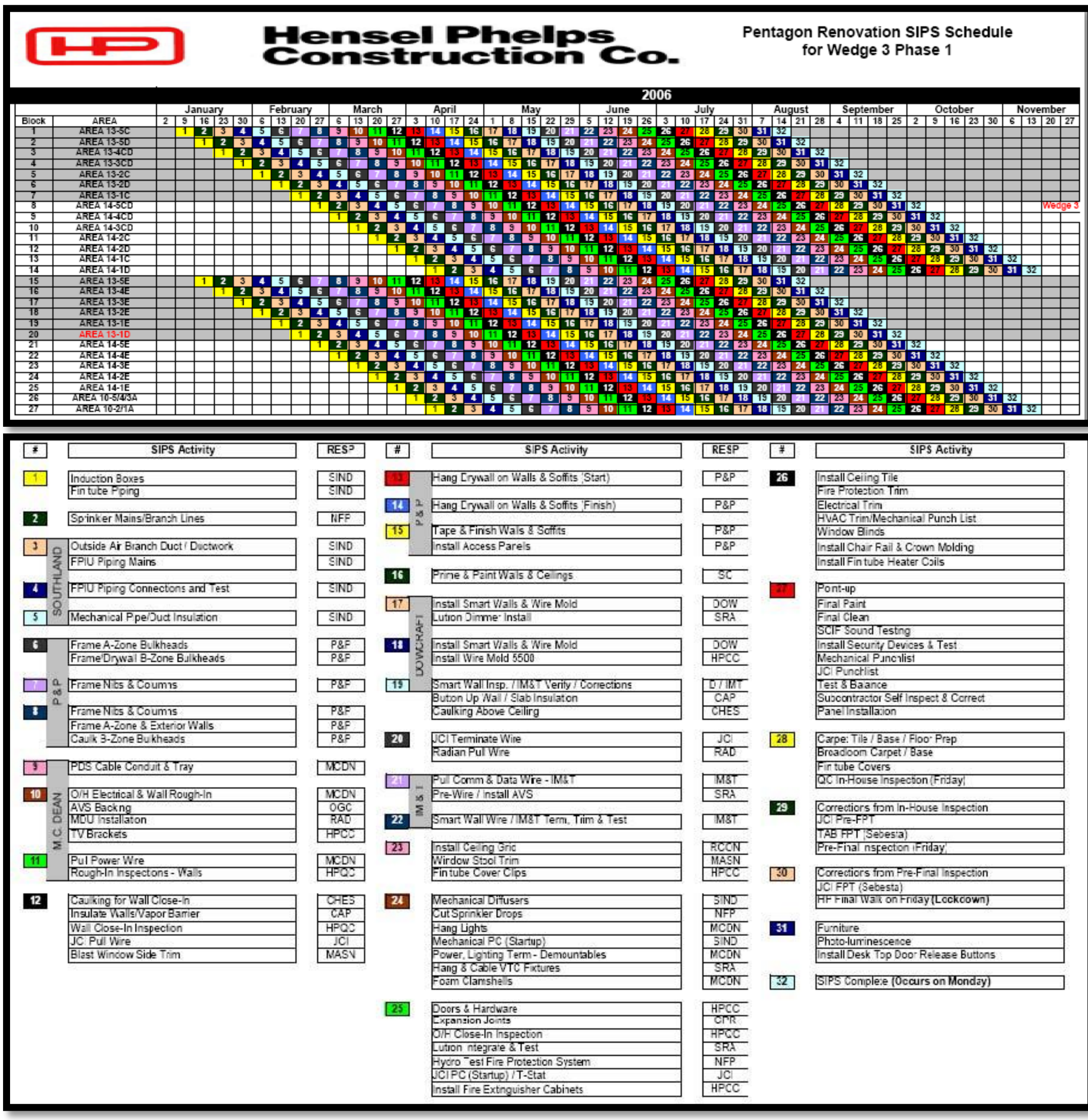


Figure 56: Non-Traditional SIPS (Sandeen)

Due to the added value SIPS produce on most projects, Hensel Phelps has taken advantage of every opportunity available to implement this scheduling technique, particularly building designs that feature repetitive sequences; these include prisons, dormitories, and hotels. They have successfully incorporated SIPS into a number of projects, specifically the Pentagon renovation project by shaving four years off of the total project schedule.

Case Study (Pentagon Renovation)
The Pentagon acts as the largest low-rise office building in the world, and until recently was one of the most outdated. Constructed in 1941 in preparation for World War II, the building had very little upgrades to the mechanical, electrical, and plumbing systems, making the facilities inadequate to meet today's technological standards. Under the guidance of the U.S. Army Corps of Engineers, Hensel Phelps was contracted to renovate wedges 2 through 5 on September, 14, 2001. With the contract being awarded only 3 days after the attack on the Pentagon, Hensel Phelps was forced to accelerate the project schedule in order to meet the office space limitations caused by the plane crash. The renovation was originally to be completed in 14 years, but after implementing a number of innovative practices, particularly SIPS, the schedule was reduced to only 4 years (Rich).

Hensel Phelps started by resequencing the design practices to support construction. They looked to the original schedule and manufactured a SIPS for the repetitive work. They grouped related activities into five-day work weeks that allowed the construction crews to flow smoothly from one area to the next. The crews were organized into a SIPS train, which progressed through the entire process of activities until the work was completed. In addition, signs were posted in each designated area labeled with the week and activities that were to be completed that week, which can be seen in Fig. 57 on the right. By posting the signs and schedules in each area throughout the building, the workers were completely aware of what was to be completed on any given week.

Figure 57: Sign for SIPS Activity for Area (Sandeen)

Although the project was incredibly successful by reducing the time of work by 10 years, there were a number of lessons learned on the project. One of the first lessons was the switch from the 5-day work week (M-F) to the 4-day work week (M-Th). Initially, it allowed for flexibility and was beneficial for both groups, since the weekends could be used as overtime for the craftsmen, but was later seen as a burden, since inspections were often pushed to the start of the next week. By switching to the 4-day work week, inspections were able to take place on Friday, as well as the movement of material and equipment in and out of the building.

Another problem incurred was the removal of manpower from the SIPS crews in order to work on punch list items. In order to counter this problem, Hensel Phelps did not allow non-SIPS work to draw on SIPS labor. The trades were forced to bring in additional manpower to maintain adequate work crews for both tasks. In addition, composite teams were composed from all of the subcontractors and were used to take on areas that needed addressed.

After finding a number of missing things to rule the room as complete, which created an extensive punch list, Hensel Phelps had to develop a system to counter the problem. Hensel Phelps had the Subcontractors create an inspection check sheet along with the Hensel Phelps' Quality Control Manager to use as an inspection on Friday each week. In addition, a $25 charge was docked for each flagged item. The system allowed for the Subcontractors to recoup the charges if the items were completed as needed.

One of the biggest lessons learned was how to properly deal with the schedule around holidays. To deal with this dilemma, Hensel Phelps created a float week to counter long holidays, such as Thanksgiving and Christmas. Additionally, they created extra SIPS areas to handle the larger floor areas. This allowed the project to remain on schedule and not throw off the flow of work (Sandeen).

Subcontractor Buy-in

Although SIPS appear to be incredibly advantageous to any project, the success of their use rests with the responsible Subcontractors. Many Subcontractors struggle to buy-in to methods that deter them from their traditional techniques, but there are a number of beneficial reasons for them to support the SIPS. The biggest reason is the increase in productivity of the trades. Workers no longer waste time trying to decide where and when to be, but rather they know exactly what they are to be doing by following the signs and schedules posted throughout the buildings or workspaces. Using SIPS helps maintain crew sizes, which puts pressure on all of the workers to maintain their pace and keeps a focus on areas of need. Problematic areas are recognized much sooner and areas are addressed at a schedule time, so that areas can be closed out sequentially. Also, having a greater order of coordination can help aid in regularized material deliveries, which can bring any project to a halt without the proper materials on-site (Sandeen).

Implementation

In order to generate a SIPS for the hollow-core planks, there are a number of guidelines to consider prior to piecing a schedule together. The first thing to consider is the type of SIPS to use. Since the process is repetitive and only involves Gate Precast, the hollow-core plank Subcontractor, the use of traditional SIPS is the most favorable option. It allows for varying time segments and greater fluctuation between crews and work areas, something that would be beneficial to Gate Precast.

The next thing to review is the project schedule, which should be examined for start and finish dates, milestones, problematic areas, and holidays. Using the most accurate schedule to the actual time of the hollow-core plank erection sequence found in Appendix I, Fig. 58 below shows the following dates associated with erecting the hollow-core planks for each building, but does not include the grouting, installation of rebar, and other miscellaneous items.

Hollow-core Plank Erection Dates (Not Including Grout, Rebar, etc.)				
	Side	Duration	Start	Finish
Building 700	North	3	11/18/10	11/24/10
	South	3	11/29/10	12/1/10
Building 500	North	3	12/6/10	12/8/10
	South	3	12/10/10	12/14/10
Building 600	West	3	12/13/10	12/16/10
	East	3	12/17/10	12/22/10

Figure 58: Hollow-Core Plank Erection Dates

Barton Malow believed it was in the best interest of the project to phase the construction of the three barracks. By phasing the buildings, work was able to flow fluidly from building to building, which can be seen in Fig. 59 to the right and in greater detail in Appendix J. It also served to mitigate the learning curve and created competition amongst the buildings. Although the phasing can be seen above by reviewing the dates, the schedule became much more compressed during the construction process with only a one week lag between buildings. To give the most accurate representation of the erection process of the hollow-core planks, I utilized the start date for Building 700 and then staggered each building by approximately one week. By deploying this strategy, it gives the closest

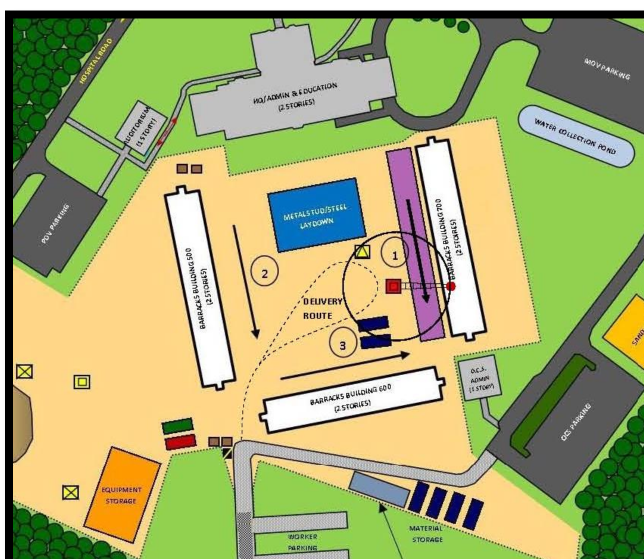


Figure 59: Hollow-Core Plank Erection Site Plan

depiction and most usable SIPS for the project team at the time of construction, a method that is typical of the SIPS generation process.

Another item to consider within the schedule is the Thanksgiving holiday. The project team decided to allocate more days to the construction of Building 700 for this reason, but I believe it will also serve as a buffer for catch-up work due to the learning curve associated with the first building. Using Barton Malow's buffer, I decided to utilize the same strategy and built in Thursday and Friday of that week as non-scheduled work.

The schedule must allow catch-up time, so that flow of construction is not disrupted by one activity that is behind. To incorporate a buffer into the schedule, I decided to implement 5-8 hour days. This eliminates Gate Precast, the Subcontractor responsible for the hollow-core planks, from having to work overtime. Additionally, if the crew falls behind, they can switch to ten hour days or work on Saturdays. I also decided to build in clean-up time segments to create a cleaner and safer job-site. At the end of each week, typically Friday, 1-2 workers will be pulled from the crew to focus on job-site clean-up. If the site is cluttered with scrap material, the flow of work could potentially be hindered or someone could be injured, resulting in a costly stoppage in work and the well-being of the workers.

One of the next tasks to perform was to set up definable and consistent work areas. By doing so it helps to maintain set crew sizes, regular material deliveries, storage plans, housekeeping accountability, and crew flow. The RTI consists of three buildings, but for the purpose of sequencing the work more effectively, each building will be broken into two regions, which are:

- Building 700 North
- Building 700 South
- Building 500 North
- Building 500 South
- Building 600 West
- Building 600 East

The next step is to define areas that are not repetitive. For this sequence, there are limited disruptions in the flow of work with the only setbacks coming at the beginning and end of the plank erection process for the entry ways. The buildings feature exterior stair cases, which require smaller hollow-core planks and are only one plank across, opposed to three across. In addition, consideration needs to be given to the mobilization/demobilization of the cranes. To account for the crane, time will be given for mobilization to start the day at the beginning of the erection process and at the end of the day for mobilization at the completion of the erection process. Access routes can be detrimental to work flow, but the campus is so large that there are no expected delays due to traffic.

Once the general time frame has been established and problematic areas have addressed, it is then time to begin creating the SIPS by investigating the original project schedule, crew descriptions, and work quantities. Using work quantities from the hollow-core plank submittals in Appendix K, durations were obtained for setting the planks, placing the rebar, and grouting the joints. The most critical piece of information was the weight of the planks, information crucial for selecting the correct crane to utilize. After speaking with Brian Bass of Barton Malow, he stated that Gate Precast used a 75 ton mobile truck crane, a crane more than suitable to carry the heaviest possible plank, which was only 5,515 lbs.

The next step was to reach an appropriate crew to estimate the work that needed to be performed. The crew utilized by Gate Precast, seen in Appendix L, was composed of truck drivers, one equipment operator, one foreman, and four journeymen. In addition to these workers, a separate crew worked behind the plank setting crew; this crew consisted of two rodman and two grouters. In order to replicate the crew that installed the planks, I altered the very similar crew proposed in RS Means, which can be seen in Appendix M, by using this output for both the grouting and setting of the planks, as well as adding two rodmen. This alteration created an identical work sequence and allowed me to include the reinforcement into the takeoffs, since RS Means did not include placing rebar in their calculations.

Once a crew was established, I then found the amount of reinforcement that needed to be installed using the hollow-core plank submittal, where the takeoffs can be seen in Appendix N. With the rebar quantities found, durations could be found using the outputs from RS Means in Appendix O. The results for the duration of each activity can be found below in Fig. 60.

Hollow-Core Plank Activity Durations			
	Quantity	Daily Output	Days
Crane Mobilization	1.11 Ea.	7.20 Ea.	0.14
Crane Demobilization	1.11 Ea.	7.20 Ea.	0.14
Set Planks & Grout (500/700)	20,455 SF	3,200 SF	6.39
Set Planks & Grout (600)	17,977	3,200 SF	5.62
Install Rebar (500/700)	1.80 Ton	1.45 Ton	1.24
Install Rebar (600)	1.60 Ton	1.45 Ton	1.10

Figure 60: Hollow-Core Plank Activity Durations

Using the durations calculated, each activity in each of the six building areas could be assigned times. As you can see on the following page in Fig. 61, there is an adequate buffer into each of the three buildings. Although the planks take just over two days to set at each part of Buildings 500 and 700, this number is slightly skewed, since the crews needed to be adjusted to give the most accurate numbers. Setting the planks takes a significant amount of time more than any other activity, so the Foreman could allocate part of the reinforcement and grout crews to the plank setting crew if need be, since they all work for Gate Precast. Regardless, there is a significant buffer built into to account for a learning curve and ensure quality work.

Typical Work Sequence				
	Activity	Days Needed	Days Given	Buffer
Building 700 (N/S)	Mobilize Crane	0.14*	0	0.86*
	Set Planks	2.13	2	-0.13
	Demobilize Crane	0.14*	0	0.86*
	Install Rebar	1.24	2	0.76
	Grout	1.07	2	0.93
		4.44	**6**	**0.56**
Building 500 (N/S)	Mobilize Crane	0.14*	0	0.86*
	Set Planks	2.13	2	-0.13
	Demobilize Crane	0.14*	0	0.86*
	Install Rebar	1.24	2	0.76
	Grout	1.07	2	0.93
		4.44	**6**	**0.56**
Building 600 (W/E)	Mobilize Crane	0.14*	0	0.86*
	Set Planks	1.87	2	-0.13
	Demobilize Crane	0.14*	0	0.86*
	Install Rebar	1.10	2	0.76
	Grout	0.94	2	0.93
		3.91	**6**	**2.09**

***Denotes Activity That Does Not Impact Buffer**

Figure 61: Typical Work Sequences

Once adequate time segments were determined for a typical building area sequence, the SIPS was able to be compiled. A typical weekly SIPS for the four week hollow-core plank erection process is shown on the following page in Fig. 62. The goal was to level the crews as evenly as possible to maintain flow, but there were a few miscellaneous activities that created a few extra needed personnel, such as laying out the upcoming building. In order to see the entire four week SIPS for the hollow-core planks, refer to Appendix P.

Following the creation of the SIPS, there are a few things that must be done prior to its use. It is important to have all of the as-built and coordination drawings before beginning construction. On top of this, there should have been a considerable amount of coordination with Gate Precast and the Barton Malow project team. Typically, Barton Malow holds weekly Subcontractor meetings to make the responsible parties aware of updates and provides two week notices for their work to begin. Materials should all be present on-site, which includes reinforcement, grout components, mixer, necessary tools, and most importantly, the hollow-core planks. Part of the risk mitigation with the material handling will be addressed in Analysis

4. Last but not least, all administrative issues need to be resolved. The RTI is located on a military base, so making sure that all of the personnel have cleared to work is a key concern.

Short Interval Production Schedule											
Week of 11/22 - 11/26											
Subcontractor: Gate Precast											
Activities: Hollow Core Planks											
Activity	Monday		Tuesday		Wednesday		Thursday		Friday		Total Man Hours
	AM	PM	AM	PM	AM	PM	AM	PM	AM	PM	
Install Rebar - 700 North	2	2	2	2							32
Grout - 700 North	2	2	2	2							32
Mobilize Crane - 700 South	1										4
Set Planks - 700 South	5	6	6	5							88
Demobilize Crane - 700 South				1							4
Layout - 500 North			2				Thanksgiving Holiday				8
Layout - 500 South				2							8
Install Rebar - 700 South					2	1					12
Grout - 700 South					2	1					12
Mobilize Crane - 500 North					1						4
Set Planks - 500 North					5	6					44
Cleanup						2					8
Manpower Totals	10	10	12	12	10	10	0	0	0	0	256
Equipment Totals (Crane Hrs)	4	4	4	4	4	4	0	0	0	0	24

Figure 62: Typical Weekly SIPS

Results

After reviewing the updated schedule, the implementation resulted in a drastic acceleration of the project schedule of 15 total day or 11 work days by moving the finish date from 12/25/10 to 12/10/10. Since this activity is along the critical path, this acceleration allowed work to begin over two weeks sooner on the exterior sheathing, shear walls, second floor load bearing stud walls, and topping slab. Since the acceleration of the schedule was attributed more to the resequencing and reorganization of the work, rather than the amount of work that needed performed, the labor hours required to perform the work remained the same. Where there were significant savings was within the crane rentals and project overhead, which can be seen in Fig. 63. It was assumed that the crane remained on-site during these stagnant times in the phasing between buildings. Although the crane remained on site during the weekends, it was more than likely not charged to the project, since it was consistent work during the week. By reducing the time that the crane was on-site by 11 work days, the project was able to save an estimated $39,325. In addition, referencing the General Conditions Estimate in Appendix C**,** the project team was able to reduce its stay on-site, which allowed Barton Malow to reduce its overhead by $78,199. Overall, this results in a total savings of $117,524.

Cost Savings		
	Unadjusted Cost	Adjusted Cost (Time=1.085) (Location=0.849)
Mobile Truck Crane	$3,575.00	$39,325
Project Overhead	$72,929.88	$78,199
	Total Cost Savings	$117,524

Figure 63: Cost Savings

Recommendation & Conclusions

The Fort Pickett Regional Training Institute project features a complex sequence of work, innovative building practices, and a number of critical path activities, but nothing was more influential to the project's success than the erecting of the precast hollow-core planks. The planks serve as an ideal candidate for the use of traditional SIPS by featuring a repetitive sequence from one building area to the next. Although the use of SIPS requires a considerable amount of coordination, its benefits far outweigh the work put into the system. After conducting a feasibility study on the RTI, the use of SIPS cut an estimated 11 work days off of the project schedule and saved $117,524, leading me to believe that it is well in the best interest of Barton Malow and the RTI to utilize a short interval production schedule on the installation of the precast hollow-core planks.

Analysis 3: Feasibility of Precast Exterior Façade Panels

Problem Identification

The billeting buildings feature a simplistic building construction means with a limited amount of complex building systems. Although the building designs are not overly complicated, there are a number of items that strongly pertain to the success of the project along the critical path of the schedule, particularly the building enclosure.

The veneer is made-up of precast concrete lintels, smooth-face CMU block, and split-face CMU block, which varies in size, color, texture, pattern, and mortar. This use of a variety of different elements created a complicated condition of extreme planning, material preparation, and material storage practices. The mason held a heavy dependence on the laborers to provide the correct materials, so that their work flow was not interrupted. In addition to the complexity of the design, a critical design change setback the erection process. The top course utilized split-face CMU, which created an uneven joint between the roofing soffit and block, a condition that was considered aesthetically unappealing to Barton Malow Design. In order to correct this flaw, a design change switched the block from split-face CMU to split-face CMU, but this change did not come without a costly schedule impact.

On top of the difficult design conditions, the erection process created a number of complications with building accessibility for safety and material delivery purposes. In order for the masonry to be constructed on the second floor, the stairs could not be set, which created unfavorable working conditions for workers to get to the second floor. According to OSHA regulations, there must be two usable exits in every construction area. In order to correct this problem, Barton Malow constructed temporary ladders to windows on the sides of the building. This served as a temporary solution, but drastically impacted the work flow. Due to the magnitude of the work involved, constructing the curtain wall on-site presented a lengthy duration of 50 days per building, which did not even include caulking of openings, cleaning, or punch list items. The curtain wall was incredibly complex and was the critical activity necessary for completion of the buildings, which made it a key concern for the project team.

Figure 64: CMU Facade

Research Goals

To investigate the effects of utilizing a precast exterior wall panel, opposed to the built in place CMU veneer. To conduct a mechanical and structural analysis of the impacts the precast panels make on the buildings. To develop an implementation strategy, including manufacturing, transporting, and erection of the panels. To investigate the feasibility of using alternative precast panels on the Fort Pickett Regional Training Institute project.

Background Information

To minimize the risk associated with completing the building enclosure in a timely manner, the use of precast panels will be investigated. Precast panels have the potential to significantly cut into the project's schedule, but with this reduction also come the introduction of a number of other variables. Manufacturing the panels off site typically results in cheaper labor costs, a safer work environment, better working conditions, and higher productivity. The use of precast panels will also shift the mentality of the design team by forcing them to consider the building enclosure earlier in the design phases. The work will be shifted to a controlled environment and will be performed in an earlier phase of the project, so that the panels can be erected as soon as the billeting buildings' structures are completed. By simultaneously manufacturing the panels off site, it will significantly shorten the project's schedule. There are a number of potential drawbacks that must be considered as well. Typically, precast panels are more expensive than constructing a CMU wall veneer in the field, due to shipping costs, erection equipment, and other costs. Outside of changing the variables associated with the enclosure, the panels will also affect the buildings' structures and mechanical properties. Using precast panels will alter the structural design of the billeting buildings from the change in loads and structural components holding the panels. The operating costs and mechanical properties of the building will be altered by negatively or positively impacting the buildings' operating performances. Overall, there are a number of items that will need to be thoroughly investigated to conclude if the use of precast panels is more beneficial to the project in comparison to the traditional field constructed CMU enclosure.

Project Constraints

Although the use of precast panels appears to be a logical strategy to accelerate the project schedule, there are a number of key constraints to overcome in order to successfully put the plan into action. The largest constraint faced by the Regional Training Institute project is the completion of the building structure. The billeting buildings are constructed using load bearing cold formed metal stud walls, precast hollow core plank floors, and cold formed metal framed roof trusses. In order to begin the erection process, the buildings' structures must be completed, so the building enclosure activities can begin. Another project constraint is simultaneous work of the roofing subcontractor. The site contains adequate space for favorable working conditions, but it is important to coordinate work with the roofing subcontractor to ensure that the panel erection process is not interfered with. The last major constraint is accessibility to the inside of the buildings, especially the second floor. The buildings were designed to host an exterior stair case at each end of the three buildings, a design that differs from typical designs that utilize interior stair wells and created a number of coordination problems. In addition, only a limited amount of exterior doors were utilized to heighten the security of the buildings, which only exacerbated the buildings' accessibility problems. Exterior doors can be seen in Fig. 65, where the red signifies the door placements around the buildings with doors located on both floors at the ends of the buildings and on the first floor at the center of the buildings.

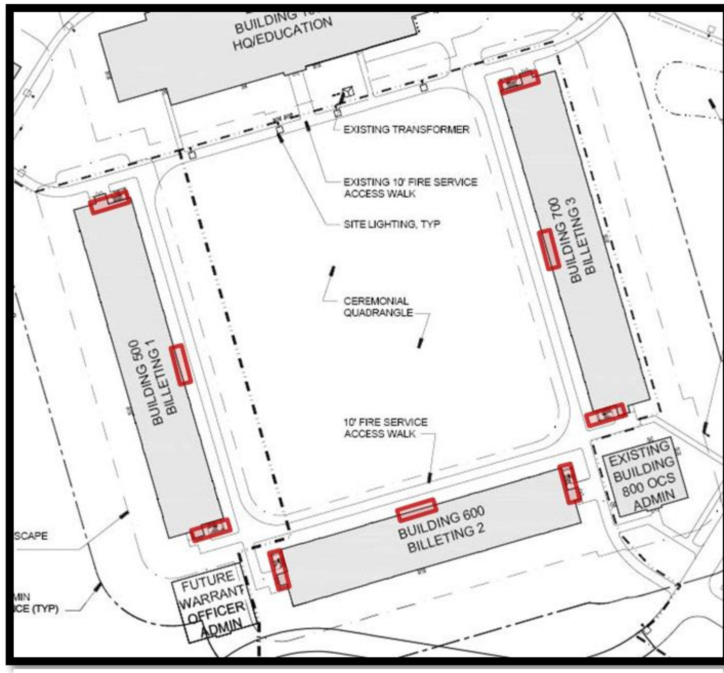


Figure 65: Building Entrances

Design

In order to provide a superior alternative to the built-in-place CMU veneer, it was absolutely critical to select the most appropriate panel design for the billeting buildings. The design process began by deepening my understanding of the manufacturing process using the aid of Mark Taylor, President of Nitterhouse Concrete Products. Mark explained that the most important design strategy to consider is the use of repetitive sizes. By designing the façade using similar panel widths and heights, it reduces coordination and costs associated with the concrete casting process. If the same concrete mold can be used for numerous panels, the cost of the manufacturing process is reduced drastically (Taylor).

The second major design item to consider was the size of the panels. The current façade system stretches two stories at a consistent height of 24' 4" along the length of the building and a sloping height at the ends of the buildings that range from 24' 4" to 29' 4". Mark recommended reducing the panels to as few as possible, specifically encompassing both stories with a single panel that stretches from the concrete foundation to the roof. By minimizing the amount of panels, it helps to reduce costs associated with additional panel connections, sealing the joints, panel formwork, and crane picks (Taylor).

Using the guidelines recommended by Mark, I proceeded with conducting a panel system designation and takeoff for each building, which can be seen in full in Appendix Q and R**.** To give an idea of the takeoff process, Fig. 66 to the right shows a limited depiction of how the panels were assigned. The building design created a number of design dilemmas, particularly the openings. Although the panels are erected without the windows and doors in place, the openings created a variety in the panels. Each of the buildings feature similar layouts, which allowed the same panels to be used at the ends of the building and near the edges, but the center of the buildings forced the incorporation of a number of unique panels. The panels at the center of the buildings are plagued with different mechanical exhaust, door, and window locations from one building to the next, due to the varying locations of the mechanical, electrical, and laundry rooms in the center of each building.

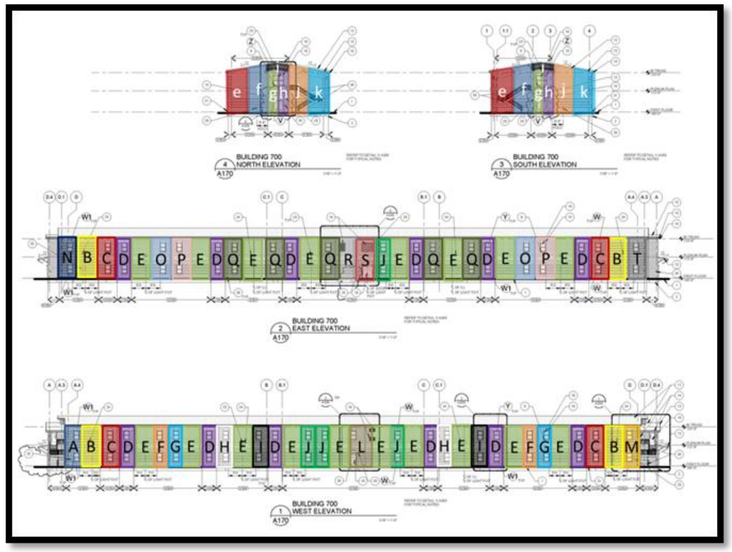


Figure 66: Panel Takeoff

After conducting the takeoff, each building featured design elements that allowed at least 15 panels to be shared on all three of the buildings. In addition to these panels, another 19 panels were required to meet the varying layouts of the center of each building. Although the center of the buildings created some complications, the design only featured 34 different panels that consisted of 7 different panel widths, a design that was said to be well suitable for a construction project of the $28M range, according to Mark of Nitterhouse Concrete Products. The following table shows a breakdown of the panels assigned to each building:

Panel Breakdown	
	Panels
Building 500	80
Building 600	70
Building 700	80
Total	230

Figure 67: Panel Breakdown

Once the panel sizes and quantities were determined, it was then necessary to consider the type of panel and architectural implications of the new system. The current system features a variety of CMU blocks and precast concrete lintels that consists of various textures and colors. In addition, the buildings are composed of bump outs and different colored horizontal strips along the length of the buildings to break up the regularity of the design. To get a better understanding of the build-out and design of the current CMU wall system, a wall section was constructed below in Fig. 68**.**

Build-Out Starting from the Inside:

- 6” Metal Studs
- ½” Exterior Sheathing
- Continuous Vapor Retarder
- 2” Rigid Insulation
- Air Space
- 4” Nominal CMU Veneer (8” at Bump Outs)

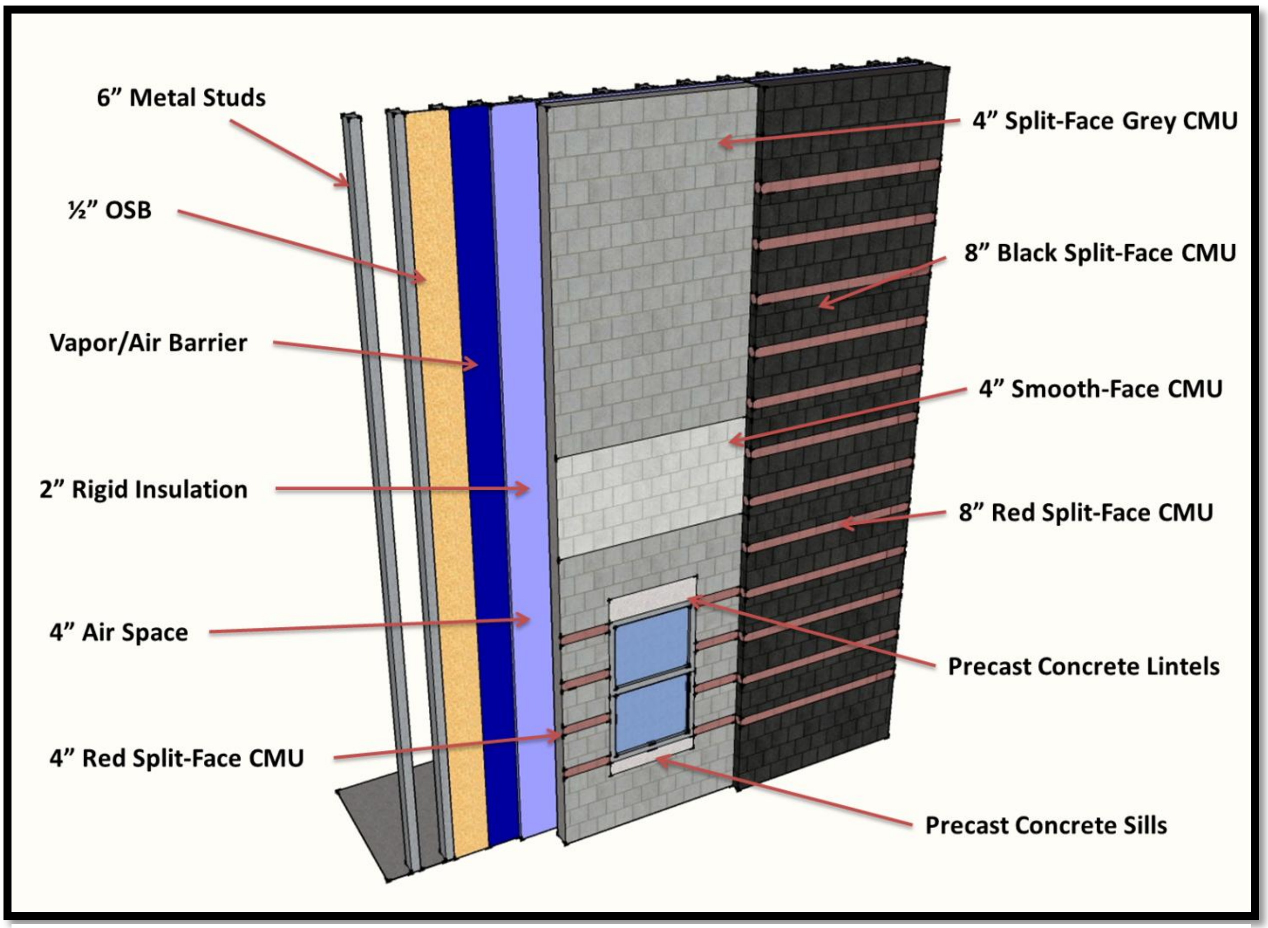


Figure 68: CMU Wall Design

In order to offer some type of visual variations in the panels, it was important to consider different finishes and systems, so that the client would remain satisfied with the end product. The first item considered was the type of system to use. The RTI was constructed with CMU finishes, but after speaking with Mark, it was found to be much more expensive to utilize precast concrete panels with CMU block embedded in the panels. The second item to investigate was the additional cost of using insulated sandwich panels. Although it was recommended to keep the existing 2" rigid insulation, it wasn't found to be in the best interest of the project team to use sandwich panels from a financial perspective, since the insulated panels added nearly $0.5M from the additional materials and separate pours necessary. After considering the various options, the uninsulated precast concrete panels were found to be the most appropriate panel for the Regional Training Institute based strictly from a financial stand point. The following table shows the considered panels and their respective attributes.

Panel Systems (59,700 SF)				
	Cost/SF	Thickness	Weight	Cost of Panel System
Concrete Panel	**$20**	**7"**	**88 PSF**	**$1,194,000**
Sandwich Panel	$30	9"	88 PSF	$1,791,000
Concrete Panel w/ CMU Embeds	$25	7"	88 PSF	$1,492,500
Sandwich Panel w/ CMU Embeds	$35	9"	88 PSF	$2,089,500

Figure 69: Panel Systems

Once the panel design was selected, the next step in the design process was the selection of finishes to incorporate in the panels, a step necessary to mitigate the architectural alterations in the design. Mark stated that using various colors or aggregates in the same panel was not a feasible option, but rather it was best to alter the entire color and add variations using different types of finishes, such as acid etched, sand blasted, or exposed aggregate. These different finishes can be observed in Fig. 70 below.

Figure 70: Panel Finishes (Gate)

It was found best to eliminate the bump outs in the new panel design, due to the increased load and cost associated with thickening the panels. Although the bump outs were eliminated from the design, those panels will still be colored black, which will cost an additional $0.50/SF, according to Fig. 71 below from Gate Precast. The remaining panels will retain a similar identity to the 4" CMU wall design that features 4 staggered 4" strips and a 40" strip near the top. Although these strips consisted of varying CMU colors and textures in the original design, the new design will utilize a sand blasting finish to give the panel a varying appearance. Since the current design features 5' of horizontal strips per linear foot, the grey panels will cost an additional $3.50/LF ("Gate Precast").

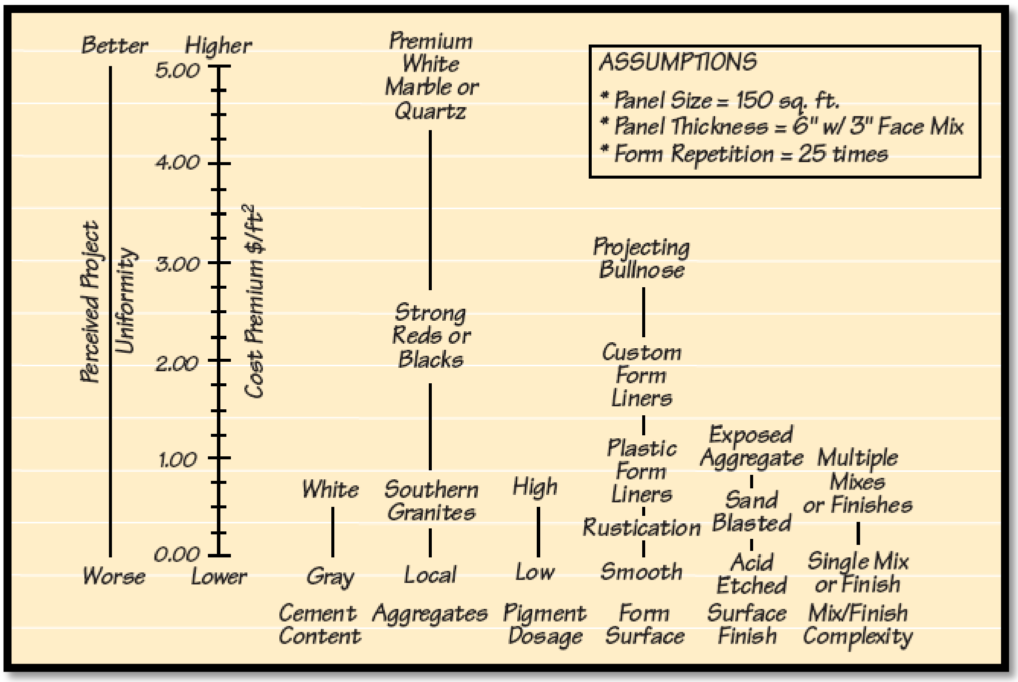


Figure 71: Additional Finish Costs ("Gate Precast")

By utilizing the 7" precast concrete panel with various finishes, the architectural appearance of the building was able to be retained. The proposed precast panel system utilizes the following build-out, which can be seen in Fig. 72 below.

Build-Out from the Inside:

- 6" Metal Studs
- ½" Exterior Sheathing
- Continuous Vapor Retarder
- 2" Rigid Insulation
- Air Space
- 7" Precast Concrete Panels

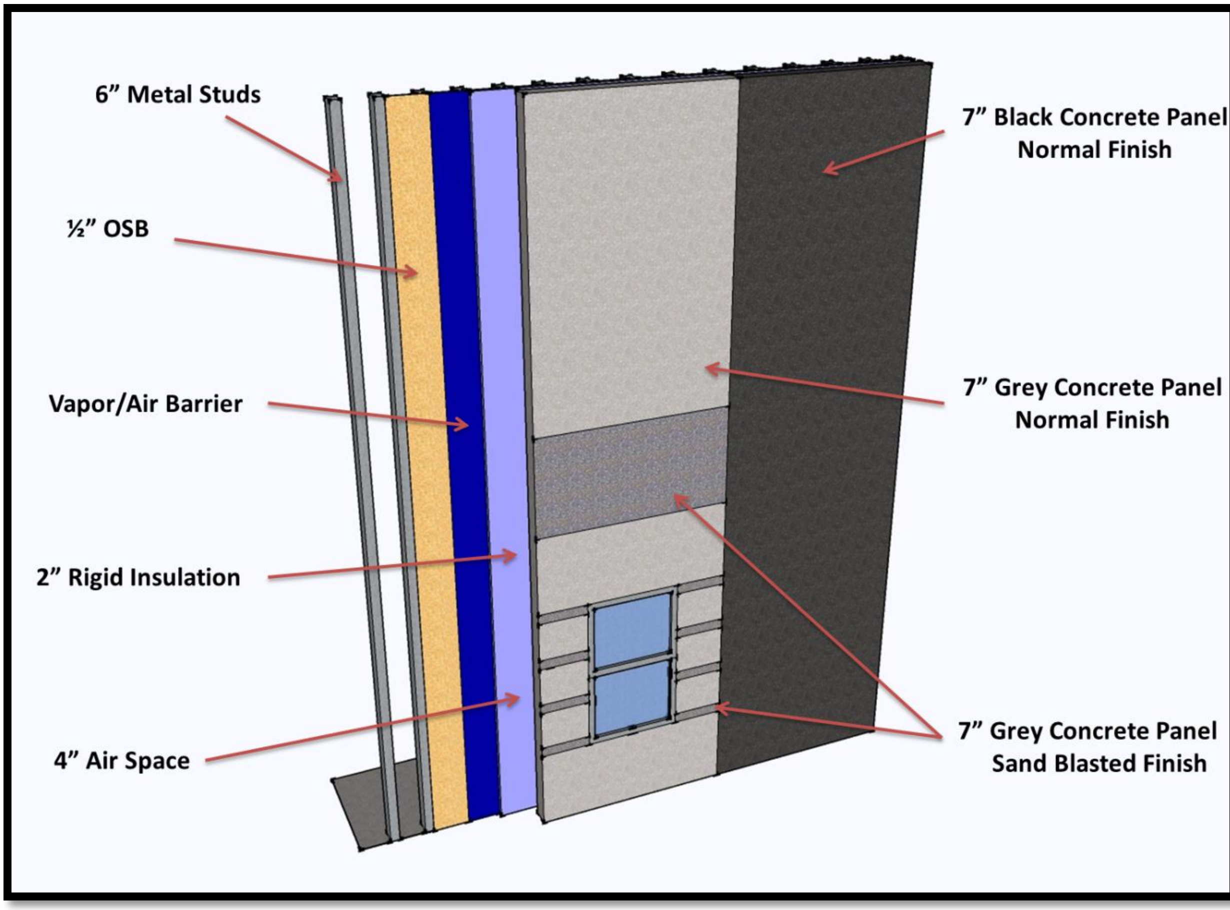


Figure 72: Precast Concrete Panel Design

Breadth #1: Structural Analysis

In order to provide a thorough analysis of the use of precast concrete panels on the building, it was critical to investigate the structural implications on the building's structure. The current enclosure system consists of a non-load bearing CMU veneer. The veneer supports only its own dead load and does not carry any gravity loads from the roof or any other part of the building. The entire exterior of the building is supported by grade beams that vary in size across the building's perimeter. Although the building's superstructure was not designed to carry any gravity loads from the panels, it is responsible for supporting lateral loads, particularly the wind. To get a better understanding of the load paths, an exterior wall section of the billeting buildings can be seen to the right in Fig. 73.

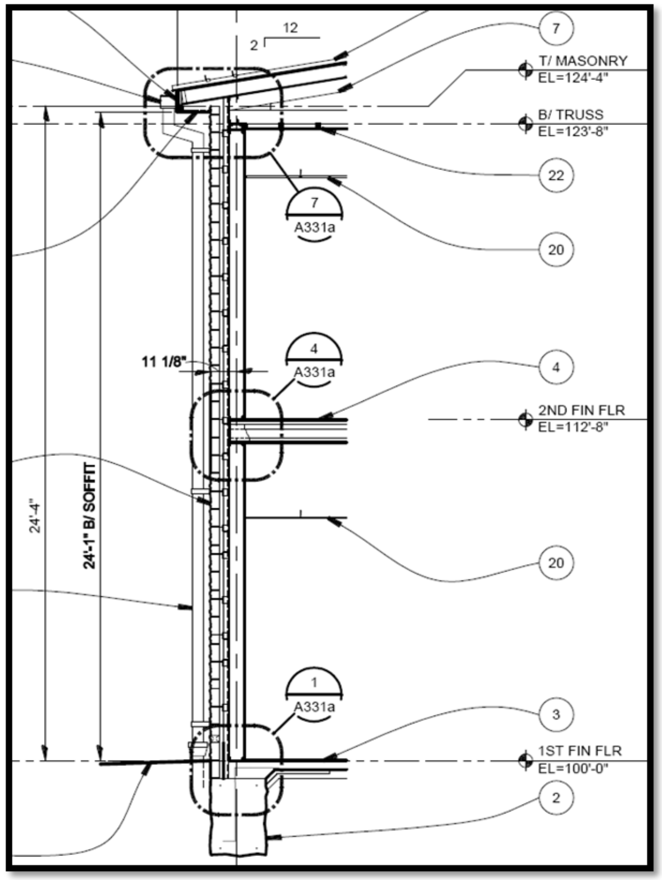


Figure 73: Exterior Wall Section

The first part of the analysis consisted of investigating the lateral forces that would be placed on the precast panels. To begin, I found the wind load design criteria in the structural drawings provided by Barton Malow, which can be seen below in Fig. 74.

Wind Loads		
Basic Wind Speed (3 sec Gust)	V = 90 mph	ASCE Fig. 6-1
Importance Factor	I = 1.0	ASCE Table 6-1
Exposure Category	C	ASCE Sec. 6.5.6.3
Internal Pressure Coefficient	+/- 0.18 (Enclosed)	ASCE Fig. 6-5

Figure 74: Wind Loads

Using tables from *Minimum Design Loads for Building and Other Structures* from ASCE found in Appendix S, it was then possible to calculate the velocity pressures on the building's façade at various heights. Using the building's mean roof height at 27.5', windward and leeward pressures on the panels were calculated, which can be seen on the following page in Fig. 75. The windward pressure was found to be the controlling pressure at 16.58 psf.

Lateral Wind Pressures		
Windward	**16.58 psf**	**Controls**
Leeward	13.87 psf	

Figure 75: Lateral Wind Pressures

Once the controlling wind pressure was found, the panel was then ready to be designed using ACI design guidelines. The panel was designed as a pin-pin connection with the connections at the base and top of the panels. This means that the panel will be supported by a grade beam at the base and by the roof trusses at the top of the panel. Although the current CMU system ties into the load bearing walls on the second floor, the panels will be tied into the cold formed metal roof trusses, since they will help support the lateral loads much more effectively. Although the roof trusses may need to be investigated to decide if the current design is capable of supporting these additional lateral loads, this consideration falls outside of my capabilities and the purpose of this breadth. The panel connections for the billeting buildings can be seen below in Fig. 76 and Fig. 77.

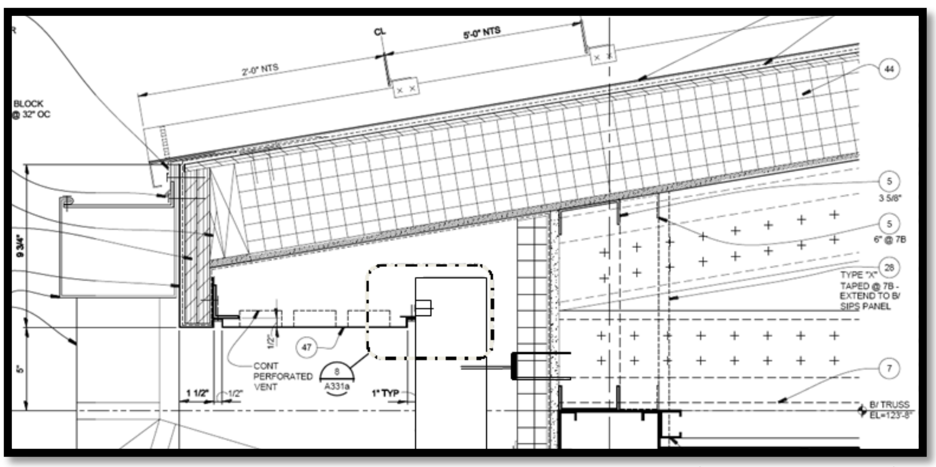


Figure 76: Top Connection

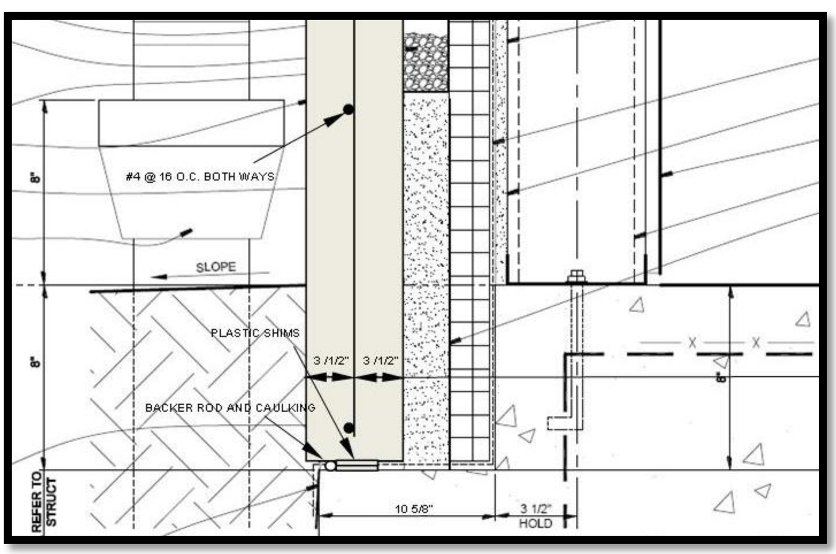


Figure 77: Base Connection

Using the desired panel thickness of 7" with the 5000psi concrete recommendation from Mark Taylor, the panel was then designed for flexure and reinforced. Using the reinforcement spacing chart found in Appendix T, the panels were designed with #4 rebar at 16" O.C. both ways. The panel was then checked for shear where it easily passed, since flexure was the controlling factor. To see the full design calculations for the design of the panels, please refer to Appendix T.

Once the panels were designed, the next step was to check the design of the foundations. This process began by developing loads to apply to the grade beams. Referencing the structural drawings, dead and live loads were able to be calculated. Fig. 78 below shows the design loads utilized for design purposes. Since the electrical and mechanical rooms are located around the perimeter of the building and have the heaviest live load of 125 psf, this was was chosen as the designed live load value for the floors.

Design Loads	
Roof Dead Loads	
Roofing	5.0 PSF
Sheathing/Insulation	3.5 PSF
Cold Formed Metal Trusses	3.5 PSF
Ceiling	5.0 PSF
Mech. & Misc.	5.0 PSF
Dry Pipe Sprinkler	3.0 PSF
Total	**25 PSF**
Roof Live Loads	
Total	**20 PSF**
Floor Dead Loads	
8" Hollow-Core Precast Plank	62 PSF
2" Concrete Topping Slab	25 PSF
Mech./Electrical	3 PSF
Ceiling	5 PSF
Sprinklers	2.5 PSF
Misc.	2.5 PSF
Total	**100 PSF**
Floor Live Loads	
Total	**125 PSF**

Figure 78: Design Loads

The next step in the design process was to derive the tributary width of the load from the building that would be placed on the grade beam located on the perimeter of the building. Fig. 79 on the following page shows the 24' wide room split in half with the left side of the room's load being transferred to the strip footing running under the corridor load bearing walls, and the right half of the room's load being transferred to the grade beam.

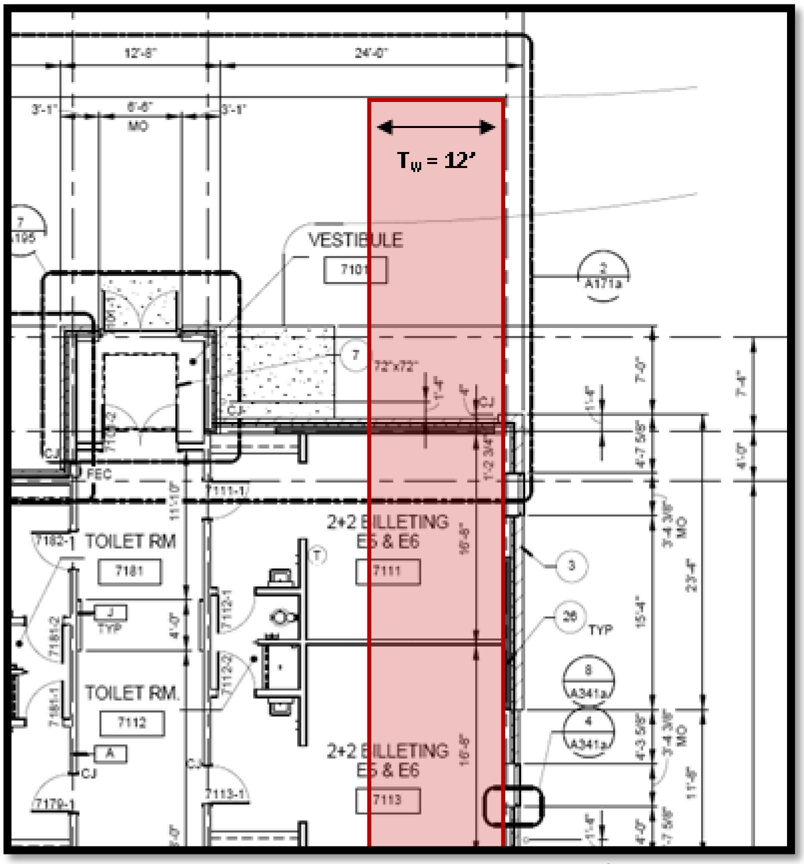


Figure 79: Tributary Width for Load Distribution

The next step was to calculate the total loads, which included the loads from the roof, second floor, and concrete panel. The loads on the first floor were assumed to be transferred into the slab-on-grade and did not impact the grade beam design. In addition, since the total live loads exceeded 100 PSF, a live load reduction was not necessary. The total distributed load was found to be 5.34 KLF.

Treating the grade beam as a simply supported structure and using the grade beam and rebar specifications from the structural drawings, design checks for flexure and shear were performed on the grade beam. The grade beam was found to be structurally sound and required no design changes, a result that was expected, since the current design features a similar load from the 8" CMU veneer at the bump outs. To take a deeper look at the structural calculations for the design check of the grade beams, refer to Appendix V. Further calculations for the spread footers were found to be beyond the scope of this breadth.

Breadth #2: Energy Analysis

The design change of the buildings' enclosures impacts a number of items that are of importance to the end-user, but none are of as much of importance as the thermal properties. To provide a more complete analysis of the influence of the change from a CMU veneer to a precast concrete panel system, it was necessary to conduct an energy analysis of one of the buildings using Design Builder Energy Plus.

The program takes into account the geographical location of the building's site, so that the analysis is performed in an as accurate setting as possible. For the purpose of the Regional Training Institute, Richmond, Virginia was selected as the location. The next step was to import a building layout that was constructed in AutoCAD to be used as the building model to be analyzed. Once the walls were built up, a pitched roof was added at a slope of 1:12. The model can be seen below in Fig. 80 to the right.

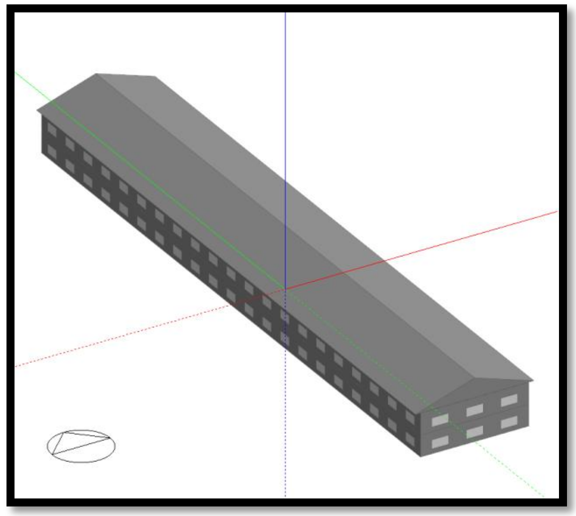


Figure 80: Building Model

The next category to address was the activity of the building. Since the buildings are barracks and have the majority of the buildings' footprint dedicated to living, bedroom dwellings were selected for the building template. Assuming that two people would be living in each room, 0.003 People/SF was calculated to be the average density of the living spaces. Additionally, the building was assumed to feature no office equipment or computers, since only a limited number of building occupants were believe to be using laptops.

The next category to adjust was the lighting and HVAC systems in the building. The lighting was modeled using suspended luminaires in dropped ceilings. In addition, a lighting density of 1.2 W/SF was calculated from the average and types of lamps and luminaires in a typical room. The HVAC equipment was modeled to mirror the systems in the RTI with hot water radiator heating, mechanical supply, and mechanical extract. Both the heating and cooling CoPs were chosen to be 1.0 to follow typical ASHRAE standards. Additionally, the heating system was fueled using natural gas and the cooling system was fueled using electricity from the grid.

The last category consisted of the various construction types, including the exterior walls, roof, floors, and partitions. Using accurate assemblies for all of the constructions, the only item that would be changed between the analyses was the exterior walls. Fig. 81 and Fig. 82 on the following page show the exterior wall build-outs that would be analyzed in the energy analyses.

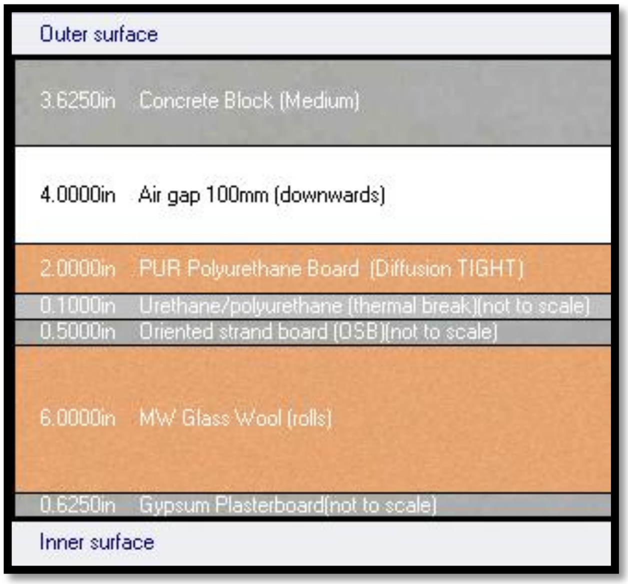


Figure 81: CMU Build-Out

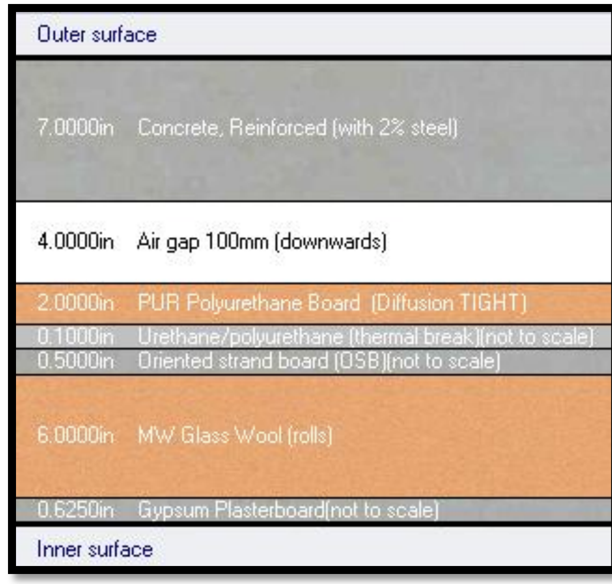


Figure 82: Concrete Panel Build-Out

The two wall assemblies were found to be almost identical in terms of heat transfer and surface properties. As seen in Fig. 83 below, the U-Values were found to be identical with a slight deviation in the R-Values. As expected, the R-Value attributed to the CMU veneer was slightly better, since the block has some air space in the center of the block and does not allow a constant heat path through the veneer.

Heat Transfer Properties		
	U – Value (Btu/h-ft2-F)	R-Value (ft2-F-hr/Btu)
CMU Veneer	0.028	36.976
Precast Concrete Wall	0.028	36.354

Figure 83: Heat Transfer Properties

Although the two veneers are different systems, both facades display nearly identical surfaces, and as a result surface properties. Fig. 84 below shows the outer surface properties attributed to the two exterior veneers.

Outer Surface Properties			
	Convective Heat Transfer Coefficient (Btu/h-ft2-F)	Radiant Heat Transfer Coefficient (Btu/h-ft2-F)	Surface Resistance (ft2-F-hr/Btu)
CMU Veneer	3.499	0.903	0.227
Precast Concrete Panel	3.499	0.903	0.227

Figure 84: Outer Surface Properties

Once all of the proper settings and variables were inputted into Design Builder Energy Plus appropriately, it was then possible to conduct an energy simulation of the buildings. The simulations generate results for a variety of items, but the most relevant item for comparison was the heat loss from the exterior walls. Shown below in Fig. 85, the CMU veneer proved to perform just slightly better by retaining 739 kBTU more per year.

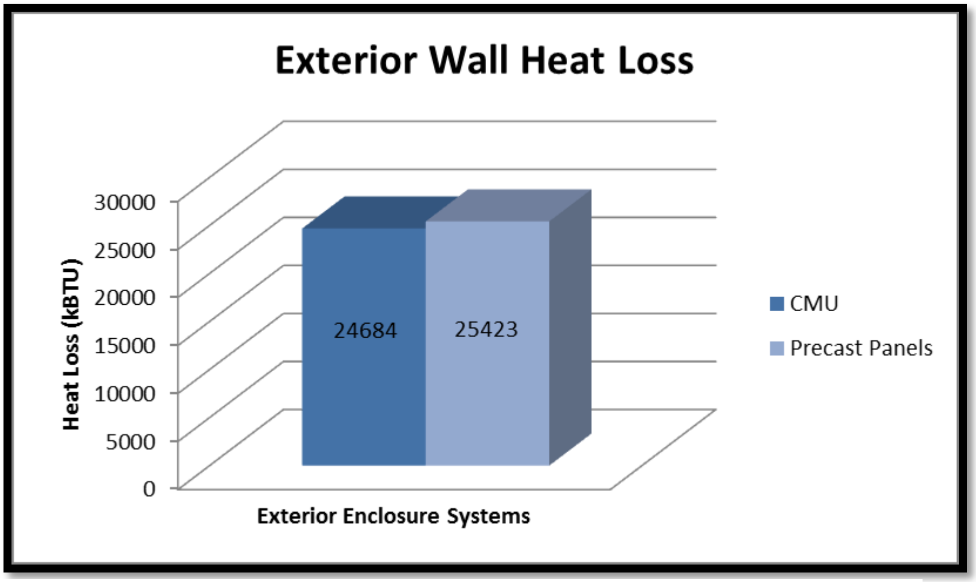


Figure 85: Exterior Wall Heat Loss

The other item of major importance for design consideration is the fuel consumption associated with this additional heat loss. As seen in Fig. 86 below, the fuel consumption between the two systems is nearly identical with the CMU system having the slight advantage.

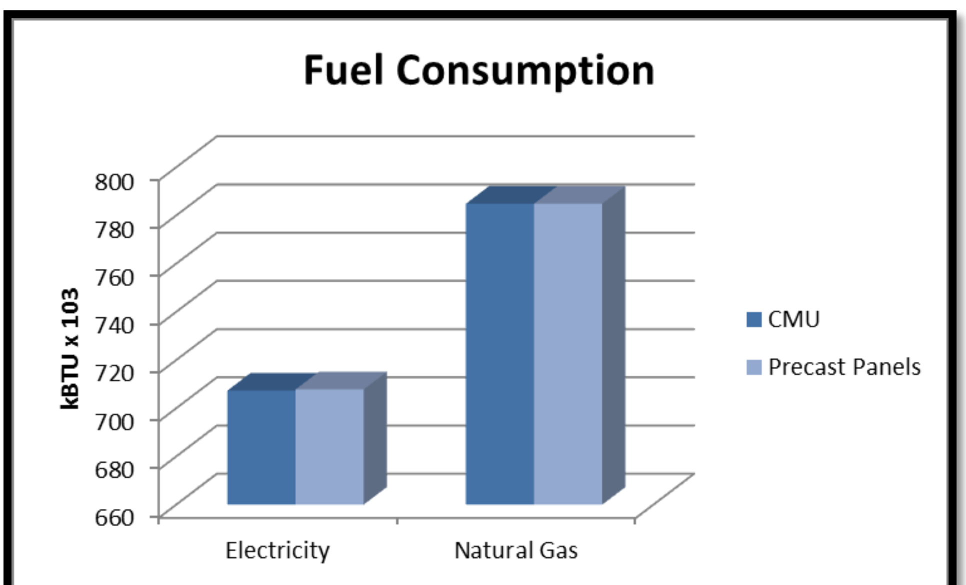


Figure 86: Fuel Consumption

From the results shown above, it is clear that the CMU veneer system is the favorable choice, but the energy impact between the two systems is minimal. Due to the negligible difference between the two enclosure systems, the impact on the overall decision to proceed with the one enclosure system over the other can be overlooked. Both systems display nearly identical thermal properties, and as a result, this part of this analysis should hold minimal weight on selecting the more beneficial enclosure system for the Regional Training Institute. To take a deeper look into the energy simulations from Design Builder Energy Plus, refer to Appendix W for the Annual Heat Loss, Appendix X for the Monthly Heat Loss, and Appendix Y for the Annual Fuel Consumption.

Manufacturing

The primary advantage of utilizing precast architectural panels is the shift of the enclosure work from the field into a manufacturing facility, a strategy that has the ability to cut deeply into the project's schedule. Although the main purpose of using precast panels is to enclose the building in a much quicker duration, there are a number of other advantages associated with using precast panels.

One of the biggest benefits of manufacturing the panels in a manufacturing facility is the shortened duration of the work involved. Constructing the panels in a factory setting creates greater efficiency through repetitive processes. Field construction is plagued with inconsistent measurements, lack of proper equipment, and deviations in work. Workers are able to make the same measurements and cuts using repetitive processes. As seen in Fig. 87 to the right, the workers are able to establish a positive work flow by using repetitive processes for the installation of the reinforcement from panel to panel.

Figure 87: Repetitive Practices ("Gate Precast")

Figure 88: Concrete Delivery ("Gate Precast")

The use of precast panels also promotes lean construction practices and minimizes waste drastically. Materials can be delivered as needed, such as the reinforcing and concrete, which eliminates the possibility of materials being damaged or vandalized on-site. As seen in Fig. 88, once the formwork and reinforcement is completed according to the design specifications, concrete can be ordered and delivered to the manufacturing facility.

In addition, factories feature a much more productive work environment. The use of a controlled environment eliminates potentially harmful working conditions, specifically weather. The erection of the façade at the Regional Training Institute began in Spring, which can be impacted drastically by rain and soil conditions. The veneer erection process becomes even more concerning during the summer months, where the heat can be incredibly detrimental to crew productivities, a setback that was faced on a number of days during the later stages of the veneer erection process in July and August. Factories even promote better safety practices, since the working environment typically involves adequate light, work space, fewer trade personnel, less necessary equipment, and work accessibility, specifically the elimination of the use of scaffolding. Fig. 89 shows the advantages of constructing the enclosure in the manufacturing facility, since the panels can be finished with adequate space, ultimately leading to a higher quality product. These facilities also provide better auxiliary services, such as bathrooms, lunch-rooms, and locker-rooms.

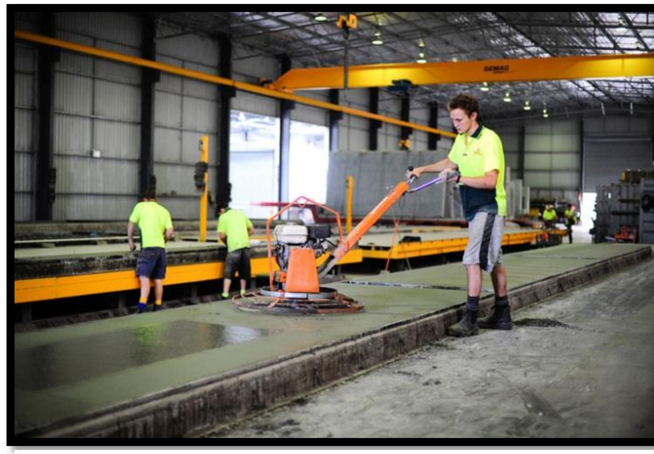


Figure 89: Working Environment ("Gate Precast")

Quality Control

Most precast manufacturing plants are PCI-certified, which results in a higher quality product. Every PCI member must pass two unannounced inspections each year to maintain their certification, a measure that ensures that the precast plants are practicing the highest level of quality work. The inspections are aimed at plant's general operations, as well as the process of which the panels are produced.

Workers are full-time tradesmen, which generates consistent work through union or non-union work. Many manufacturing facilities utilize union labor, which results in a higher dedication to the job and more consistent work practices. Work is also more repetitive and leads to a more steady work flow, leading to the same standard of quality from each panel to the next.

Delivery

Once the panels are completed, they are ready to be shipped to the site. The largest item to consider is the panel size, which for the most economical strategy is a maximum of 12' in width, according to Mark Taylor of Nitterhouse Concrete Products, since it doesn't require the use of special permitting. Using this panel guideline as a design consideration, I was able to ensure that none of the panels exceeded this width. In addition,

Figure 90: Panels Being Placed on Truck Bed ("Gate Precast")

the panels are well below the typical 50' truck bed length. Since the quote that I received from Mark included the price of materials, labor, transportation, and erection, there is no need to investigate the actual cost of transportation as an individual item (Taylor).

The panels are to be picked and placed on truck beds using only the lift points specified in the shop drawings. The panels are to be shipped on non-staining, shock absorbing materials to ensure the panels are not damaged during delivery. In addition, non-staining resilient spacers of even thickness are to be placed between each panel ("Gate Precast").

Using Nitterhouse Concrete Products as the manufacturer for the Fort Pickett Project, it was possible to calculate the best delivery route and time for deliveries using GoogleMaps. Nitterhouse Concrete Products is located in Chambersburg, PA, which is an estimated 250 miles, and a 5 hour delivery route assuming that Interstate 95 is the primary transportation path. The route can be seen in Fig. 91 to right.

In addition to the just-in-time material deliveries, finished panels are able to be shipped according to the project's schedule. Panels can be shipped just prior to erection, so that the panels do not sit around the job-site where they risk being damaged or consume valuable work space.

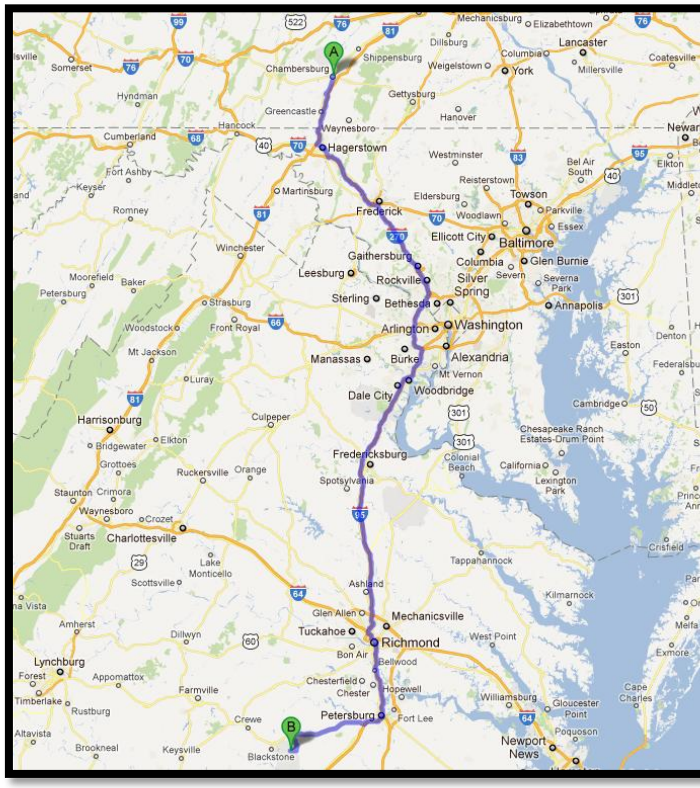


Figure 91: Panel Delivery Route (Google Maps)

Erection

The field construction of the masonry veneer faced a number of problems during the erection stage, specifically with the coordination of the scaffolding with other trades for material delivery and accessibility purposes. By using the precast concrete façade system, these coordination problems can be completely eliminated by removing the need for scaffolding, lulls, mortar mixers, material stock piles, and waste materials. In addition, the duration necessary to erect the panels is significantly reduced, which results in fewer clashes with the workers of other trades, specifically the stair subcontractor and roofing subcontractor.

Figure 92: Accessibility Problems

In order to get a better idea of the problems that can now be eliminated concerning the building accessibility situation incurred by the Fort Picket project during the erection of the CMU wall system, see Fig.92 to the left. The use of precast panels completely eliminates these coordination and accessibility problems, and instead draws focus primarily to the planning of the deliveries and crane paths.

The use of precast panels minimizes coordination issues drastically by reducing the amount of materials, machinery, and personnel on site. With just-in-time deliveries being the goal of the project team, the deliveries must be carefully managed. Shown below in Fig. 93 and seen in further detail in Appendix Z**,** the deliveries will solely come from the south entrance, which is used for all deliveries and as an entrance for workers. The site contains more than adequate room and accessibility for trucks to enter the center of the building campus to deliver the panels. From here, the 40 ton crawler crane can pick the necessary panels and immediately erect them into their desired location. Additionally, the panels are to be picked by specified lift points from the shop drawings. The construction sequencing can be observed on the site plan with Building 700 being the initiator in the panel erection sequence.

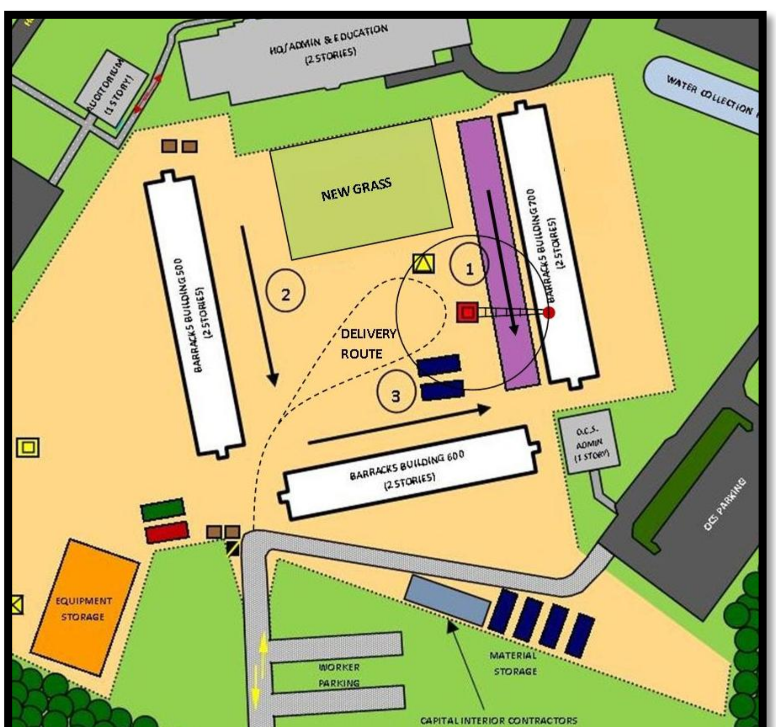


Figure 93: Panel Erection Phase Site Plan

Schedule Analysis

The main driver for investigating the use of precast concrete panels on the Fort Pickett Regional Training Institute project was the potential to accelerate the schedule. Although it was previously believed that the only schedule gains would come in the form of replacing the masonry erection activities with the panel erection activities, the use of panels actually created a much more favorable sequence of work creating additional schedule gains.

The current enclosure schedule, which can be seen in Appendix AA, shows a number of inefficient work strategies. Due to the lengthy duration associated with constructing the CMU veneer in the field, activities were scheduled sporadically to allow as much time as possible for the masons to erect the CMU façade. The north elevations on Building 700 and 500, as well as the west elevation on Building 600, all began to install the sheathing, vapor barrier, and insulation prior to the second floor's exterior load bearing walls being erected. Although the schedule shows just these elevations performing work prior the completion of the load bearing walls, the work was actually distributed amongst all of the elevations, so that the build-out could do what work was available on the first floors prior to the completion of the second floor's exterior walls.

Another activity that was able to be adjusted was the installation of windows and doors. Due to the extensive duration required to complete the CMU walls, American Doors and Glass, the window and door subcontractor, was forced to visit the site as the work was available. Rather than complete all of the work in one continuous timeframe, workers visited the site as the walls were completed and ready for the windows to be punched.

The last major activity impacted was the cleaning and quality control attributed to the CMU wall system. Since the work was performed in the field, there were a number of quality control issues with variations in mortar colors, mortar joints, mortar splashes on the block, and irregularities with the block. These problems resulted in a number of different pressure washes and chemical treatments to provide a uniform look to the veneer.

In addition to the reformed sequencing, a number of activities were responsible for cutting deeply into the schedule. Observed in Fig. 94 on the following page, the 50 day duration for erecting the CMU walls was able to be reduced drastically to 5 days. This resulted in a savings of 45 days per building. Additionally, the cleaning of the CMU walls was found to require the same amount of time as sealing and cleaning the precast panels combined. Overall, the project was able to save 135 work days from all three buildings combined from simply utilizing new activities with no consideration to the new sequencing possibilities. Although there was an overall reduction in the masonry work, an extra week was allocated to each building during the construction of the exterior load bearing walls to account for the panel connections that needed to be installed, which is noted on the revised schedule.

Building Enclosure Activity Accelerations		
Activity	**Duration/Building**	**Duration/Project**
CMU Wall		
Erect CMU Walls	50	150
Clean CMU Walls	20	60
Total	**70**	**210**
Precast Panels		
Erect Panels	5	15
Seal Joints/Clean Panels	20	60
Total	**25**	**75**
Days Saved on Enclosure	**45**	**135**

Figure 94: Building Enclosure Activity Accelerations

Using the new activity durations and taking advantage of the new sequencing availabilities, it was then possible to build a new schedule for Building 700, which also reflects the same sequence and durations as the other buildings, but with a one week lag in dates for Building 500 and a two week lag for Building 600. The revised schedule and activities using the precast panels for Building 700 can be found in full in Appendix BB and summarized below in Fig. 95.

Schedule Impacts Building 700							
	Previous			Proposed			
Activity	Start Date	Finish Date	Duration	Start Date	Finish Date	Duration	Days Saved
Exterior Sheathing	12/23/10	3/7/11	53	1/24/11	3/18/11	40	13
Vapor Barrier/Insulation	1/13/11	3/31/11	56	1/31/11	4/1/11	45	11
Erect Masonry/Panels	1/7/11	5/20/11	96	3/28/11	4/8/11	10	86
Seal Joints/Clean	1/27/11	6/3/11	92	4/11/11	5/6/11	20	72
Punch Windows	2/4/11	6/10/11	91	4/18/11	5/13/11	20	71
Aluminum Storefronts	5/13/11	5/17/11	3	4/20/11	4/22/11	3	0
Caulk Exterior of Windows	6/16/11	7/11/11	18	4/20/11	5/13/11	18	0
Caulk Exterior of Doors	6/6/11	6/10/11	5	4/25/11	4/29/11	5	0
Leak Test Windows & Storefronts	7/25/11	7/28/11	4	5/16/11	5/19/11	4	0
Overall	**12/23/10**	**7/28/11**	**156**	**1/24/11**	**5/19/11**	**84**	**72**

Figure 95: Schedule Impacts Building 700

The new schedule uses a new start date for the enclosure sequence of 1/24/11 and a new end date of 5/19/11. This means that work is able to begin 4.5 weeks later on-site, creating less site congestion from materials, equipment, and personnel during the pouring of the topping slab and erection of the second floor's load bearing walls. The system also results in an acceleration of the construction sequence by completing work 10 weeks sooner than the CMU wall system. Overall, the precast concrete panel system was able to recoup 14.5 weeks off of the project schedule, which can be seen below in Fig. 96. Although this schedule reduction has the potential to accelerate the building enclosure process, the constraining activity rests with the roof work, since the core and shell activities cannot be completed until the roof is complete.

Time Savings from Use of Precast Panels	
	Duration
Prior to Constructing Building Enclosure	4.5 Weeks
Post Construction of Building Enclosure	10 Weeks
Total Time Saved	**14.5 Weeks**

Figure 96: Time Savings from Use of Precast Panels

Cost Analysis

Where uncertainty typically rests with precast panel systems is with the cost to implement and materials. The current system's complex design boasts a nightmare for design coordination, as well as a heavy cost of $2,490,660, which was provided by the Barton Malow project team. This value encompasses the entire build-out, so in order to provide an accurate cost of the panel system, I used RSMeans to calculate the additional work not associated with Mark Taylor's quote. Shown in Appendix CC, the sheathing, air/vapor barrier, and rigid insulation was estimated to account for these absences from Mark's quote. Fig. 97 below shows the costs of the components necessary to construct the enclosure.

Cost of Precast Panel System			
	Cost/Quantity	Quantity	Cost
½"OSB Sheathing	$1.09	59,700 SF	$65,073
Air/Vapor Barrier	$0.33	59,700 SF	$19,701
2" Rigid Insulation	$1.84	59,700 SF	$109,848
7" Precast Panels (Material/Delivery/Installation)	$20/SF	59,700 SF	$1,194,000
Black Finish on Panels	$0.50/SF	13,294 SF	$6,647
Sandblasting Finish on Panels	$3.50/LF	1,924 LF	$6,734
Joints	$0.25 LF	5,574 LF	$1,394
Connections	$5.00 SF	59,700 LF	$298,500
		Total Cost	**$1,701,897**

Figure 97: Cost of Precast Panel System

Once the complete cost for the precast panel build-out was calculated, it was then possible to compare the two systems. Although the design implications to the cold formed metal roof trusses and its associated cost impacts is unknown due to its relevance beyond this analysis, the estimate above provides a relatively accurate estimate for the proposed system. After comparing the two systems, the precast panel system was found to be much cheaper, which is believed to be due to the simplification of the design and its resulting reduction in labor costs. The current system requires an enormous amount of coordination, labor, and material waste, since the construction in the field was so complicated. Additionally, the block that made up the wall was colored split-face and smooth architectural block, which can add significant costs. The decision to select the precast panels without the CMU embeds was a decision that made a tremendous influence on the overall panel cost by saving over $0.5M. Although the design was simplified, the architectural look was able to be preserved by adding special finishes without generating an enormous additional cost. Since the first 4.5 weeks saved prior to beginning the building enclosure process did not impact the overall schedule, only the time save after the sequence was totaled for potential cost savings. Overall, the use of precast concrete panels had a $1,094,129 savings, which can be seen below in Fig. 98.

Cost Savings	
CMU Wall Enclosure	
CMU Walls	$2,490,660
Total	**$2,490,660**
Precast Panel Enclosure	
Precast Walls	$1,701,897
General Conditions (10 Weeks)	$305,366
Total	**$1,396,531**
Total Cost Savings	**$1,094,129**

Figure 98: Cost Savings

Recommendation & Conclusions

The use of precast concrete panels is typically associated with accelerating project schedules, but in the case of the Fort Pickett Regional Training Institute, the panels displayed a number of other advantages. The overall wall enclosure process was able to be reduced by 14.5 weeks, which resulted in a possible 10 week shortening of the overall project schedule. On top of the schedule savings, the system showed a potential savings of $1,094,129 from the combined general conditions and veneer costs. Although the architectural design was altered, a similar design was able to be created to keep a lot of the architectural elements intact. After conducting a thorough analysis of the use of precast architectural panels, it is strongly recommended that the Fort Pickett project team implement the proposed system.

Analysis 4: Integration of Material Tracking Technologies

Problem Identification

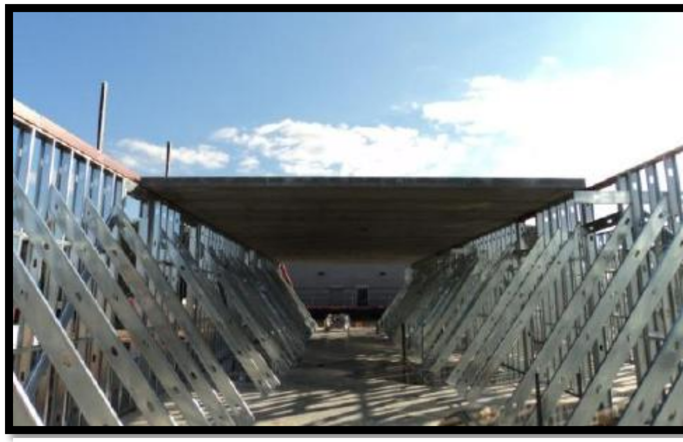


Figure 99: Precast Hollow-core Floor Planks - Courtesy of Barton Malow

Although the uses of precast hollow-core floor planks and structurally insulated roof panels have given the project team a great opportunity to accelerate the project schedule, they also carry a significant amount of risk. With the possible introduction of modularized rooms and precast façade panels, there is a significant amount of coordination and planning that needs to be allocated to the materials. Many of the materials have long lead times, are manufactured off-site, and require careful planning for deliveries. With the use of such specialized building materials, it is absolutely critical that extreme planning and consideration goes into tracking materials. A missed delivery or misplacement of an item could result in a major project delay and potentially bring work to a standstill. Although the management of materials is critical for a number of items, the precast hollow-core planks hold the greatest potential to derail the project and bring construction to a hold. With so many activities dependent on the placement of the floor planks, it is dire that the materials arrive on-site as needed and in the correct specifications of the design.

Research Goals

To determine the most appropriate material identification tagging system: barcodes, passive tags, or active tags. To develop an implementation strategy for the use of material tracking on the Fort Pickett project. To investigate the feasibility associated with utilizing material tracking technologies on the Fort Pickett project, specifically the impacts to the project's schedule, costs, and coordination.

Background Information

In order to combat the chaos introduced with so many prefabricated and shop manufactured items, the implementation of a material tracking system will be analyzed. There are currently a number of software programs that are on the market, including Vela Systems, Latista, and LocateWare. These programs, in addition to the growing collaboration with 4D modeling software, such as NavisWorks and Tekla, have generated a great deal of interest in their potential on the construction site. The programs involve complex tracking systems that have the capabilities of tracking materials from the manufacturing phase to the final installation of the product on-site. The technology consists of material tracking software, scanners, and material tags, which ranges from high-end active RFID (radio frequency identification) tags with GPS capabilities to cheaper, simpler barcode tags. Although material tracking technology has made tremendous strides over the last few years in the industrial and manufacturing industries, there exists only a limited amount of reported cases of its use within the construction industry, two of them being referenced later in this analysis. These systems have shown incredible worth on large scale project, but its use on smaller projects, such as Fort Pickett is something that needs to be investigated. In addition, due to the relatively new introduction of this technology in construction, there are a number of implementation items that will need to be decided, such as what tagging system to use and what software to select. In order to utilize material tracking, it will require the manufacturers, subcontractors, and construction management team to buy-in to the system. This buy-in requires full collaboration and training in order to reach a level of success. The technology has the capacity to greatly improve material management on job-sites, but there exist a number of hurdles to overcome, including the overhead cost of the equipment, training, and legal implications. Using a number of research papers, case studies, webinars, and interviews, a plan was developed to be implemented on the Fort Pickett Regional Training Institute in hopes of mitigating the risks and accelerate the project schedule.

Case Studies

Meadowlands Stadium

One successful implementation of material tracking technologies was the New Meadowlands Stadium in New Jersey, a $998 million, 2.2 million square foot stadium, which currently acts as the home of the New York Giants and New York Jets, two National Football League teams. With valuable experience from constructing Gillette Stadium in Foxboro, MA, Skanska USA Building served as the lead contractor on the design-build project. With the upcoming football season acting as the schedule driver, the project boasted an extremely aggressive schedule. For this reason, Skanska was forced to identify the critical-path materials and resolve

Figure 100: New Meadowlands Stadium – (Sawyer)

the potential conflict issues in the earlier stages of the project, reducing risks of jeopardizing the just-in-time supply chain approach.

Figure 101: Precast Members Being Delivered - (Sawyer)

In order to fast track the schedule, the 3,200 precast members were identified as a key activity to address. The 3,200 concrete members each weighed more than 45,000 pounds and measured 44 feet by 10 feet. In addition, the elements were custom-made for a specific location within the stadium, which eliminated the possibility of interchanging pieces. To tackle the problem, Skanska deployed a just-in-time supply chain technique that allowed the members to be erected directly off of the trucks upon delivery, which eliminated timely material movement activities. In order for this to be possible, the precast members needed to meet the quality control standards required for erection, which meant that there could be no flaws with the members or the construction work could be brought to a standstill. With such a tight schedule and over 3,200 custom-made precast riser elements to be erected, Skanska turned to Vela Systems and Tekla Corporation to complete the stadium on time using a Field BIM solution.

Vela Systems is a company that specializes in field software, which in combination with tablet PCs has the capability of streamlining and expediting field processes. Their software can be used to compose field reports, work lists, safety inspections, punchlists, schedule updates, and has the ability to store the project's construction drawings for editing and reviews. The use of their software has shown savings of 5-10 hours per week per user, an acceleration of two days per month, a reduction in litigation through proper documentation, and greater quality control.

Using the innovative material tracking software created by Vela, over 3,000 pre-cast concrete elements that will form the seating bowl of the stadium featured RFID tags that were embedded in the elements upon casting. The pieces proceeded through four scanning phases of the production process. The precast elements are first scanned upon casting and moved to the desired location in the supplier's facilities. The second scan comes when the pieces undergo a quality control inspection upon shipping out of the facility. The third scan is performed upon successful delivery to the project site and inspection for damages. The fourth and final scan is completed during the erection process to ensure that the elements have been placed in the proper location.

As the pieces move through the various phases of the production process, the information gathered from the RFID tags are fed into Tekla Structures, a BIM software that models the stadium's structure from the earlier design stages, to fabrication, and into the installation of the pieces. The combination of Tekla's BIM technology with Vela's material tracking software creates the ability for Skanska to track the status of each precast member throughout the supply chain. The status of each piece can be checked by looking into Tekla's 3D model of the stadium, where each concrete member displays varying colors that depict the status of the elements. This innovative material tracking solution serves as the first example in the United States to combine the material tracking software, tablet PCs, RFID tags, and BIM in the construction industry. With the introduction of this material tracking strategy, the project was able to reduce the construction schedule by 10 days, which resulted in a savings of $100,000 per day or a total savings of $1 million. All information presented in this case study can be referenced in the work cited under Sawyer.

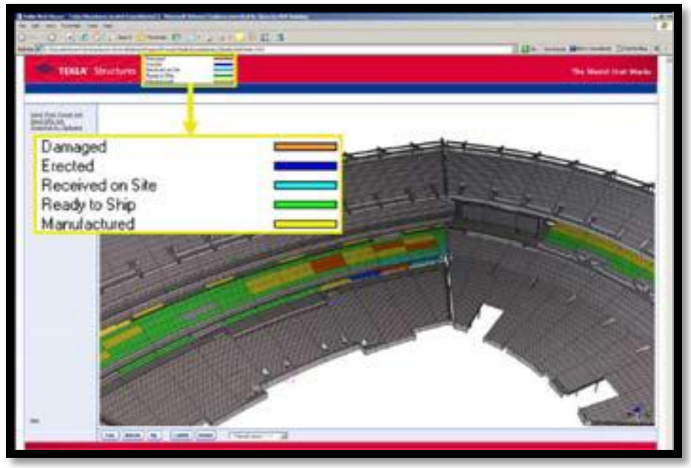


Figure 102: Screenshot of BIM Model – (Sawyer)

UCSC Porter B College

Another application of material tracking technologies took place on the UCSC Porter B College project, where DPR Construction acted as the General Contractor. The project team was successfully able to combine Vela's field mobility software, tablet PCs, and Tekla's BIM software to manage the material management of the project's doors, frames, and hardware (DFH), which was able to accelerate the schedule by 20%.

In order to improve the material management of the DFH, DPR replaced their traditional pencil and paper methods that consisted of paper logs, drawings, and countless hours of updating, fixing, and updating paper progress reports with a computer managed solution. Initially, the DFH were modeled in Tekla Structures and each item was attached with information. Upon arrival to the construction site, the doors were tagged with preprinted barcodes and then scanned using Vela Systems with the aid of the table PCs. The barcodes were scanned throughout the various stages, including receiving, storage, and installation. This allowed the field personnel to check the availability and order completeness for given parts of the building.

Once the materials were scanned, the information was wirelessly updated and available to any member of the project team to view. In addition, the BIM model showed the status of each door within Tekla Structures, which allowed the team to process any issues that were present.

In addition to the study conducted in the field, Stanford's Center for Integrated Facility Engineering conducted studies with three key benefit areas: time savings, clear project visibility, and reorder rate reduction. In order to deliver a more thorough investigation, the study analyzed workflow processes before and after the implementation of the integrated field system.

Regarding time savings, the study showed a 50-80% time savings for DFH tasks. There was more than 28 hours of time saved in documentation, communication, and reporting, which led to a 20% improvement of DFH productivity in work. These savings were due to a removal of steps, faster information flow, and quicker processes. The improvements were found in the QA/QC inspections, installation inspections, and final walkthroughs. On top of these savings, two older steps were transformed into more efficient processes. One of these methods was the replacement of updating delivery statuses using barcode scanning in the field, opposed to manually reviewing plans and updating the statuses. The other major change was the automatic update of QA/QC issues, which in the past could take days using the manual input using the aid of daily reports.

The second area of investigation was the ability to update the web-based BIM model in real-time. The project team and workers could check the current status of each component, which allowed them to plan their work sequence more accurately. In addition, it also helped DPR to publish accurate progress reports and manpower information.

The final area of research was the amount of reorders needed using the new system. Usually, reorders constitute financial loss to the project, but the new material tracking system was successfully able to mitigate this cost. The system increased visibility into the availability of openings (ordered, onsite, damaged, installed), which meant that there were no reorders necessary. With the information being updated instantaneously, the DFH foreman was able to make better decisions on what and when to reorder. This created immediate insight into the reorder requirements and a higher level of assurance and accountability. According to Lisa Thomas, Project Manager at DPR, "The 2% of job cost related to QA/QC and reorder is now virtually nil." All information in this case study was referenced in the works cited under "Vela Systems."

Inefficiencies with Material Management Process

In order to fully understand the uses and potential for material tracking technology, it is first critical to address the problematic areas that are currently hindering material management. Within the four major phases of the construction material management process there are a number of problems, which can be outlined below in Fig. 103.

Phases	Problems
Ordering	• Over-ordering • Ordering the wrong type, quality, size • Ordering standard lengths rather than the lengths required • Ordering for delivery at the wrong time
Delivery	• Damage during unloading • Delivery to inappropriate areas of site • Accepting incorrect deliveries, specifications or quantity
Storage	• Exceed shelf lives • Damage or contamination from incorrect storage, loss, theft, or vandalism
Handling	• Damage or spillage through incorrect or repetitive handling • Delivering the wrong materials the workplace

Figure 103: Material Management Inefficiencies (Chesser)

Most problems develop due to the lack of proper material management techniques. These flaws disrupt information flow between material management phases, which causes a number of the problems previously outlined. Below in Fig. 104, the information flow throughout a typical construction project is shown, where a number of problematic areas are symbolized with question marks (Ren, Sha, and Hassan 401-406).

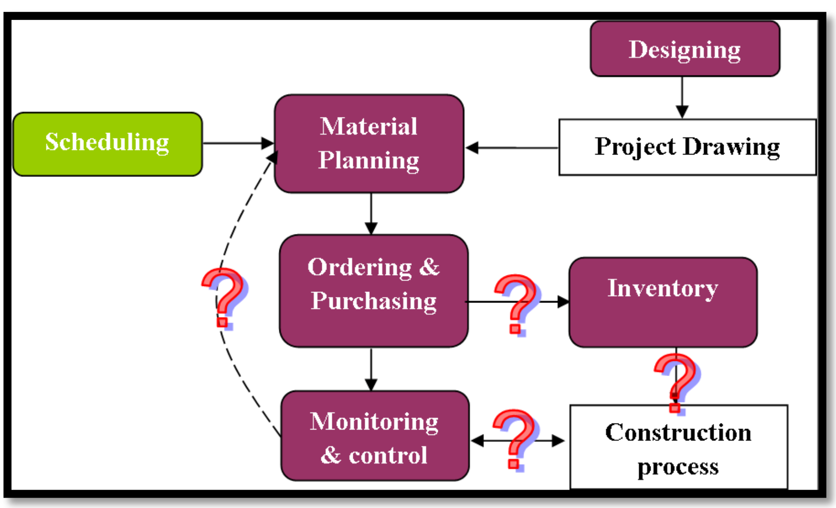


Figure 104: Material Tracking Problems (Ren, Sha, and Hassan 401-406)

Where there exists the greatest concern along the chain is in the construction process or site management. In order to gain a further understanding of the challenges and steps that go into implementing a material tracking plan at this phase, I utilized the information presented by John Chesser, VP of Construction Solutions at Atlas RDID Solutions. Atlas RFID Solutions is the world's largest resource for mobile material management. In their latest initiative, they have taken input from some of the industry leaders, including Bechtel, Kiewit, and Westinghouse, in order to create the most efficient process possible. The webinar reviewed how EPC firms are improving upstream and downstream construction productivity by streamlining their field data using material tracking technologies, such as barcodes, passive RFID, active RFID, and GPS in conjunction with material tracking software that is being managed through mobile devices.

As shown below, site materials management is composed of five key phases: Receiving, Storage, Request, Locate-Pick, and Issue. Within each of these phases lie a number of critical concerns that must be addressed to ensure that the integrity of the supply chain is not compromised. Fig. 105 highlights a number of these inefficiencies below.

Typical Points of Inefficiencies:	
Receiving	• Receiving crew is often unaware of what material is coming. • Receiving crew uses paper packing list to mark receipt. • Manual data entry of material received using paper by receiving crew.
Storage	• Laydown crew manually records storage location on paper. • Data entry clerks records storage location. • Dynamic storage areas where material can be moved.
Requesting	• Requester completes paper request form. • Requester lacks important information about material. • Paper-based process creates communication issues between requestor, warehouse, and construction.
Locate/Pick	• Smaller items present big problems. • Original recorded location could have been recorded incorrectly. • Laydown crew lacks important information about material being requested. • Length of time required to locate means adding a step of flagging material to later be picked.
Issuing	• Visibility ends when material is issued. • Laydown crew manually records where and to whom material has been issued. • Data entry clerks manually enter the information provided by laydown crew.

Figure 105: Typical Points of Inefficiencies (Chesser)

Material Tags

In order to overcome these inefficiencies, there are a number of deployment methods that can be utilized to ensure that the process is not negatively impacted, but it is dire to select the right pieces. Material tracking systems require four critical components to work together in order to reach a desired end-result: software, tagging, hardware, and services, which can be seen in Fig. 106 to the right.

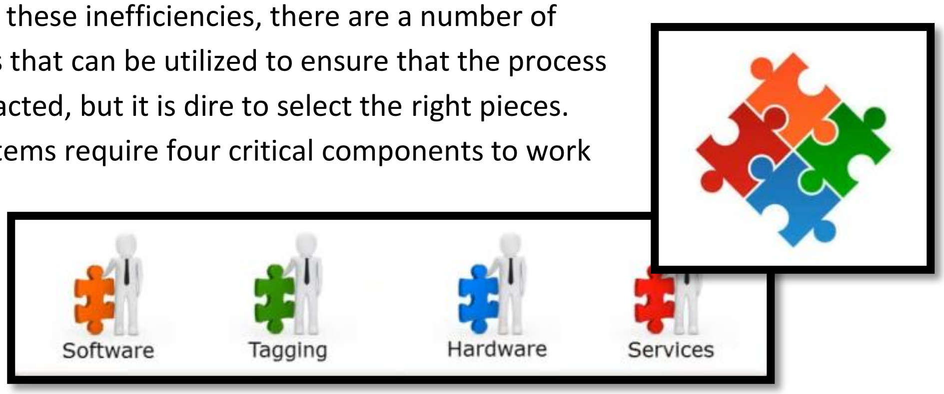


Figure 106: Puzzle Pieces - (Chesser)

The first key decision to make is to decide on what tags to utilize, which depends on the level of sophistication and intended use of the system. Within the proposed material tracking technology, there are a number of different tagging systems to utilize, which includes RFID, barcodes, and QR.

RFID is composed of three major components, the reader, tags, and antenna. The antenna enables the chip to transmit the information from the tag to the reader. From here, the reader takes the information and transmits the information into a computer data base for use. Within RFID tagging, there are two forms of tags: active and passive.

The active tags are internally powered by a battery and hold GPS capabilities. The more sophisticated active RFID tags have the capability of storing information in regards to delivery, storage, installation, and warranties within the tags. Additionally, these tags demonstrate the ability to contain GPS and proximity tracking to allow for inventory sweeps of construction sites. This is advantageous, since the project team can know exactly where any given item is located on-site without having to manually search for the item.

Passive tags are operated using the power generated from the reader. Although the passive tags are much cheaper, they have a limited read range and don't contain the data storage capacity that active tags possess. Although these tags have greater capabilities over other tagging systems, there cost heavily deters there use on most projects. In addition, according to Brian Clarke, Director of Sales at Vela Systems, "the ability for the RFID tags to store information is not typically of much use, since other tags can be scanned and have the information store in the database."

Another form of tags that is become more regularly used is barcodes. Barcoding systems have been utilized throughout the industrial and manufacturing processes for some time and are now becoming the front-runner in the construction world due to its affordability. Barcodes are much cheaper in comparison to RFID tags and have greater versatility for coordination. Using material tag generating software, such as Bartender, tags can be printed in the manufacturing facility or on-site and attached to the desired material. Another alternative is to purchase tags that have already been given identification numbers. This means that the tags can simply be ordered online and then applied to the material upon arrival. Although the system is advantageous from a cost standpoint, there are a few drawbacks. Barcodes have limited data storage and requires line of site scanning, which could create problems with congested sites and poor weather conditions.

Active RFID Tags	Passive RFID Tags	Barcode Tags	Barcode Labels
100 Meter read range; can be read under snow & ice	10 – 20' read range; cannot be read under snow & ice	Less than 1' read range; cannot be read under snow and ice	Less than 1' read range; cannot be read under snow and ice
Does not require line of site to scan; can be used with inventory sweeps to update GPS location	Does not require line of site to scan	Does require line of site to scan	Does require line of site to scan
$$$	$$	$	--

Figure 107: Types of Tags - (Chesser)

In order to decide which tags to proceed with, it is important to determine the logistics of the site. If the site is very dynamic and involves moving materials frequently around the site, it may be in the best interest of the team to deploy active RFID tags with GPS capabilities. This eliminates the possibility of not being able to find critical materials and having to reprocure the desired items. If the materials are to be located in the same spot upon arrival, it may be best to utilize barcodes or passive tags, since the cost of these tags are much cheaper.

For the case of Fort Pickett, the intended purpose of applying tags to the precast hollow-core planks is solely for tracking capabilities and not data storage. The RTI's campus also demonstrates adequate space for scanning and limited congestion. These factors combined with the favorable costs makes barcodes the preferred choice.

Hardware

The next item of consideration is the hardware to utilize on the Fort Pickett project. There are a number of different potential scanning methods, but the strategy that is gaining the most momentum is the use of the iPad in conjunction with a scanner. Due to the recent decline in the price of the iPad, its use is being adopted throughout the industry with one example being

Balfour Beatty. Recently, Balfour Beatty Construction chose to implement a company-wide adoption of Vela Systems software in combination with the iPad for project management purposes on-site. The low cost, long battery life, and ease of use has made the iPad the ideal choice in comparison to costly, outdated tablet PCs. The iPad features a touch screen that is much more convenient than carrying around a pen to navigate the hardware. Brian Clarke, Director Sales at Vela Systems, recommended using the 32 GB iPad with wifi capabilities. The 32 GB iPad gives the user adequate data storage, as well as an affordable price of only $599.00 (Clarke).

Figure 108: Balfour Beatty's Adoption of iPad ("Vela Systems")

Where durability issues bring the iPads use into question, companies such as OtterBox have developed hard cases to allow the iPad to endure the rugged construction environment. Otterbox's Defender Series have been tailor made to protect the use of the iPad in working environments. The cases run for around $75 each, but their benefits far outweigh the one-time cost.

In conjunction with the iPad, Opticon's latest scanners have made material scanning easier than ever. As seen in Fig. 109 below, the scanners have been reduced in size to make their accessibility and transportation incredibly favorable. Opticon has even developed a Bluetooth scanner, so that the scanning process can take place hands free. By simply uploading the Opticon material scanning application in iTunes and syncing the scanner with the iPad, the scanner is ready for use in minutes. The cost attached to the recommended Bluetooth scanner is around $250, slightly expensive, but its use is seen as incredibly advantageous by freeing up the hands of the individual responsible for performing the material scanning on-site.

Figure 109: Opticon's Bluetooth Scanner (Opticon)

Brian Clarke, Director of Sales at Vela Systems, stated the combination of Apple's iPad, OtterBox's Defender Series case, and Opticon's Bluetooth scanner is the superior choice for implementing a material tracking system on any project. The versatility, innovativeness, and affordability of all of the items make this combination the ideal choice for the Fort Pickett project.

Software

One of the most critical items to establish is the type of material tracking software to utilize on the project. Currently there are a number of software on the market, including Latista and LocateWare, but the most prominent and commonly utilized is Vela Systems. Due to Vela Systems' growing versatility and its use on the Fort Pickett project for quality control and punch list items, I chose to investigate this software for further use.

Vela Systems is a company that specializes in field software, which in collaboration with tablet PCs has the capability of improving and expediting field processes. Although its capacity to manage and track materials is the primary focus of this analysis, their software has the ability to perform a number of other tasks, including composing field reports, work lists, safety inspections, punch lists, schedule updates, BIM model referencing, and documentation reviews.

Figure 110: Vela ("Vela Systems")

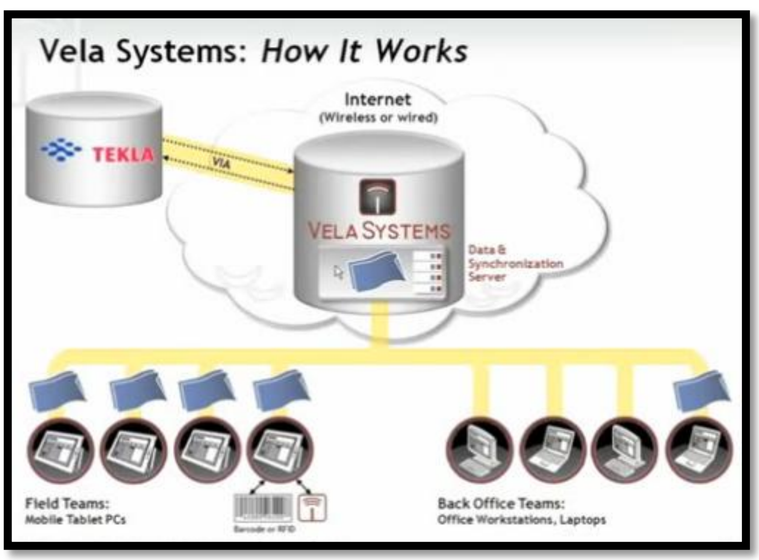


Figure 111: Vela Process ("Vela Systems")

Vela Systems operates through a webserver, so the database can be accessed in any location that has internet available. Regarding material tracking, the material tags are scanned using the tag reader and is then wirelessly sent to the iPad where it is registered by Vela Systems. The information is then synced to the Vela network by entering a wifi zone or through the use of Vela's mobile program, which allows updates anywhere using 4G wireless internet. Once the information has been updated, any computer with a login name can access the information via the internet. The figure to the left shows the relationship between the key components involved with Vela.

In addition to managing the materials through Vela, the items can be tracked through collaboration with BIM technology, a feature within Vela Systems called Field BIM. Currently, NavisWorks and Tekla are the two most utilized 4D modeling software on the market. The RTI incorporated a model of the billeting buildings within NavisWorks for constructability issues, but with the adaption of the material tracking system, NavisWorks can serve as a 4D indicator of the status of each piece. The planks can be identified in the model and assigned a color, so that at any given time an individual could simply open the model and know where each precast member is currently located.

As mentioned earlier, the Fort Pickett project used Vela Systems for safety and quality purposes, but did not get involved with the material tracking capabilities within the software. The project team purchased a 12 month license for Phase II that was available to two users. Each user paid $200 per month to access the software, which translated to $4,800 for the life of the project. In addition, the training for one day cost $1,800 and $1,500 for services. Overall, Barton Malow invested $8,100 for the use of Vela on the project.

Figure 112: Vela ("Vela Systems")

In order to implement the material tracking system, as well as potentially adding the Field BIM service, there are a few additional costs to the existing plan. After speaking with Brian Clarke, Director of Sales at Vela Systems, I was able to obtain an accurate cost estimate of the various services. The first and most important change would be to switch the Vela License from a pay by user fee to a project fee. Making the transition to an Unlimited User License for 12 months would cost the project an additional $2,800, which means a total cost of $10,900. This package includes material tracking, QA/QC, safety, and I&P. To add the Vela Field BIM, it would be an additional $4,200 plus $1,500 for services.

The last piece of software critical for implementation is the barcoding software. Since the barcodes were found to be the more appropriate tagging alternative, a software is needed to print the barcodes. Following the trend of Barton Malow at the Maryland General Hospital project, I decided to use Bartender as the tagging software. Bartender is incredibly cheap and provides flexibility by allowing the project team to print barcodes for whatever they please. Barcodes can be printed for materials, equipment, tools, or even restrict access in certain areas. The Bartender bar coding software can be purchased online for $250 and is a one-time cost, which can be later used on future projects.

Implementation

One of the first things to realize is that every project is different. Attempting to implement a successful strategy from another project may not be the right plan, but rather one should attempt to mold each plan specific for the intended project. It is important to define what materials are within the scope of work. Often, items are neglected by either the supplier, installer, or a third party because the scope was not defined adequately. It is dire to ensure that all of the necessary items are covered in full through numerous discussions and planning. For the case of Fort Pickett, only the precast hollow-core planks are being analyzed, but the use of material tracking has potential with a number of other items, including the structurally insulated panels, door hardware, MEP racks, and MEP equipment.

Another item to discuss is how far along the material management process to track the materials. Material tracking can be utilized beginning at the manufacturer and all the way to use by the owner for facility management purposes. Although there are a tremendous amount of advantages to using the tags for facility management purposes, they have little benefit for this analysis and the precast hollow-core planks.

The next item of discussion is to decide who is responsible for tagging the precast members. The best strategy for the project is to tag the planks at Gate Precast's facilities, the precast plank manufacturer. Within this path there are two alternatives for tagging the planks. Barton Malow could create the tags themselves and pre-associate the tags with each plank. This would mean that Barton Malow would go into Vela themselves and assign tag identification numbers for each plank and then give the tags to Gate Precast to place on the necessary planks upon completion. The other alternative would be for Gate Precast to tag each item using unassociated tags and then scan each plank upon completion, so that each member is linked to an identification number in Vela. Both alternatives are perfectly acceptable, but I feel that the second choice would be more preferred, since it reduces coordination problems. Regardless of the option, it is absolutely critical to establish this work relationship upfront and in writing in the form of a contract, so that legal responsibility can be mitigated properly by the project team.

Another item to consider is the responsibilities of each party along the material management process. It is important to develop a work process flow diagram supporting project specific procedures, complete with names, scheduled interviews, output requirements, and various other items. Within this process chart, individuals should be selected to be responsible for overseeing proper management of the material tracking. This person will be responsible for working with the stakeholders, vendors, engineers, superintendents, and warehouse personnel. This position should be seen as a leadership role, which could constitute a leadership opportunity for a younger member of a project team to take on. According to Jon Chesser, "Projects that have been successful have used new college graduates, since they are more familiar with technology and eager to gain responsibility (Chesser)." Using Chesser's recommendation, I believe that the best individual of the project team to take on this responsibility is Corey Pomeroy, the Quality Control Manager. He was assigned to the project for the entire duration of the project, work daily with the US Army Corps of Engineers, is responsible for quality control and safety items, and oversees the project's Vela System.

Another item to investigate is the project schedule in order to plan accordingly for peak periods of necessary tags. By using material delivery and installation schedules, tag utilization can be optimized, which opens the possibility of reusing tags and ordering less tags for use. Fig. 113 on the right shows the progression of the project's schedule over time with a representation of the tags utilized at any given time period along the vertical axis (Chesser). Although this is important consideration for most cases, since the planks are the only item being monitored, there is no chance of reusing tags, because all of the planks will be manufactured, transported, and erected at the same time period.

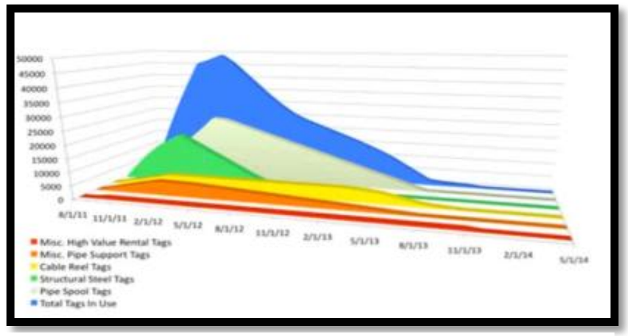


Figure 113: Tags in Operation vs. Schedule

The last major item to decide is the scanning procedures for the planks. The process begins at Gate Precast's facilities where the planks tagged upon creation of the precast members. It is here that the planks are scanned for the first time. Next, the tags are moved and prepared to be shipped. Prior to shipment, the planks are inspected for defects and if the planks are satisfactory, the members are scanned for the second time. Once the precast members arrive at the site, the responsibility for tracking switches to Barton Malow, specifically the Quality Control Manager. The third scan takes place as the planks are removed from the trucks and placed in the laydown area. Last but not least, the planks are scanned for a fourth time just before the planks are set into place. This ensures that proper plank is in set in its proper location. Fig. 114 below shows the entire material management process.

Figure 114: Material Management Process

Additional Uses

Although barcode and RFID tags are making enormous strides in the construction industry within material tracking, there are also a number of other uses for these systems. Tags could be used to track tools and equipment to prevent mishandling and wrongful installation. These systems could be used to improve security and maintenance on the job-site, such as restricting personnel from entering secure rooms with high priced materials. Televisions, cameras, and expensive electronics are high theft items, so implementing these tags for security purposes could greatly protect any project's assets. Tagging systems could be used to keep records of maintenance on equipment and retain proper documentation for warranties. Work on equipment can be scanned and documented, so that a standing record exists of its last known maintenance. Last but not least, RFID tags could be used for document control, which could contain shop drawings, specifications, change orders, and billings requests for materials. Although this analysis does not go into depth regarding these alternative uses of the tags, they are often used on other project, since the only additional cost is the tags themselves.

Results

In order to combat many of the problems the construction industry faces in terms of material management, implementing material tracking technology can act as a viable solution. The Fort Pickett Regional Training Institute project consists of a number of long lead-time items that are manufactured off-site and heavily influence the project schedule. Tracking systems target detrimental information gaps at the planning, inventory, monitoring, and maintenance steps, which can hopefully mitigate the risk of these high priority items. The only item addressed in this analysis was the precast hollow-core planks, the most critical item in the project's schedule.

In order to give an accurate estimate of the cost to implement a material tracking system on the project, I was able to obtain help via phone interviews with Adam Omansky, Co-Founder of Vela Systems, and Brian Clarke, Director of Sales. After presenting the details of my project and explaining the intended use of the material tracking system, they were able to recommend the most suitable system. From here, a cost estimate was compiled between the current Vela System at Fort Pickett, which used two users and non-Field BIM services, and the proposed system, which used an unlimited user license and the Field BIM package. Fig. 115 on the following page details the cost of each line item, as well as shows the additional cost to enact the material tracking system. Using the proposed system creates an additional $9,300 investment, but as you will see later in the results, this cost is minimal in comparison to the potential savings.

Cost to Implement Material Tracking			
Item	**Existing System**	**Proposed System**	**Additional Cost**
Vela			
System	$4,800	$7,600	$2,800
Base Services	$1,500	$1,500	$0
Training	$1,800	$1,800	$0
Field BIM	-	$4,200	$4,200
Field BIM Services	-	$1,500	$1,500
iPad	$600	$600	$0
OtterBox Case	$75	$75	$0
NavisWorks	-	-	$0
Opticon Scanner	-	$250	$250
Bartender	-	$250	$250
Barcodes	-	$300	$300
Totals	**$8,775**	**$18,075**	**$9,300**

Figure 115: Cost to Implement Material Tracking

In order to give a clear indication of the importance of erecting the precast hollow-core planks within the scheduled duration, I investigated the penalties for not turning the project over on the specified turnover date. For every calendar day that the project is over schedule, Barton Malow faces $2,281 in liquidated damages. This means that if the plank erection delays the project just one week, the initial cost of the material tracking technology is already outweighed by the cost of the liquidated damages. In addition, the U.S. Army Corps of Engineers evaluates every project that they represent and assign that project a grade. A poor evaluation can result in an exclusion from future opportunities that the Army Corps of Engineers represents for the military.

Although the system is relatively new to the construction industry, studies have shown a tremendous amount of upside. According to Stanford's Center for Integrated Facility Engineering, "material tracking technology eliminates 2% of job related QA/QC and eliminates reorders." This equates to a $440,634 in savings, a tremendous savings. This comes at a time where companies are looking outside of the box given the current state of the economy. Adam Omansky from Vela Systems reported that Vela users have found an average of 2-4 hours per day save in paperwork. Although it is difficult to assign a specific amount of savings to the project, the following companies, as well as a larger list found in Appendix DD, serve as examples of the benefits associated with Vela Systems and its material tracking technologies.

- **DPR Construction** – The USCS Porter B College project reported a 20% schedule acceleration and 28 man hours/week saved from the use of material tracking on the doors, frame, and hardware items by eliminating timely paperwork and inefficient practices.
- **Tocci Building Corporation** – CEO said "they save millions by measuring cost of deficient work items in Vela as they occur and using cost of quality reports to back charge subcontractors as needed."
- **Skanska** – Saved 10 days and $1,000,000 on the Meadowlands project due to better supply chain visibility, improved quality and accountability, and better schedule risk management.
- **Barton Malow** – Saved $468,000 from the use of barcode material tracking on the field commissioning from improved efficiency using the BIM model with data and documents linked to it.
- **Turner Construction Company** – EVP reported a savings of $900,000 because the project could report faster project completion times from improved information transfer from the field to the team and subs.
- **Hensel Phelps** – Saved $150,000 and headcount (1-2 hours/day/user) on the new aircraft launch system for the US Navy by automating field construction quality inspection processes, and using electronic documents.

Recommendation & Conclusions

The construction industry is incredibly dynamic and complex with material management constantly challenged with problems related to planning, ordering, receiving, storing, handling, distributing, site usage, and monitoring. Due to the complexity of these projects, these problems can often lead to low construction productivity, cost overruns, and delays on the job-site. With so many potential problems related to material tracking, Vela Systems and other competitors are leading the way towards minimizing these threats. After conducting a thorough analysis of the feasibility of a barcoding system's use on the Fort Pickett Regional Training Institute project, I believe that it is well in the best interest of Barton Malow to enact the proposed system.

MAE Requirements

The integrated BAE/MAE requirements for this thesis were achieved by incorporating a number of different topics and techniques from the following courses:

AE570: Production Management in Construction

For this course, short interval production schedules were introduced and examined from a number of aspects that could heavily influence a construction project's schedule and productivity. These innovative scheduling techniques were thoroughly examined and further reinforced with case studies and guest speakers. The information learned in this class was incredibly beneficial during the development of my short interval production schedule in Analysis #2 for the precast hollow-core plank system.

AE572: Project Development and Delivery Planning

For this course, project development and delivery planning practices were analyzed in order to provide a better background on various construction management strategies. The information learned through the course was influential on considering delivery methods and design coordination within my remaining three analyses: Analysis #1 Modularized Bathroom Units, Analysis #2: Feasibility of Precast Exterior Façade Panels, and Analysis #3: Integration of Material Tracking Technologies. All three analyses demand a tremendous amount of additional design coordination during the initial stages of the project life in comparison to traditional building methods. Using the knowledge obtained within this course, I was able to allocate proper attention to the planning and coordination necessary to deliver a more feasible and accurate investigation of each of the three analyses.

Final Recommendation and Conclusions

Over the course of the academic year, the Fort Pickett Regional Training Institute was thoroughly analyzed to identify potential areas of design and construction that have the opportunity to enhance the project. After serving as a member of Barton Malow's project management team, as well as conducting a thorough investigation of the project, four areas were chosen to be investigated. This report discusses the opportunities, implementation strategies, and results of enacting four main research topics: modularization of bathroom units, implementation of short interval production schedules, feasibility of precast exterior façade panels, and integration of material tracking technologies. Although these areas were found to provide the greatest opportunity for improvement, these analyses are not to be perceived as criticisms, but rather areas of study for educational purposes.

Analysis #1: Modularization of Bathroom Units

The first analysis looked to bridge the gap in the schedule between the time allocated towards the bathrooms and the much simpler construction of the bedrooms. In addition, the bathrooms demonstrated a number of quality issues due to the high concentration of work and number of trades located into such a confined work area. To rectify this problem, the use of bathroom pods constructed in an off-site facility was investigated for potential use. The design-build delivery system in conjunction with the repetitive nature of the buildings created an incredibly favorable situation, which was proved to be beneficial to the project after performing the analysis. The fit-out schedule was able to be accelerated by 8 weeks and save an estimated $213,903. Additionally, by using bathroom pods constructed in a controlled work environment, the quality of the bathrooms was found to be delivered in a standard that was unachievable in the field. Although the use of pods generates heightened coordination issues, the use of modularized bathroom units was found to be well in the best interest of the project team.

Analysis #2: Implementation of Short Interval Production Schedules

The second analysis investigated the use of short interval production schedules (SIPS) on the Fort Pickett project, in order to help mitigate the risk involved with erecting the precast hollow-core planks. The planks were determined to be the most critical activity on the project's schedule with the ability to interfere with the second floor's structure, building enclosure, and fit-out of the building. For this reason, a SIPS was developed to provide better coordination and security of the crew reaching the scheduled durations. The SIPS looked to provide more consistent work sequences and improve the flow of construction from on building to the next. After performing the analysis, the SIPS was found to shorten the sequence of work by 11 work days and save $117,524. With liquidated damages valued at $2,281 per day and a number of dependent work activities following the erection of the planks, the use of SIPS is recommended.

Analysis #3: Feasibility of Precast Exterior Façade Panels

The third analysis aimed to reduce the lengthy duration associated with constructing the exterior CMU veneer. Construction of the masonry wall proved to be a troublesome area in regards to schedule and quality. To resolve these issues, the use of precast concrete panels was investigated for feasibility on the For Pickett site. After conducting a thorough study, the panels were found to be incredibly beneficial to the project. The panels were able to save 14.5 weeks from the building enclosure schedule, as well as save $1,094,129. Although the architectural design was slightly altered, many of the features were able to be retained. In addition, the panels provide a much higher quality product, since the panels can be manufactured in a controlled work environment. Due to the impact made in the building design using precast panels, the decision ultimately rests with the owner and architect, but it is my recommendation that the project team proceed forward with the plan proposed in this study.

Analysis #4: Integration of Material Tracking Technologies

The fourth analysis looked to provide better coordination and security with the management of the precast hollow-core plank activities. This activity served as the most critical schedule item, making the planks an opportune area of focus for further coordination through the use of material tracking technology. After researching the influence of material tracking on past and existing projects, it was found to be well in the best interest of the project team to enact a material tracking system. The $9,300 price tag attached to implement the entire system is believed to be minimal in comparison to the future costs associated with rectifying a potential delay in the schedule from mishandled or manufactured precast floor planks.

The analysis areas researched within this report were all determined to be incredibly advantageous to the Fort Pickett project team, specifically in addressing the schedule concerns. Although this report provides results that serve as a benchmark for the AEC industry for innovative construction practices, the work involved in this paper have provided me with a much stronger foundation of the challenges and correctives practices that are gaining momentum in the construction market. It is hoped that this report helps better the AEC industry, as well as myself in future construction related endeavors.

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