ANALYSIS 3: CURTAIN WALL INSTALLATION PROCEDURES

MAE Graduate-Level Component

Problem / Opportunity Statement

The curtain wall of Constitution Center is another construction management issue that will provide an area for research. The installation of the façade played a major role in how the exterior site work was phased and researching the installation will allow the productivity to be tracked.

MAE Graduate-Level Component

With this research, *CE 533 – Construction Productivity Analysis and Performance Evaluation* graduate class will be incorporated into the thesis research. Within this class, productivity measurements, control, and forecasting were addressed, along with the factors affecting productivity and the methods for improving the productivity. All of these elements play an important role in the installation of the curtain wall.

Potential Solution(s)

A potential solution to the installation of the curtain wall is to use a prefabricated system instead of installing each piece separately. This may have potential schedule and cost saving impacts that affect the overall construction of Constitution Center.

Research Steps

1. Research the panel descriptions (dimensions, weight, etc.) and become familiar with the installation requirements.
2. Determine how the panels were shipped and how often.
3. Determine where the panels were stored and if there were any restrictions.
4. Determine if preparation was needed before the panels were installed.
5. Determine what type of equipment was needed to install the panels.
6. Interview the DAVIS project team to see if they kept a record of how many people worked on the installation each day and how many pieces were installed on that particular day
7. Determine if weather was a factor in the installation process.
8. Determine the Rules of Credit using R.S. Means
9. Using CE 533 information, calculate:
    1. Expected and Actual Productivity
    2. Expected Performance Factor
    3. Planned and Actual Manning
    4. Actual Percent Complete
    5. Control Budget
10. If any delays occurred, determine the factors for the delays.
11. Compare this data to the data collected from the CE 533 semester project of the Dickinson School of Law to determine if the installation procedure is productive.

Expected Outcome

The expected outcome of this research is to familiarize myself with the curtain wall installation procedures. After that I will be able to apply my knowledge learned in CE 533 to

determine the productivity of the installation. If it does not met a satisfactory productivity I will determine other productive ways to install the curtain wall.

> ***Note:*** Although an analysis of the actual curtain wall panels are not permitted due to security reasons, a study of the façade from a constructability perspective will take place and will not be affected by the security requirements.

Analysis

On the site of Constitution Center, there are nearly 5,000 curtain wall panels that need to be installed. The subcontractor that is responsible for their installation is Enclos Corp. This company is based out of Eagan, Minnesota and has completed over 145 custom curtain wall systems. Some examples include the Newseum and Federal Triangle based out of Washington, DC, Children's Hospital of Philadelphia, PA, and the Gannett/USA Today Headquarters in McLean, VA.

Constitution Center is another custom system that Enclos has been brought on to install. The overall cost of the exterior curtain wall is $46,697,203 or $31.13/SF. This price is 19% of the total cost of the building. Additionally, it was determined the each curtain wall panel is $9,626/panel. The curtain wall panels are different sizes depending on their location on the building. Figure 20 represents a mock up of the streetside curtain wall. For example, the plaza level storefront panels are 5' by 12' to 13' weighing about 1,100 to 1,300 pounds. However, levels 2 to 7 are 5' by 23' and weigh 2,300 to 2,500 pounds. Finally, levels 8 to 10 are 5' by 10' and weigh only 500 to 600 pounds. Figure 22 shows the majority of the different curtain wall pieces that need to be installed. As one can see, for this particular section there are ten different types of curtain wall panels. Since the panels are different sizes and weighs, the manpower for them may vary. Additionally, the training to install each type is similar, but different depending on the equipment needed to do the setting of the panels. For the streetside curtain wall, a crane was used to set levels two through eight. However, the courtyard curtain wall was installed using a monorail. Figure 15 is a photograph of the Enclos crew using the monorail to install the curtain wall panel. As you can see from there picture, there are 3 people working on the installation, while another person is putting the finishing touches on the previous piece. One the other hand, the storefront panels "they have used multiple types of equipment pending the existing conditions found."[23]

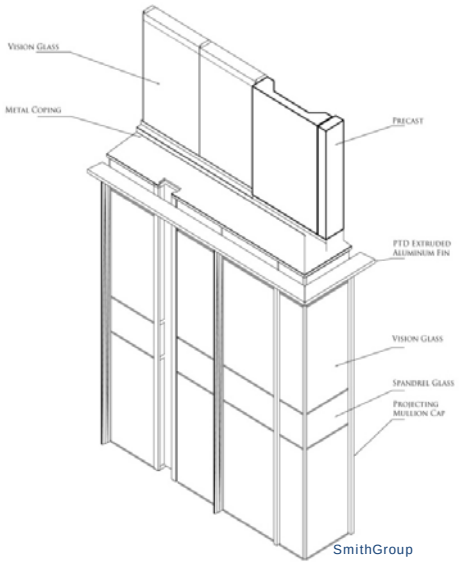
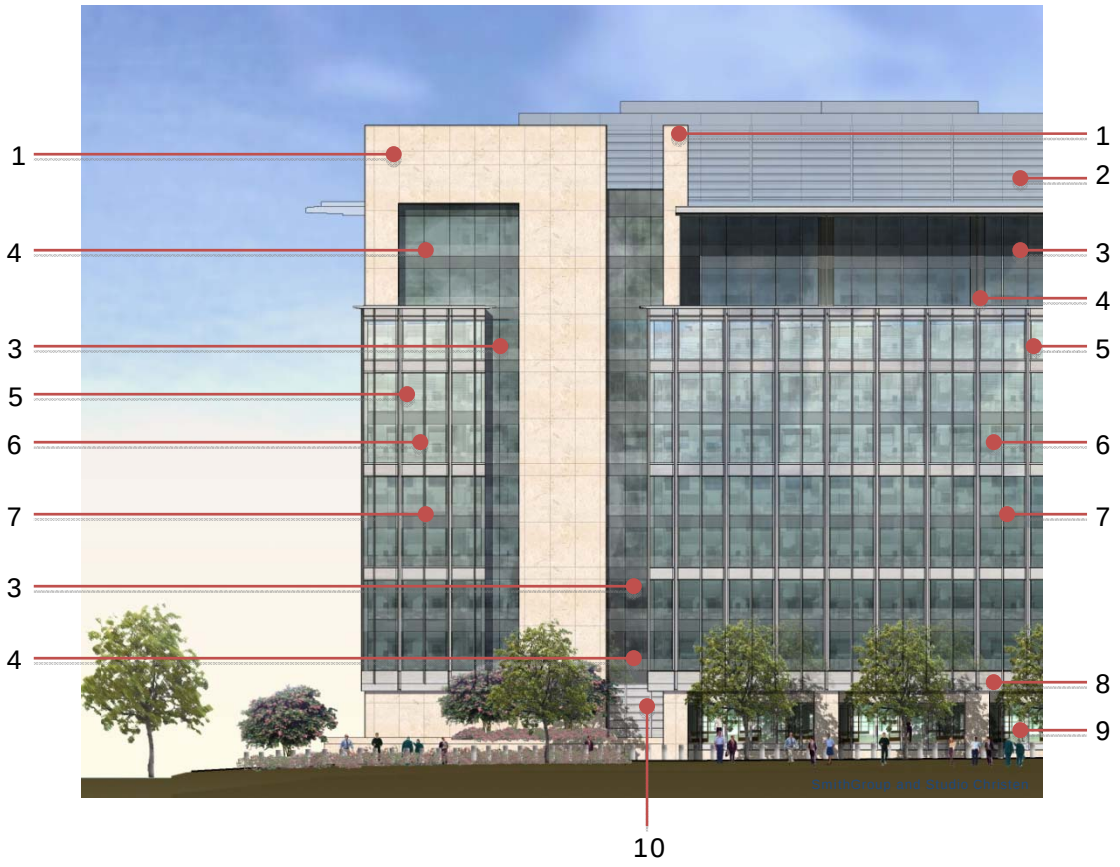


Figure 20: Streetside Laboratory Mock Up

Figure 21: Photograph showing the installation of a curtain wall panel

[23] (Ulrich)



1. Precast Concrete Panels
2. Penthouse: Metal Panels & Louvers
3. Vision Glass – (30" of frit)
   GL-3 (2nd and 3rd Floors)
   GL-5 (4th Floor and up)
4. Spandrel Glass
   GL-3S (2nd and 3rd Floors)
   GL-5S (4th Floor and up)
5. Vertical Aluminum Mullion
6. Vision Glass – (30" of frit)
   GL-4 (2nd and 3rd Floors)
   GL-6 (4th Floor and up)
7. Spandrel Glass
   GL-4S (2nd and 3rd Floors)
   GL-6S (4th Floor and up)
8. Metal Panel
9. Vision Glass – GL-2
10. Spandrel Glass – GL-2S (at Plaza Only)

Figure 22: Street Facade Glazing Rendering

The installation of the panels started on March 21, 2008 on the north side of the building. The reason why they started with this is area is because the northeast quadrant will be the turned over first. Additionally, the L'Enfant metro station entrance was scheduled to be reopened on July 1, 2008 and there were safety concerns, therefore the north façade needed to be completely installed before its opening. Table 10 is a summary of the sequence for the curtain wall demolition and installation. As one can see, the curtain wall is scheduled to be completed at the end of April 2009.

Task	Duration	Start	Finish
Exterior Façade	366	10/1/2007	2/23/2009
North	328	10/1/2007	12/31/2008
Fabrications for Slab Extensions	32	10/1/2007	11/13/2007
Demo & Shoring 2nd Floor at Blast Beams	10	11/6/2007	11/19/2007
Slab Extensions	1	12/17/2007	12/17/2007
Encase Perimeter Columns at Blast Beams	1	12/5/2007	12/5/2007
F,R&P Blast Beams	1	1/18/2008	1/18/2008
Fab Anchors & Plates for Curtain wall	1	1/21/2008	1/21/2008
Install Anchors & Plates for Curtain wall	1	3/12/2008	3/12/2008
Erect Curtain wall	91	2/22/2008	6/27/2008
Erect Metal Panels	20	7/28/2008	8/22/2008
Erect Exterior Storefront	17	11/12/2008	12/4/2008
Erect Exterior Stone	17	12/9/2008	12/31/2008
East	311	10/1/2007	12/8/2008
West	266	1/22/2008	1/27/2009
South	272	2/8/2008	2/23/2009
NE Corner - Erect Precast	24	1/31/2008	3/4/2008
NW Corner - Erect Precast	21	4/23/2008	5/21/2008
SE Corner - Erect Precast	21	5/22/2008	6/19/2008
SW Corner - Erect Precast	21	6/20/2008	7/18/2008
Courtyard Façade	332	1/22/2008	4/29/2009
North	232	1/22/2008	12/10/2008
Fab Anchors & Plates for Ctyd Curtain wall	25	1/22/2008	2/25/2008
Install Anchors & Plates for Curtain wall	21	4/11/2008	5/9/2008
Erect Structural Steel & Deck	16	5/12/2008	6/2/2008
Erect Curtain wall	26	8/26/2008	9/30/2008
Erect Metal Panels	1	10/13/2008	10/13/2008
Erect Storefront	12	11/25/2008	12/10/2008
East	207	2/8/2008	11/24/2008
West	163	5/12/2008	12/24/2008
South	247	5/20/2008	4/29/2009

Table 10: Summary of the Facade Sequence

According to Enclos, the steps of the installation are as follows:[24]

1. Boot span between frames at sill starter chicken head
2. Hook up lifting lug to picking bar
3. QC unit (check that gaskets are installed, gaskets are long enough, all access holes are sealed, ab clips are installed and not damaged)
4. Lift frame vertically and wait for top half of crew is ready for installation
5. Align frame male leg of set frame and female leg of frame being installed.
6. Snap female leg and male leg together
7. Make sure ab clips did not snap on the outside of the female leg
8. Slide frame over the two alignment bars (stab bars)
9. Shoot the frames height and engage the set screw to maintain the frame height.

These steps are important to the productivity of the installation. If one of the steps is not completed, then the entire setting has to be redone. Also, if the crew is not properly trained in how each panel needs to be installed then the productivity will decrease. Typically, the only preparation work needed was to unwrap the panels from the delivery. Table 11 gives a breakdown of how many people were on a typical crew size for the installation depending on its location and equipment needed to install the panels. A breakdown of how many people Enlcos had onsite can be found in Table 12 and Appendix A. Depending on the day, there

[24] (Sullivan)

were usually an engineer, foreman, helper, mechanic, worker, project manager, and/or apprentice on the site for Enclos. Additionally, four more people were needed to unload the delivery of the panels. These people were separate from the crew setting the panels. The deliveries were arranged in advance in order to ensure the proper number of people were onsite to handle the installation and deliveries. For the units spanning two floors (streetside levels 2 – 8), typically a delivery consisted of 12 panels. However, for the single span units (courtyard), there are usually 18 to 24 panels on the trucks. After the panels were delivered, they were than stored on the proper floor in order to ensure a quick installation once the crew made it to that floor. One of the requirements for the storage was that they had to be in the center of the building, close to the columns so that the floor did not have any problems holding a large amount of additional weight.

Location	Level	Crew Size	Equipment
Streetside	2 – 8	6	Crane
Streetside	9 – 10	4	Crane
Courtyard	2 – 10	6*	Monorail
Storefront	1	4 – 6	Multiple Types

Table 11: Crew and Equipment Breakdown for the Exterior Curtain wall
** 4 people used for the monorail installation, and two would follow behind for the sealants and/or boot*

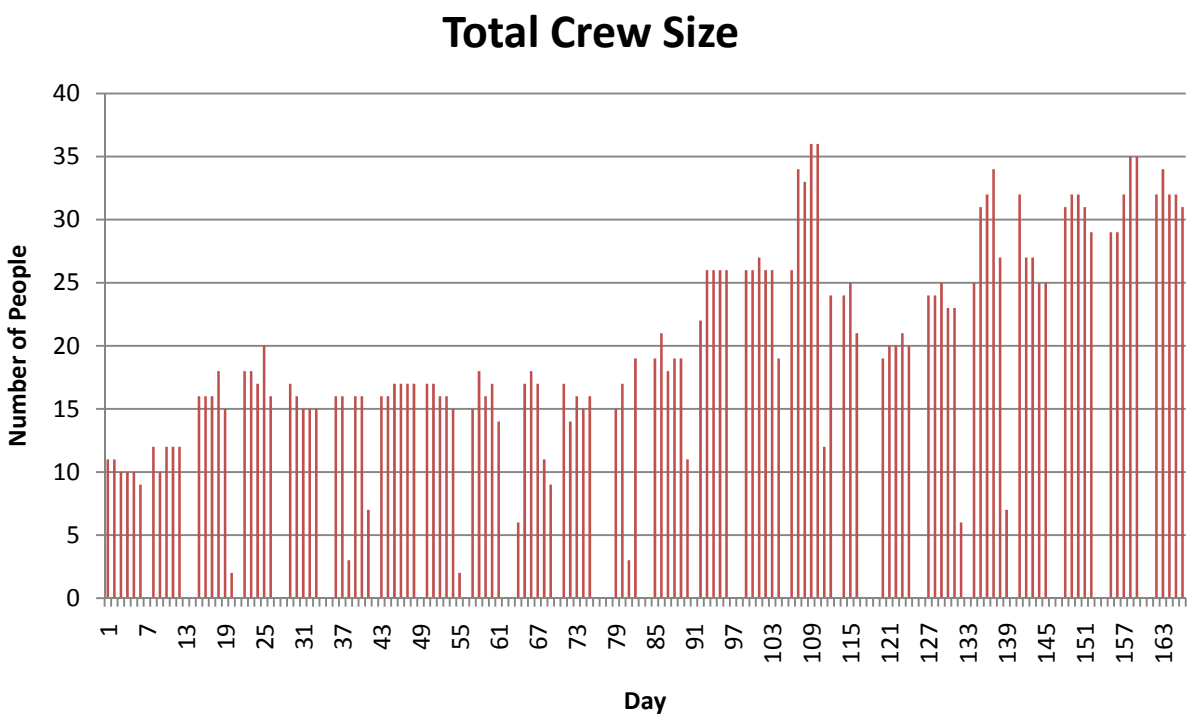


Table 12: The daily crew size for Enclos Corp.

A typical crew for the streetside curtain wall averaged between 20 to 30 panels per day. However, 35 to 40 panels for the courtyard could be installed a day. The reason for the setting difference is because the streetside panels spanned two floors, while the courtyard panels were only single spans. As one can see from Table 13, the installation of the panels varied depending on the location. Additionally, please note that there are numerous days where they did not install any panels. Most of these days are on weekends when they did not work. The only time they worked on weekends was if they fell behind schedule.

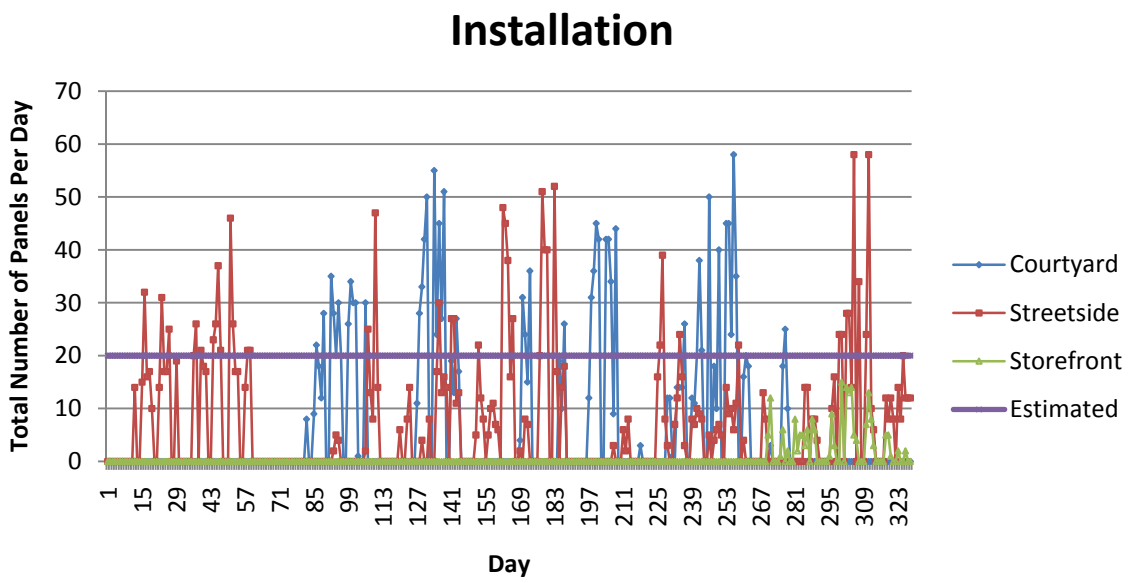


Table 13: Actual number of panels installed per day

Throughout *CE 533 – Construction Productivity Analysis and Performance Evaluation*, the steps of productivity were outlined in order to determine if a project had good productivity. The first step was to determine the Rules of Credit. However, since the curtain wall panels require little preparation, there is not a need to have Rules of Credit. The next step is to determine the expected and actual productivity of the installation. To do this, the total manpower was divided by the total number of panels. The numbers used for this calculation can be found in Appendix A, Appendix B, Appendix C, and Appendix D. Table 14 represents these calculations in a table format. As one can see, the estimated productivity is around 2.22 and the majority of the actual productivity is much lower than the estimated. Please note that from August of 2008 to March of 2009 the manpower was not provided.

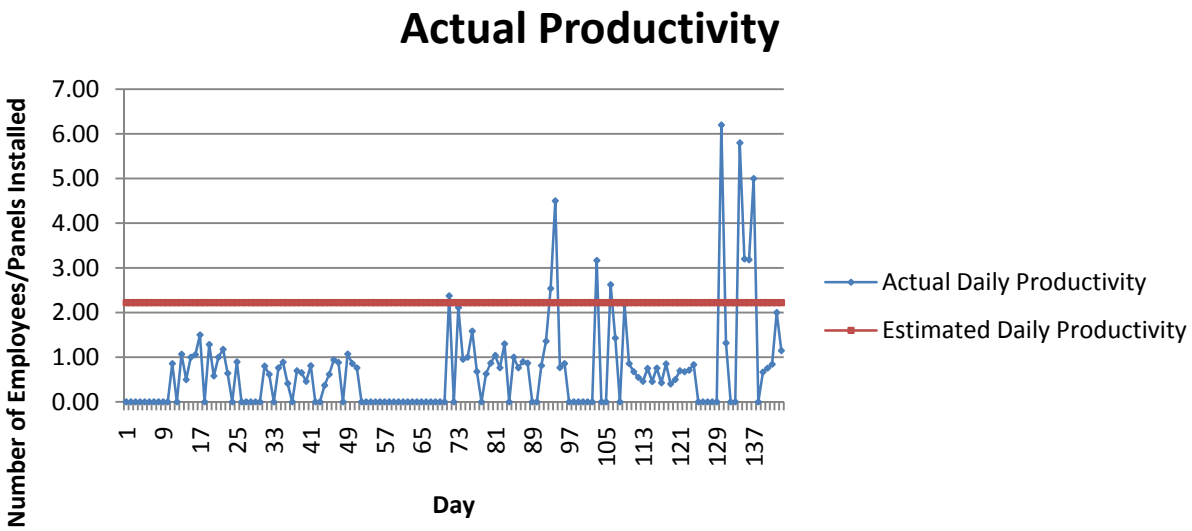


Table 14: Actual and Estimated Daily Productivity

After the productivity was calculated, the expected performance factors were established. In order to do this calculation, the estimated number of panels per day is divided by the actual number of panels per day. This information can be found in Appendix B, Appendix C, and Appendix D. Again, as one can see, the estimated performance is one and most of the actual performance is slightly above one.

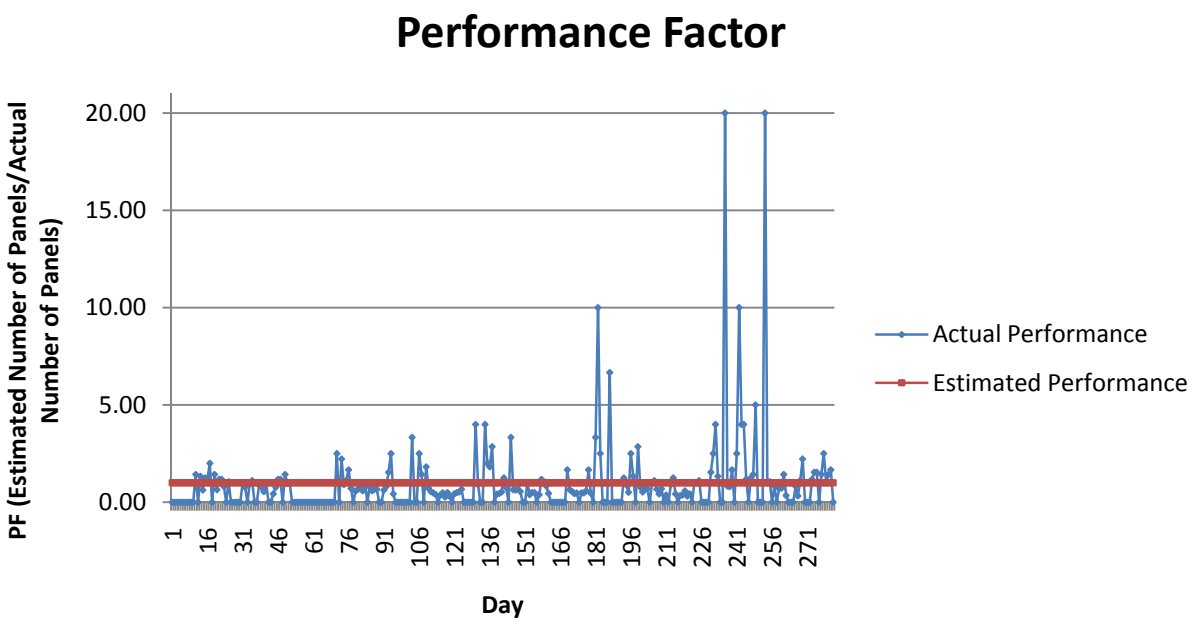


Table 15: Actual and estimated curtain wall installation performance

After calculating the performance factor, the planned and actual manning needs to be compared. As discussed on page 41, the planned manning depends on which curtain wall pieces were being installed (please see Table 11 for more information). The actual manning is shown both in Table 12 and Table 16. As one can see from the table, the most employees onsite were workers who were actually doing the labor of installing the panels.

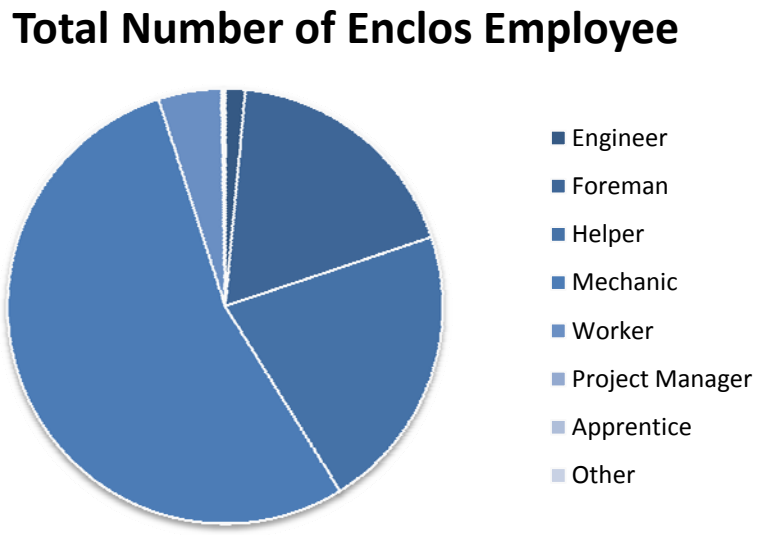


Table 16: Total Number of Enclos Employees

Additionally, the actual percent complete must be determined. In order to do this, the cumulative number of panels was compared for both the actual and the estimated number of panels per day. Table 17 shows the comparison of the two data. As one can see, the actual number was constantly lower than the estimated number of panels per day.

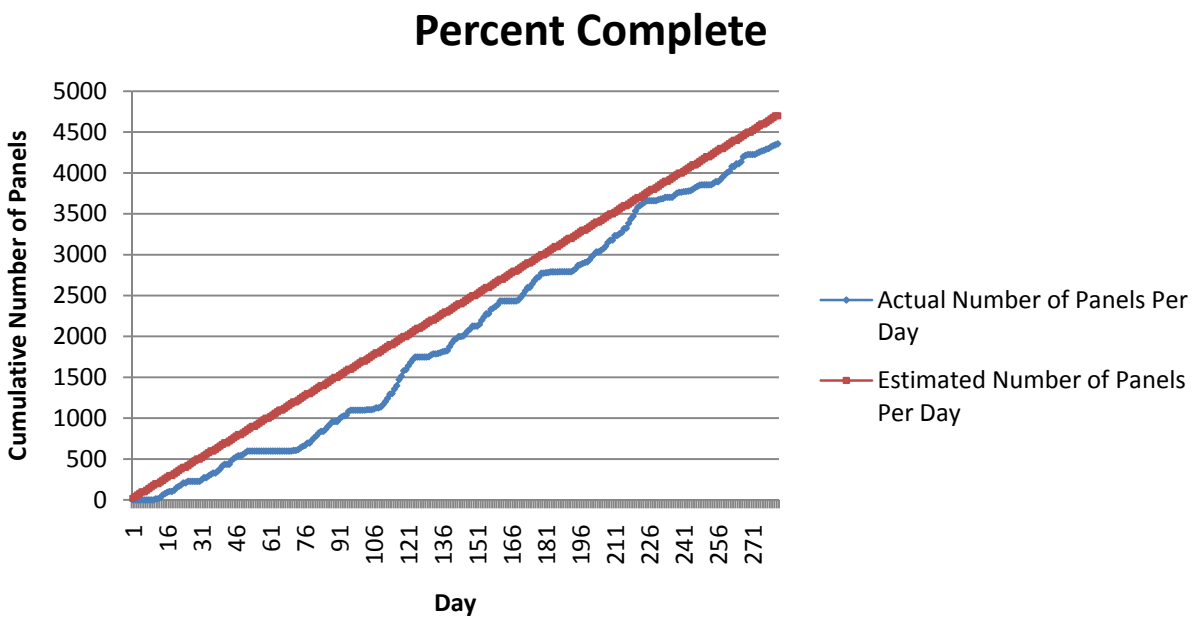


Table 17: Percent complete for curtain wall installation

Therefore the final step was to determine the control budget of the project. Since it was determine that each panel had a cost of $9,626/panel, the control budget is cumulatively adding the cost of the panels compared to the number of panels installed per day. Table 18 shows the control budget of the period of time the curtain wall was being installed. This information helps the contractor and owner determine the amount of money needed to be paid based on the actual number of panels installed.

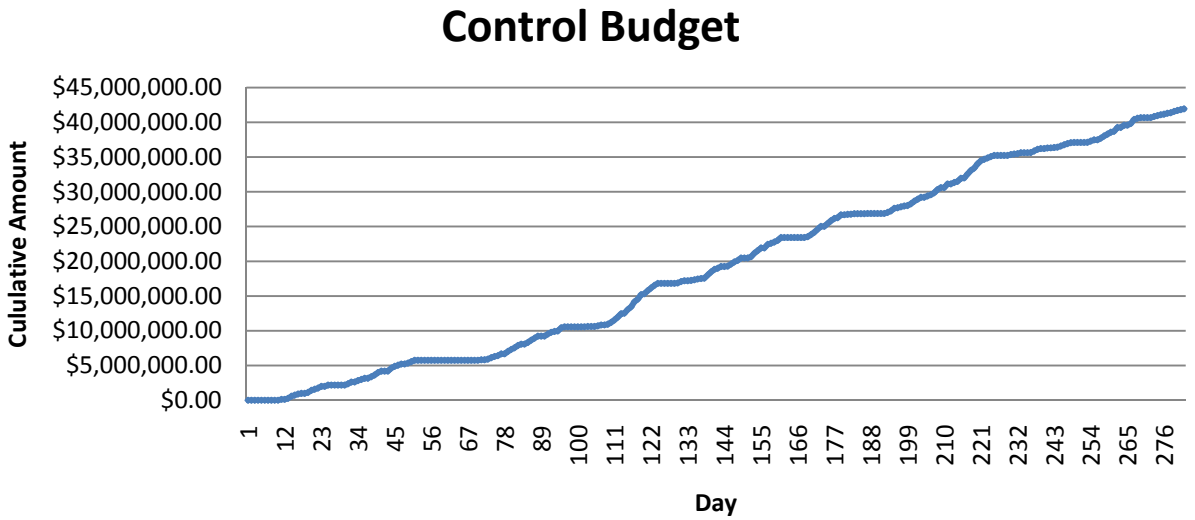


Table 18: Control budget for the cumulative number of panels installed per day

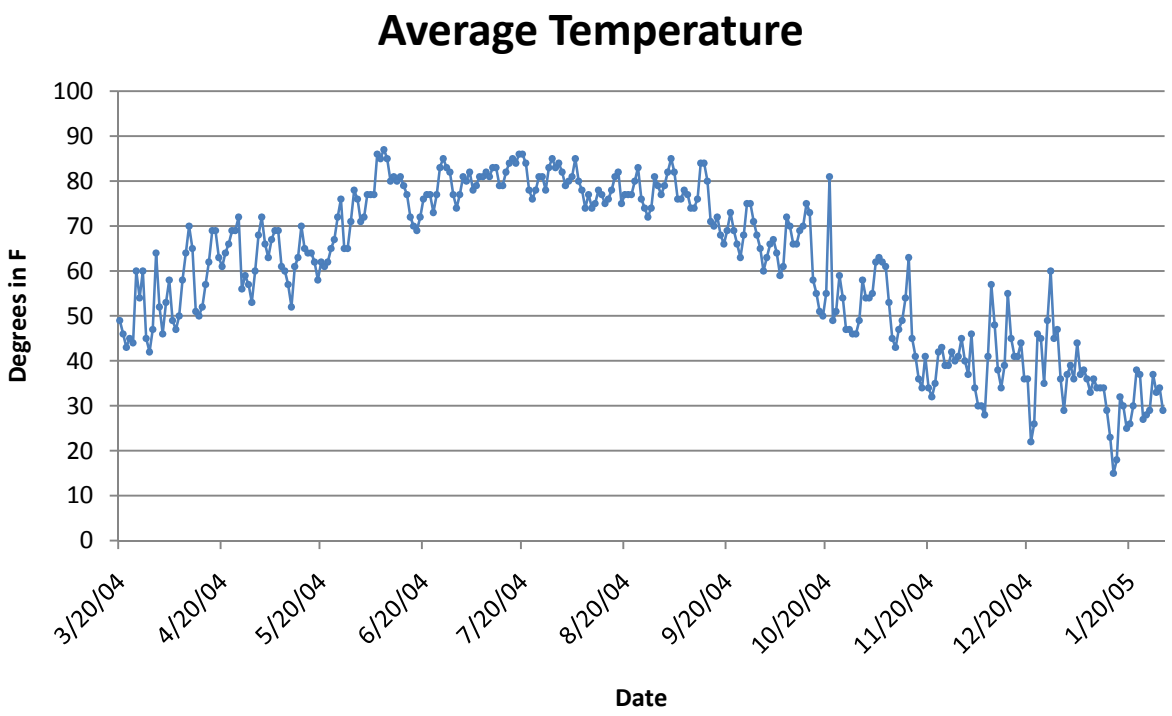


Table 19: Average temperature for the curtain wall installation

After all of the above information was collected, it was necessary to determine if the installation was actually productive. Overall, one can tell from Tables 14, 15, and 17 that it is slightly below the estimated values. There are several reasons why this may have occurred. First, weather could have played a large part in the delays. Appendix E contains the weather data that was researched. Table 19 illustrates the average temperature, while Table 20 shows both the daily high and low temperatures. Additionally, along with the actual temperature, precipitation and wind were a factor for delay. Both of these delays can be found in Tables 21 and 22. Overall, weather is typically a factor for delay in any construction project. Another delay was when rebar interfered with the anchors that had to be updated to support the panels. Since the waffle slabs have tensioned rebar from the original construction, it was a concern when rebar was struck during the installation of the new anchors. These anchors are shown in Figure 20 to the right. As one can see, there are typically two bolts need to secure the anchors, however, if rebar was encountered, then three or more bolts would be necessary to properly fasten the anchors. Another typical delay on projects is when other trades are working in the same area. Since the panels were stored in the middle of the building, in order to move them to the exterior, the pathway needs to be cleared of all other trades. Typical trade interference included the MEP contactors. A final factor for delay is when a frame was found to be deficient. If this occurred, then the installed would be slowed to allow time to fix the problem. Typically, since the building is almost identical on the mirrored side, a panel could be barrowed in order to not delay the installation that long.

Figure 23: Curtainwall panel's anchors

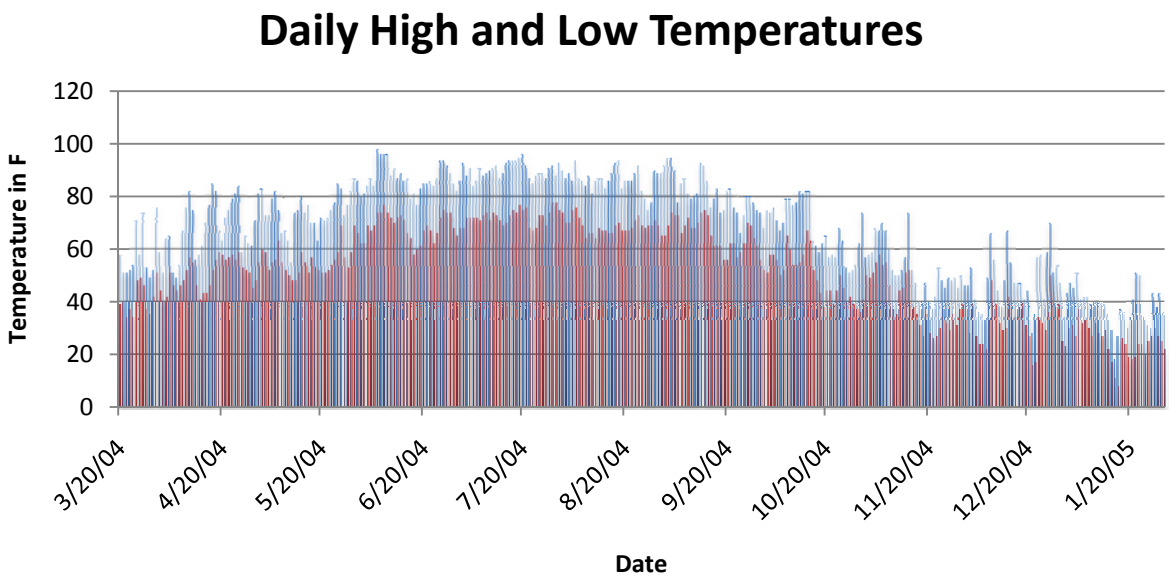


Table 20: Daily high and low temperatures for the curtain wall installation

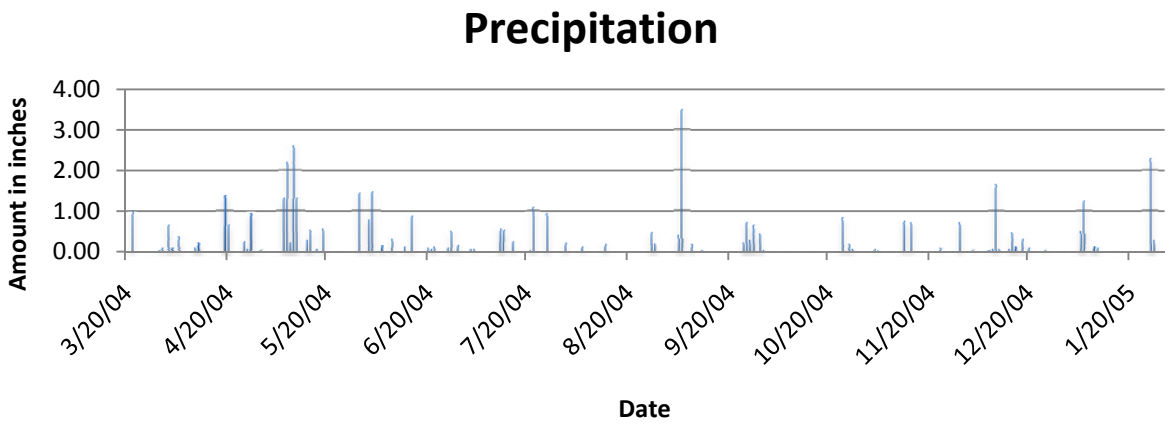


Table 21: Precipitation during the curtain wall installation

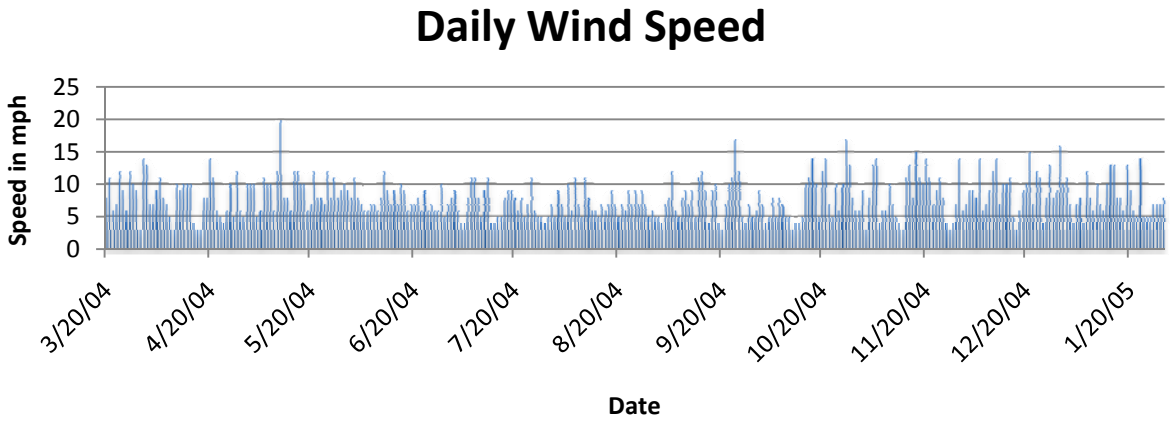


Table 22: Daily wind speed during the curtain wall installation

Outcome

Overall, it was learned that the productivity of the curtain wall installation was slightly under the estimated productivity. However, in order to get back on schedule there are several areas they could accelerate in. First, as long as the deliveries could be pushed ahead, they have the opportunity to work on weekends in order to put in 16-20 additional hours of installation. If these types of shifts are use, then the site will more than likely be less congested and quieter. Also, if possible, Enclos could bring in double the manpower in order to have two (or more) crews installing the panels. However, with this option, there will be a need for more tools and equipment. Overall, there were several factors that played a part in reducing the productivity, if Enclos feels it is necessary, there are areas where they can accelerate the installation if necessary.