THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF ARCHITECTURAL ENGINEERING

UNITY MEMORIAL HOSPITAL: A CONSTRUCTION CASE STUDY

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A thesis
submitted in partial fulfillment
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in Architectural Engineering
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ABSTRACT

UNITY MEMORIAL HOSPITAL
EMERGENCY ROOM EXPANSION &
CLINICAL DECISION UNIT (CDU) RENOVATION

BUILDING INFORMATION:

- **Occupancy**: Healthcare
- **Renovation Size**: 26,000 square feet
- **Total number of levels**: 4
- **Dates of construction**: Aug 2018-June 2019
- **Project delivery method**: CM at Risk
- **Contract Type**: GMP

PROJECT TEAM:

- **Owner**: Unity Memorial Hospital
- **General Contractor:** Turner Construction
- **Architect / Structural & MEP Engineer:** Stantec Architecture and Engineering LLC

ELECTRICAL SYSTEM:

- Use of existing panels and power supply
- Conduit relocation and refeeding
- New nurse-call system
- Rough in for new security system

MECHANICAL SYSTEM:

- Demolition of current AHU (Installation of replacement AHU by others)
- VAV Boxes with reheat terminal units in patient rooms (recycled)
- 3 exhaust fans ducted to roof
- Duct demolition and relocation done in phases, as described in construction process

ARCHITECTURE & CONSTRUCTION:

This project is a renovation of storage space, which will start with significant demolition. This will be an emergency department expansion of 20+ beds for a new CDU. There are also new access hallways and office space. The most unique aspect to this project is that this renovation includes a linen and mail room that need to remain operational for the duration of the project. There are 3 phases of construction to that allow for the demolition and rebuilding of these two rooms in particular.

STRUCTURE & ENVELOPE:

- Building structure will not be changed.
- Space is adjacent to a loading dock (building envelope will not need to be penetrated for equipment load-in)
- Asphalt roof penetration

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- My Pappy Jack, I know you’re watching over me! I love you!

Executive Summary

Unity Memorial Hospital is currently undergoing renovation construction in multiple areas. Turner Construction is renovating the areas of the Clinical Decision Unit and Emergency Room Expansion, which also includes “back of house” areas, such as storage, mail, and linen rooms. The area, in total, is approximately 26,000 square feet and is being delivered under an $8.6 million guaranteed maximum price (GMP) contract.

This hospital renovation project will be used as a senior thesis case study project. This senior thesis project utilizes information learned throughout the five-year architectural engineering program to perform three analyses pertaining to the building’s construction. Additionally, a research topic and two breadth topics were evaluated.

Unity Memorial Hospital (UMH) is a fictitious name that is used throughout the duration of this paper to ensure the confidentiality of the building owner.

Theme

The theme that runs across all four of the analyses is that the project team must ensure that Unity Memorial Hospital remains fully operational during construction while coordinating with the owner’s additional renovation projects that impact sequence and scheduling. The analyses aim to pursue new solutions and applications to make the construction process easier and more efficient.

Analysis 1: Phasing Analysis of Temporary Pharmacy Relocation

The first analysis completed involves improving the phasing of the project so the work can be completed more fluidly and efficiently. This was done by analyzing how a temporary pharmacy relocation would aid in the construction of the mail and linen rooms. The driving force behind this analysis is that the new pharmacy project is six months behind schedule and forced the original phasing plan to be modified. This was expected to be a more efficient plan with less wasted time in the movement and relocation of workers and materials to a space. It was concluded that the temporary pharmacy would be more cost and schedule effective, as well as permit a more fluid construction flow.

Analysis 2: Managing Project Conflicts through Portfolio Management

This analysis stems from the conflict arising from the use of multiple concurrent contracts causing the construction projects interfering with one another. The goal of the analysis was to evaluate a number of portfolio management strategies utilized by numerous owners and owner's representatives. Using this research, a comparison was done between the original strategy and the alternative strategies, which has led to an alternate course of action for packaging different scopes of work within Unity Memorial Hospital. It was concluded that UMH can evaluate contractor selection, phasing and logistics, delivery method, and funding to better enhance their project and portfolio management strategy.

Analysis 3: Schedule Improvement through Prefabricated Ductwork

Because Unity Memorial Hospital is on a strict schedule of completion, the project team is looking for ways to save construction time. One of the solutions to this problem that was analyzed as a part of this depth is the effect that prefabricating the above ceiling systems has the project schedule, as well as the budget. Laser scanning was suggested to gather information on the existing conditions and assemble prefabricated racks. It was concluded that although 3 weeks of schedule time would be saved, the costs outweigh this savings due to the potential logistics impacts.

Analysis 4: Virtual Reality's Effect on Value Engineering

The final analysis was done through research of virtual reality and its applications in the construction industry. On the Unity Memorial Hospital Project, the construction manager utilized virtual

reality to improve their value engineering practices. Further research was performed through a series of interviews to evaluate ways that virtual reality can affect value engineering.

Chapter 1

Project Background

1.1 Project Description

The Unity Memorial Hospital project is a 26,000 square foot renovation performed by Turner Construction and designed and engineered by Stantec in the North Eastern Region of the U.S. The renovation of storage space, a pharmacy, linen and mail rooms, and offices will first start with significant demolition of interior walls, moving of electrical conduit, and the removal of most mechanical, electrical, and plumbing systems to make room for new, more efficient ones. There are four total floors in this building; however, the renovation is only taking place on the second floor. Of course, there will be small work on the remaining floors for utilities to enter and exit the building via the roof and floors below.

These spaces will be converted into an emergency department expansion of approximately 20 beds for a new CDU (clinical decision unit), which includes a nurses station and staff offices and lounges, as well new storage, mail, and soiled linen spaces, commonly called the "back of house" spaces. The overall floorplan of the hospital is shown in Figure 1, and the shaded portion is the specific location for where the renovations will take place. As depicted, this is just a small portion of the hospital, which will need to continue to be fully operational at all times.

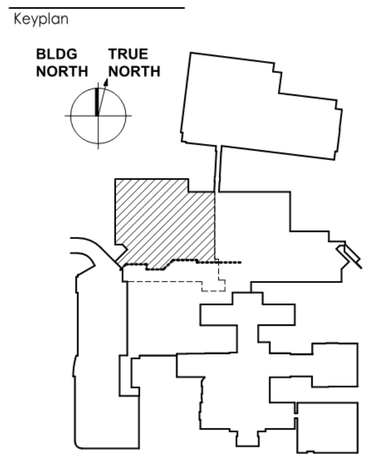


Figure 1: Unity Memorial Hospital Floor Plan Showing Renovation Location

1.2 Client Information

The primary tenant of the Unity Memorial Hospital is the owner of the building and the surrounding campus. This owner is also a large health insurance provider, in addition to a healthcare provider. The reasoning behind this renovation is that the owner's insurance arm has recently discontinued their relationship with another local healthcare provider. Their contract originally included a reciprocity clause for health insurance, meaning that no matter your health insurance carrier, you could attend either hospital as a patient. However, with their split, patients will be locked into one hospital or the other, depending on their health insurance provider. It has been anticipated that the capacity of the hospital will need to increase to accommodate more beds, as more patients will be attending Unity Memorial Hospital.

For this reason, the owner is very strict on the schedule of this project. The splitting of the two insurance providers will officially go into effect on July 1, 2019. It is very important for construction to be completed by this date so that the space can be used.

Another requirement of the owner is that the hospital must continue to function as is. The most important aspect to this renovation is keeping the linen room functional; it is critical to hospital operations (the new one must be complete before the demolition of the old one to make room for the new hospital rooms that will go in that area). The phasing and schedule of the project needs to align with this functionality.

1.3 Project Delivery Method

A Construction Manager at Risk strategy is being used to deliver this project. This strategy was chosen along with a guaranteed maximum price (GMP) contract to involve the general contractor in the demolition and logistics as soon as possible, as well as provide the project to the owner at a lower price. Turner Construction is not contracted to the design team in any way.

For the demolition, Turner has subcontracted to their own self-perform group. The other trades have not been awarded subcontracts yet; however, the subcontracts are out for bid to several different subcontractors in the area.

Further coordination will be needed due to other additions and renovation projects that are also taking place in the hospital. The mechanical systems for this renovation project will be sharing an air handling unit with other systems and renovations that are occurring in other parts of the hospital. For that reason, the owner has contracted directly to a mechanical company, McKamish, to install the air handling units that will be shared by two renovation projects. For the organizational chart that shows contractual relationships for the Unity Memorial Hospital Renovation Project, please see Figure 2.

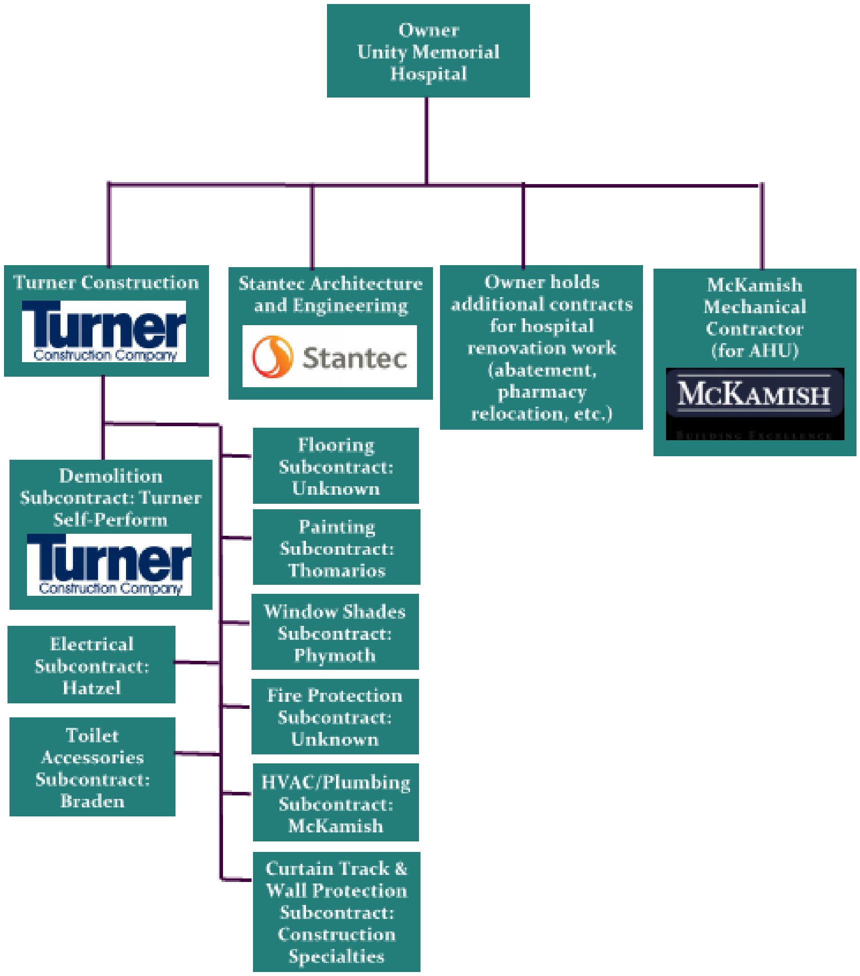


Figure 2: Project Delivery

1.4 Project Team Staffing Plan

Unity Memorial Hospital is a project that is being run out of Turner Construction's Special Projects Division (SPD). This means that many of the staff on this project are also working on other projects throughout the division. Usually, the project manager is based in the office, not on the project site, which is typical of a renovation project such as this. However, the superintendent will be on-site at all times, including through the demolition process. During the preconstruction process, the procurement and estimating departments were heavily involved to bid the job and produce the guaranteed maximum price (GMP estimate) for the contract. For Turner's Staffing chart, please see Figure 3.

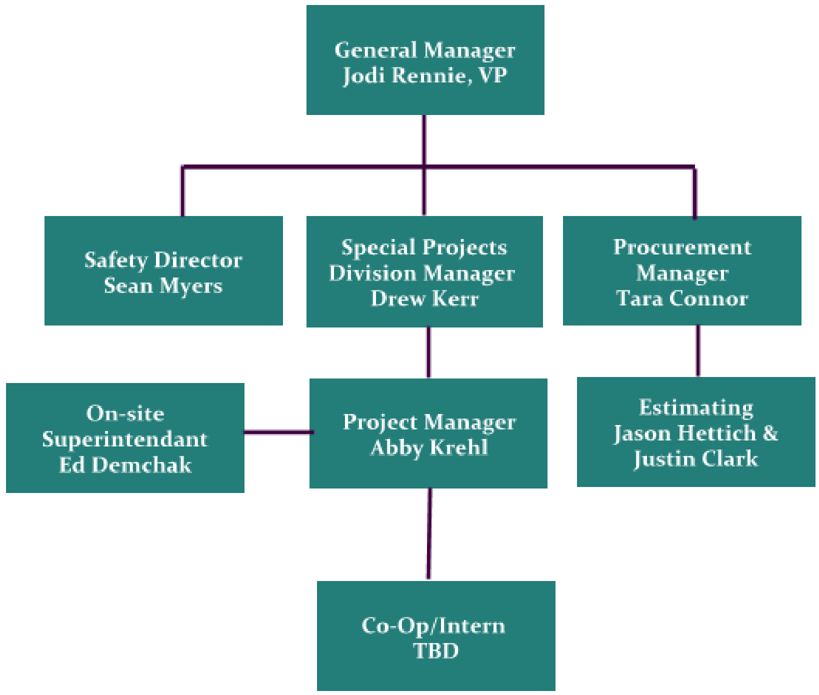


Figure 3: Turner Staffing Chart

1.5 Project Management Services

Turner Construction has completed a number of hospitals for this owner and is familiar with their services, practices, and goals, which gave them a leg-up during the bidding process. Turner submitted a General Contractor Fee proposal and was shortlisted along with two other general contractors. They did not give the owner a presentation to be awarded the job, but instead, sat with them for a roundtable discussion and provided the owner with booklets that outlined and explained their project approach and previous healthcare experience. This discussion involved Turner's full project team, which was a benefit for the owner, as they were able to meet the personnel they would be working with on the project.

Once they were awarded the job, Turner began to notice some challenges; fortunately, they were challenges that Turner had encountered before from working with this particular hospital on previous projects. One of the main challenges is that the owner uses Uniformat as compared to the CSI Division for all estimates and billing practices. This is especially complicated due to the fact that many project teams are not accustomed to using this format. The owner uses this format because one of the executives had previously worked for the government, where this format is very popular. According to some Turner staff, it is believed that this format is more beneficial in analyzing and comparing past data, but there is no significant proof of this being true. Therefore, the project team feels that it is doing more of a disservice to the owner and the project, than it is in helping them.

Challenges aside, Turner was still tasked with performing estimates for each stage of design, including the design development and schematic design phases, as well as to provide a final guaranteed maximum price as a part of the preconstruction services. The Turner project management team also attended the design meetings once they were awarded the job in order to help with value engineering.

Because of the small size of the renovation project, the engineering analyses were done only when necessary. The main analysis that was performed involved the mechanical air handling units, specifically which air handling units should be utilized for the spaces being renovated. Through the analysis, it was concluded that even though it would be at a higher initial cost to the owner, all the spaces should utilize the new air handling unit rather than the initial design, which had the back of house space still utilizing the old air handling unit. The benefit here is that it takes some of the load from the old air handling unit, making it more energy efficient in the long run.

1.6 Cost Evaluation

Evaluating the square foot cost of this project was completed by first establishing an estimated demolition cost per square foot. As RS Means does not have specific demolition costs, online research was done to estimate this cost at $6/sf (Masters). RS Means 2018 Construction Cost Data was then used for estimating the renovation/rebuild of the area post-demolition. This process was based on percentages due to the fact that RS Means' costs per square foot includes the structure and façade costs, both of which are not necessary for this renovation project. Table 1 shows the estimated costs for each division; however, see also Appendix A for details and steps taken to create the square foot estimate.

Table 1: Cost per Square Foot

Package	Cost/SF	Total Cost
Interiors	$63.95	$1,662,570.00
Plumbing	$40.06	$1,041,495.00
HVAC	$81.95	$2,130,765.00
Fire Protection	$5.88	$152,880.00
Electrical	$46.67	$1,213,485.00
Equipment/Furnishings	$60.27	$1,567,020.00
Total	$298.78	$7,768,215.00

After the completion of the square foot estimate, it was compared to Turner's estimate: Turner's cost came out to be $200 per square foot and $8.6mil, while the RS Means square foot estimate concluded costs to be $300 per square foot and $7.9mil. One of the reasons for the difference in per square foot costs is that the square footage calculations were different. For the RS Means square foot estimate, only the square foot of the rooms being demolished and worked in was counted, but Turner used the square footage of the entire area/wing as well as the square foot of the roof where the air handling units are being installed. It is believed that the RS Means estimate's overall total cost of the project is a little lower because less square footage was calculated, and because the data available through RS Means was very limited for demolition and renovation projects, especially for a hospital of a single floor renovation.

1.7 Schedule Overview

The schedule for the Unity Memorial Hospital is included in Appendix A. The overall preconstruction process will last 8 months, while overlapping the demolition and start of new construction, which will last 10 months. This results in an overall schedule of 14 months. In addition to the preconstruction phase, there are 3 additional phases of the construction schedule that allow for the operation of the linen and mail rooms to continue through construction. The first phase addresses early demolition in the clinical decision unit (CDU) and the establishment of the back corridor. The second phase addresses the back of house areas, which include the linen and mail room buildouts, some office space, and the soiled corridor spaces. Finally, the third phase is the completion of the project with the CDU buildout. These phases and their relation to the construction schedule will be more thoroughly discussed in Chapter 3.

1.8 Site Logistics and Phasing

The Existing Conditions Site Plan is shown in Appendix A. Because this is a renovation project, there are no significant site utilities that will impact the project or be affected. All electrical systems, mechanical systems, etc. will be tied into what is existing building infrastructure. However, the existing site plan does show the current locations of the electrical, mechanical, and telecommunications rooms that will be utilized and necessary for the renovation project.

It is also important to note the loading dock area, where all deliveries will be made for the materials and equipment needed on-site during construction. However, this is also located near the emergency entry for the hospital, so it is important that delivery drivers and laborers are aware that these areas cannot be blocked at any time. They also must be very safety-conscious when moving through the area.

The construction sequence and phasing of this project has proved that the hospital's needs will force workers to move around the jobsite. The hospital has a number of other renovations being done simultaneously that affect this renovation project. For one, the air-handling unit that will be installed through another contract held by the owner impacts the schedule of this project, as Turner does not have control over this work. Additionally, owner asbestos abatement and pharmacy relocation projects will determine the phasing that can occur within this portion of the hospital. These phases and their relation to site logistics will be more thoroughly discussed in Chapter 3.

1.9 Value Engineering

In order to implement value engineering on this renovation project, Turner's project management team utilized a virtual reality tool to walk the end user through the building and allow them to visualize what the end-product would look like for each value engineering option. For the end user, the most important product in this renovation project was the patient head walls because they are of the utmost importance to the patients, as well as their usability for the doctors and nurses. They were also one of the highest valued items on the project. The final patient room headwall is shown in the virtual reality image in Figure 4. Virtual reality was a great tool for this value engineering decision because the owner and end-users were able to visualize different options and choose which option would work best based on cost and functionality.

Figure 4: UMH Patient Headwalls Modeled in Virtual Reality

The first, and most expensive, value engineering option for the patient head walls was a pre-manufactured unit that houses the medical gases, as opposed to a second option, where the medical gas is piped down through the drywall. This second option does not have the headboard as a “stand alone focus point.” In the end, the end user chose the most expensive option for the patient head walls, with the intention of keeping it consistent with their other hospital locations.

These head walls are a crucial piece of equipment for the productivity of the hospital, which is why they were a focus for value engineering. More value engineering would have been done for other aspects of the project, if the GMP were to have come in higher than for what the hospital originally budgeted. However, the GMP was very close to their budget, so they did not feel that additional value engineering was necessary.

If additional value engineering were to have been done, one of the suggestions would be to replace the heavy sliding aluminum glass doors at each patient room with a less expensive material that would still provide the necessary acoustical privacy. Another idea would be to analyze the cost difference between the block walls in the back of house space, versus the possibility of providing a drywall with a diamond-plated wall protection. The project team felt that since the extra space was available for a wider block wall, this would be an optimum application for the schedule. However, this was not something that was analyzed in detail.

Turner wishes that they were brought on earlier in the design process so that more spaces could have been modeled and more value engineering could have occurred. Being brought on earlier would have given them more time to propose different option for the Nurse’s station and more variety in the layouts for the overall floor plan. The nurse’s station that was modeled in VR is shown in Figure 5.

Figure 5: UMH Nurse's Station Modeled in Virtual Reality

1.10 Building Information Modeling Implementation

One of the leading construction industry innovations in the current construction market to build efficiently and promote planning is Building Information Modeling (BIM). There are a number of ways to integrate BIM, which range from cost estimation to 4D Modeling. The strategies that can be implemented through BIM contribute to the success of a construction project through the sharing of information across the team.

One of the first steps in implementing BIM on a project is defining the goals of the project. These goals help to determine which of the various BIM uses would aid in achieving success. This can be accomplished using Table 2. Goals must be relevant to the project to eliminate the possibility of the project team performing unnecessary work. The implementation of BIM is meant to add value to the project and achieve a specific goal; these should be discussed within the project team, then assigned a number to rate their priority and determine their importance on the project. The following have been determined to be the most important on this job site.

Table 2: BIM Goals Worksheet

Priority (1-3) **- 1- Most Important**	**Goal Description / Value Added Objectives**	**Potential BIM Uses**
3	Develop an accurate budget for the project	Cost Estimate
2	Develop a phase plan	4D Modeling
3	Select the most effective MEP systems for the building's life cycle	Engineering Analysis
3	Provide as-built and system information for future facilities management	Maintenance Scheduling
2	Define the existing conditions of the building accurately	Existing Conditions Modeling
1	Increase the effectiveness of design	Design Reviews
1	Increase end user satisfaction	Virtual Mock-Ups / 3D Modeling

The project team found it unnecessary to create an existing conditions model because of the small size of the renovation project. The existing conditions can be easily worked around, especially in the back of house space, making adjusting for clashes fairly simple. The prefabrication analysis presented in Chapter 5 analyzes the feasibility of existing conditions modeling and how it can be used for a prefabrication process. Not modeling the existing conditions makes it very difficult to coordinate a 4D model. Although a 4D model would be helpful for the phasing analysis of this renovation project, a 2D visual representation of the phases, as shown in Chapter 2, is sufficient for this project.

Due to the project team not seeing the value in creating an existing conditions model, the 3-dimentional coordination for clash detection only has the ability to detect clashes between the new MEP systems, not any of the existing structures or MEP that is not being adjusted as a part of the renovation. To increase the value of 3D coordination for this project, the implementation of the existing conditions model would be helpful.

Chapter 2

Building Systems

2.1 Building Enclosure and Structure

As this is a renovation project to a large interior section of the hospital, the structure and enclosure have little effect on the project scope. The building enclosure and structure will not be altered during the renovation process. The space is adjacent to a loading dock that is large enough for all the equipment that needs to enter the building during construction; therefore, no penetrations through the enclosure will need to be made to accommodate the installation of large equipment.

However, the current roofing is an asphalt roof that will need to be penetrated for two new exhaust fans that are a part of the new systems to be installed into the building. This asphalt roofing system is very easily cut and patched as a very standard operation for asphalt roof building renovations.

2.2 Demolition

The demolition plan for this building includes removing most elements of the interior spaces. This includes architectural components, such as partition walls, existing flooring, acoustical ceilings, doors, and door frames. Holes will be cut into certain partition walls for doorways and windows that are necessary for the new space. In addition to architectural changes, there will be a significant amount of electrical demolition. First, most of the current lighting fixtures are to be removed during the demolition process, some of which will be relocated for the final product. The demolition phase is also to include the disconnect of all existing equipment and receptacles that are not included in the renovation. Also involved is the relocation of conduits. For more information, see the conduit relocation detail in Figure 6, which shows the way in which electrical power is transmitted to the second-floor renovation. The mechanical demolition includes the removal of the air-handling unit and the complete removal of all systems inside the building. The VAV boxes will be saved and relocated for the renovation. The new air-handling units will not be installed by Turner, but by a mechanical contractor that was hired by the owner directly.

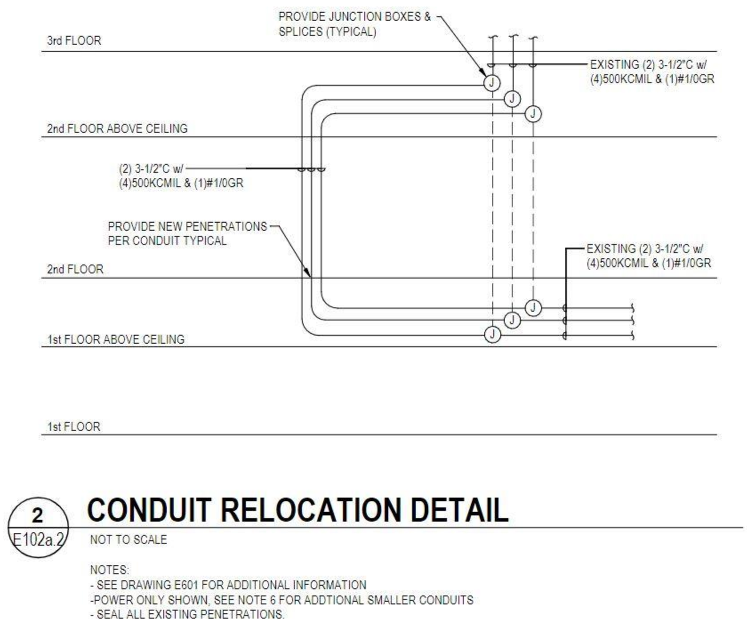


Figure 6: Conduit Relocation Detail

2.3 Mechanical

The mechanical system will utilize a new air handling to the space. (The mechanical systems for this renovation project will be sharing an air handling unit with other systems and renovations that are occurring in other parts of the hospital.) Most of the new ductwork being installed for this project will tap into supply ducts that are currently located in the space. There is a total of about 10 locations were new supply duct will meet and connect into the old supply ducts. In the patient rooms, the supply air is connected to VAV boxes with reheat terminal units. A few of these previously existed before renovation and will be relocated to be reused. The VAV boxes pressurize the spaces to ensure that air is not able to escape and contaminate other patient rooms. Additionally, there are 3 exhaust fans that serve isolation spaces and rest rooms that are also being installed and ducted up to the roof of the building.

2.4 Electrical

Post demolition, the bulk of the electrical work is refeeding the new areas once the conduits have been relocated per the new layout. Additional power will be necessary in all of these spaces, especially for the new patient rooms in the CDU. The main source of power for this area of the hospital is the electrical room (01) in the north-west corner of the building. This existing 208/120V, 3PH, 4W power center distributes power to 8 existing and 6 new panels that then feed receptacles, lighting, equipment, etc. Also being installed by Turner is a new nurse-call system which will need power. This will be implemented in all the new patient rooms in the clinical decision unit.

2.5 Lighting

The ceiling mounted lighting will utilize ceiling mounted occupancy sensors to turn them on and off. Most fixtures run at 120/277 Voltage and are about a 4000K color temperature. Additionally, all lighting fixtures contain LED lights. These are all new lighting apparatuses, as the ones recovered from demolition will not be saved and reused.

2.6 Fire Protection

The fire protection system for this renovation project is being completely updated and will be mandated by and comply with NFPA 13. The system will be tie into the existing system at the existing fire protection riser at the loading dock location.

2.7 Transportation

There are no new significant transportation systems with this renovation project. However, during different phases of construction, exit corridors will relocate to access the loading dock, depending on where the demolition and work is occurring for each of the three construction phasing plans.

2.8 Telecommunications

Demolition of the spaces will include the removal of all obsolete telecommunications wiring. New racks with all new wiring will be installed and based in the telecommunications room that will be constructed as a result of the renovation. Coordination is necessary with the existing hospital and their respective departments in order for this system to tie into their existing system.

Chapter 3

Analysis 1: Phasing Analysis of Temporary Pharmacy Relocation

3.1 Problem Background

When workers must move from space to space according to when work becomes available, time is wasted in the process of moving materials and equipment from one location to another. In addition, any momentum, strategy, or system that the workers may have is lost as they have to restart their process in a new area. The work may also be forgotten while workers lose track of their progress in the context of a process. These are just some of the reasons why flow is so important in a construction sequence, and why a new phasing plan could help with the efficiency and the productivity of the work that is occurring.

3.2 Problem Identification: Current Phasing Plan

The phasing plan for this project is intense and requires frequent updating due to the changing of the hospital’s logistical needs, as well as the work being located in small pockets of space at different times within the construction sequence. Therefore, workers often jump around between working in different spaces, which decreases efficiency and productivity. The phasing plans, broken into three phasing steps, are depicted in Figures 7-9.

The primary area influenced by this worker movement is the pharmacy space, which is highlighted in red in Figure 7. The new pharmacy space is under construction in a different part of the hospital and is a part of a different contract held by the owner. Having this new pharmacy space completed is critical to Turner’s scope, so the current pharmacy can relocate. Phase one of construction was planned around this space becoming available the beginning of January and was not affected.

However, as shown in Figure 7, phase one includes the relocation of the mail space from its current location, in pink, to its future location: the South East Equipment Storage Room, shown in dark purple. The linen Room is to remain in place during phases one and two, waiting until the pharmacy has been relocated to move to its new location.

Figure 7: Original Phase One Building Plan

During the second phase, shown in Figure 8, the pharmacy was supposed to undergo demolition and complete its buildout into the new linen and mailroom spaces. During this phase, the linen room was planned to remain in place, and the mail room would be temporarily relocated for the corridor relocation to begin in the clinical decision unit. This temporary space is a critical step to the project as these two spaces need to remain fully operational for the duration of the project.

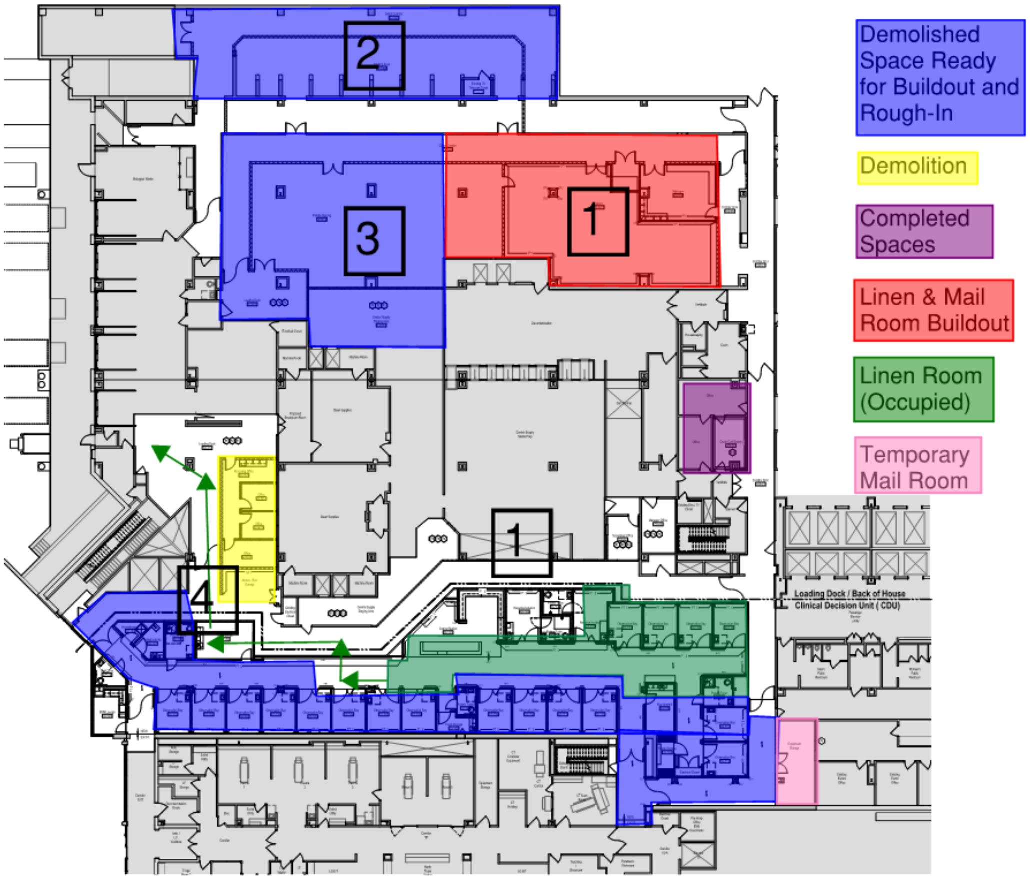


Figure 8: Original Phase Two Building Plan

However, after these plans were made, there have been some phasing changes due to hospital logistics. The new pharmacy project has been delayed and was not due to be turned over for linen and mail room build out until May 6, which is over four months behind schedule. This has caused the phasing plans to be updated, so the original phase 3 plan in Figure 9 is no longer applicable.

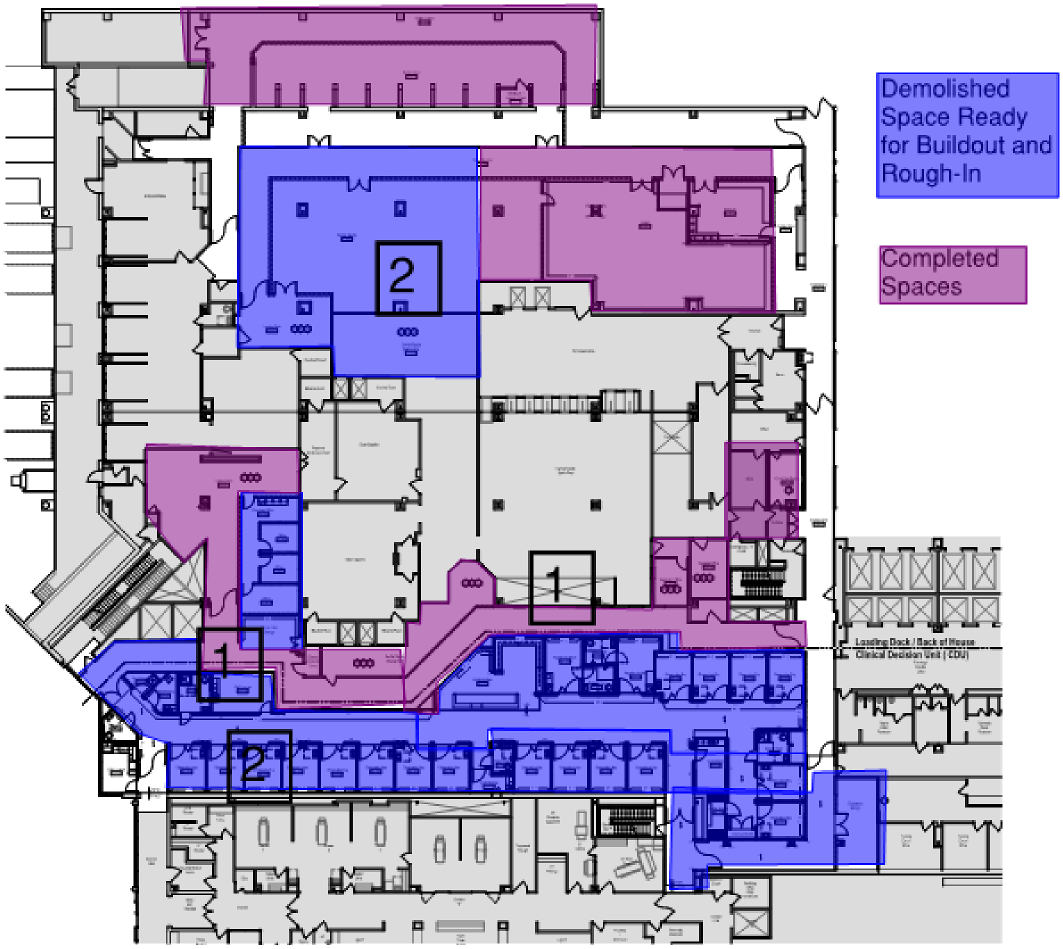


Figure 9: Original Phase 3 Building Plan

In order to combat this, the project team's solution was to relocate the linen room to the palette staging area. This has pushed back the completion of the project in its entirety until October 2019. However, because the decision was made to relocate the linen room temporarily, the CDU will still be able to be turned over to the owner by the end of June, which is a crucial date for the owner, as discussed in the client information section in Chapter 1. The new schedule that the project team is utilizing to obtain this can be found in the Appendix B.

As the current pharmacy is going to be staying in its location for much longer than expected and disrupting the phasing plan and the relocation of the linen and mail room, a potential solution is to relocate the pharmacy rather than keep the current pharmacy. This would allow the project team to avoid building temporary structures for the linen room and only occupy one room for the temporary mail and pharmacy space. The potential options for the relocation of the pharmacy space is either the future soiled linen space (at the top of the plans), which is currently a storage area for the hospital, or to a new temporary trailer at the parking deck location.

3.3 Temporary Location Selection

If a temporary pharmacy were to be utilized during this construction project, the first decision needed is the identification of a new temporary location. Two options would be the current storage area (future soiled corridor and staging area) at the north side of the current phasing plans or providing temporary trailers outside of the main Emergency Room doors. Of course, the final option would be to continue the current plan of action and maintain the current pharmacy location despite the challenge and delay that it is causing the project team. The locations of these spaces are depicted in Figure 10.

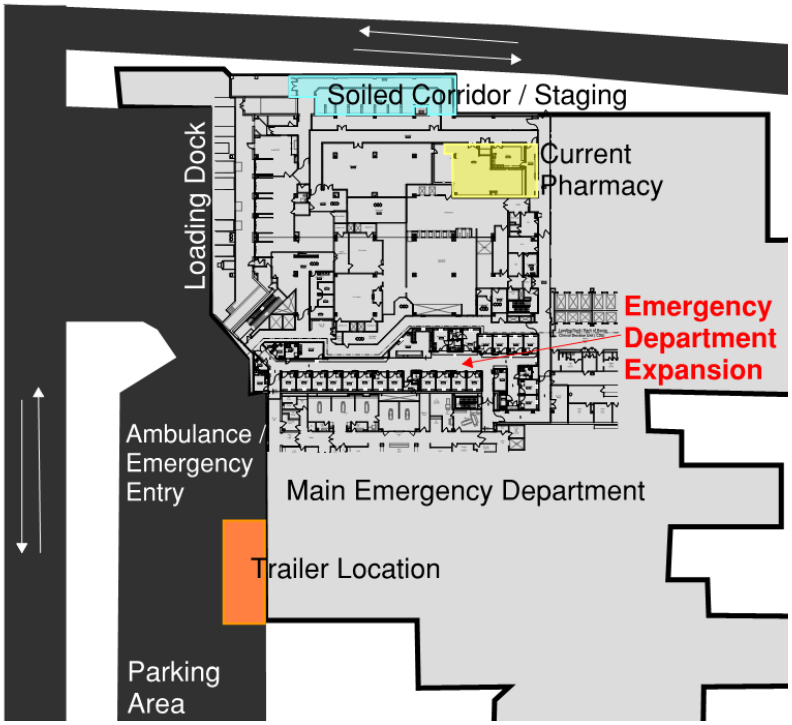


Figure 10: Temporary Pharmacy Relocation Options

Table 3 was used to consider and evaluate the soiled corridor and staging space versus temporary trailers for the relocation of the pharmacy space based on the following criteria: available space, layout capability and effectiveness, amount of additional movement required for staff members traveling back and forth to the pharmacy, hospital logistics, and the cost of renting or acquiring the space.

The current pharmacy location would not require any additional movement by the construction team, but instead would delay construction by four or more months. This option would be preferred by the staff; however, its relocation would allow the new mail room and linen space to be fully functional at an earlier date, which is equally as important to hospital staff.

The soiled corridor and staging area is not far from the current pharmacy and is large enough in size, making it an ideal location for a temporary pharmacy. In fact, this space is large enough that it could also fit the temporary mail room, so that the equipment storage location can be completed with the rest of the CDU. However, the options to layout the space are limited by seven structural supports that jut out from the south wall. Additionally, the space is full of storage that would need to be cleaned out by head nursing staff. Typically, this would be a cost to obtaining the space because hospital staff hours would be spent doing this, but this needs to occur whether or not a temporary pharmacy is going to be placed in this location. The challenge would be if hospital staff would have the storage moved out when construction needs to be started.

Finally, the temporary trailers would provide the most ideal layout space, but the cost to the project would be high, with $2,500 in set up and tear down fees, approximately$1000/month for rent, and at least $2,000 for add-ons, such as electricity connection, a locking mechanism for security purposes, and interior finish-out with floors, shelves, desks, cabinets, and lighting necessary for the work to be performed (Mobile Office). The trailers would also cause a security risk, as there would be many types of medications in this space requiring equivalent supervision and security surrounding it. In addition, the security risks also extend to more staff going in and out of the hospital. Finally, there is a safety risk with this trailer being parked close to where ambulances and emergency vehicles may be driving through the hospital.

Table 3: Temporary Pharmacy Location Selection

Option	Distance from Original (FT)	Distance from Emergency Room Department (FT)	Space Available (SQFT)	Layout Capability	Cost of Renting / Obtaining Space* ($)
Current Location	0	122	1,980	Ideal	0
Soiled Corridor and Staging	95	217	2,675	Structural Supports and Storage Obstruction	0
Temporary Trailers	400	120	1,960 (28'x 70' double wide)	Ideal	$11,000

*Does not include construction induced costs of using space.

Construction costs will be analyzed further in the next section.

For these reasons, the preferred temporary relocation space is the soiled corridor and staging area. Because this space has enough additional square footage, the analysis will include the temporary mail room in this location, as well, freeing the equipment storage room in the CDU and make it available during the time of CDU turnover. This space will be evaluated further in the following sections in comparison to keeping the pharmacy in its current location throughout the construction process.

3.4 New Phasing Plans

In order to better visualize the possibility of relocating the pharmacy space temporarily, new phasing plans have been developed. There will be four phases to this process, which will start with the demolition of the soiled corridor and staging space. This is the space that will be used for the temporary mail and pharmacy spaces. It is a 2,700 square foot area, making it large enough to house both a temporary pharmacy (2,000 square feet) and a temporary mail space (6,000 square feet). This will occur while the pharmacy, linen, and mail rooms are all still occupied. While this is occurring, the demolition of the clinical decision unit will begin and asbestos abatement will occur where necessary. The rest of the back of house spaces will be on hold until the next phase so all of the back of house spaces can go through demolition and buildout simultaneously. This should help with the productivity of the space, as many of the walls can be demolished one after another and not disturb the pharmacy. This is depicted in Figure 11.

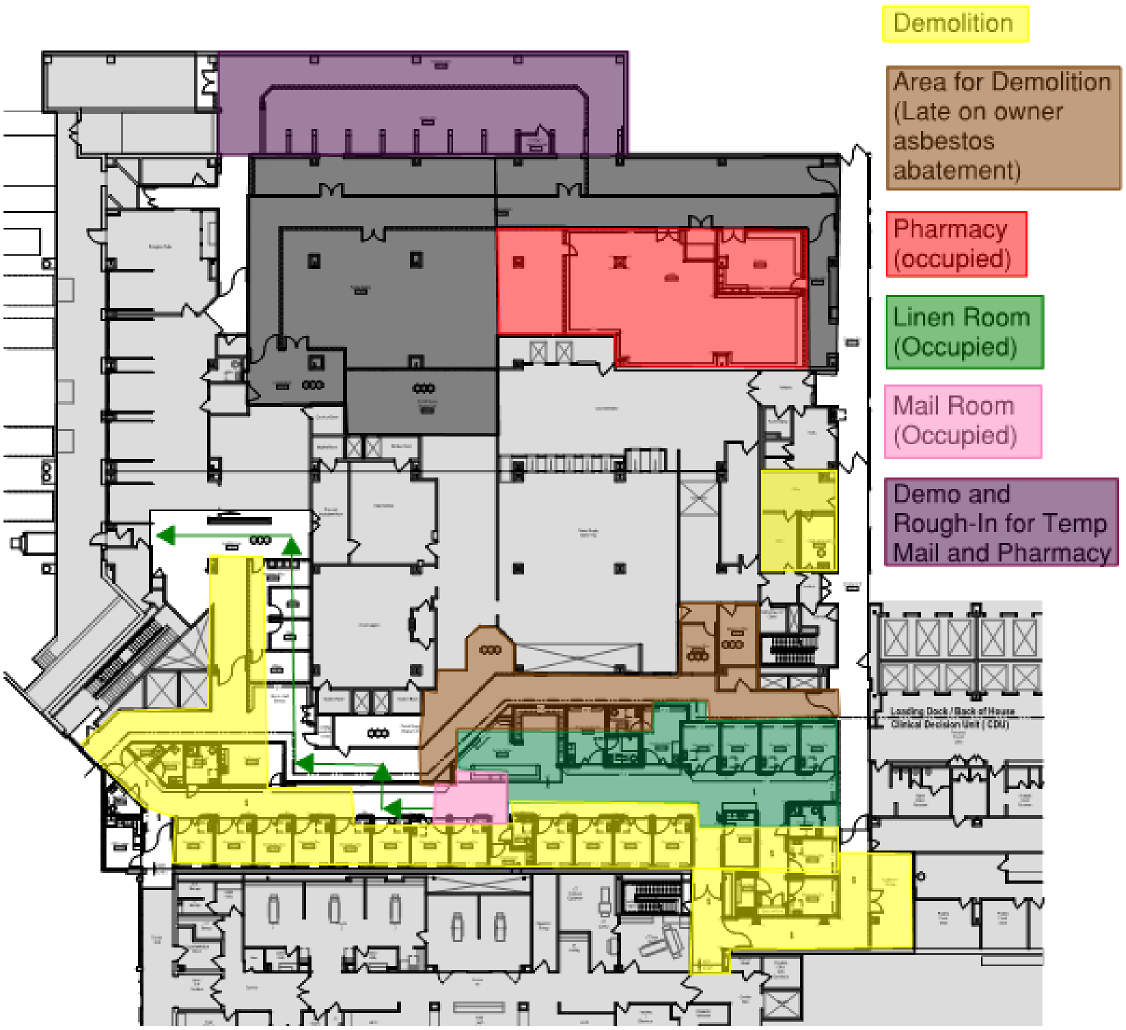


Figure 11: Relocated Pharmacy Phase 1 Plan

The second phase allows demolition to begin in the back of house space, as the pharmacy and mail room are temporarily relocated to the soiled corridor and staging area. This phase also includes the construction of the new mail and linen rooms in the back of house space. Freeing up the mail room allows the CDU demolition to continue and the hallways in that area to be constructed. Additionally, with the mail room being relocated to the soiled corridor / staging area, the equipment storage room can be a part of the rest of the CDU demolition and build out. This change will likely increase the productivity, as it will eliminate the need to return to this space at a later date for further demolition and build out. It can occur simultaneously with the rest of the spaces in the area.

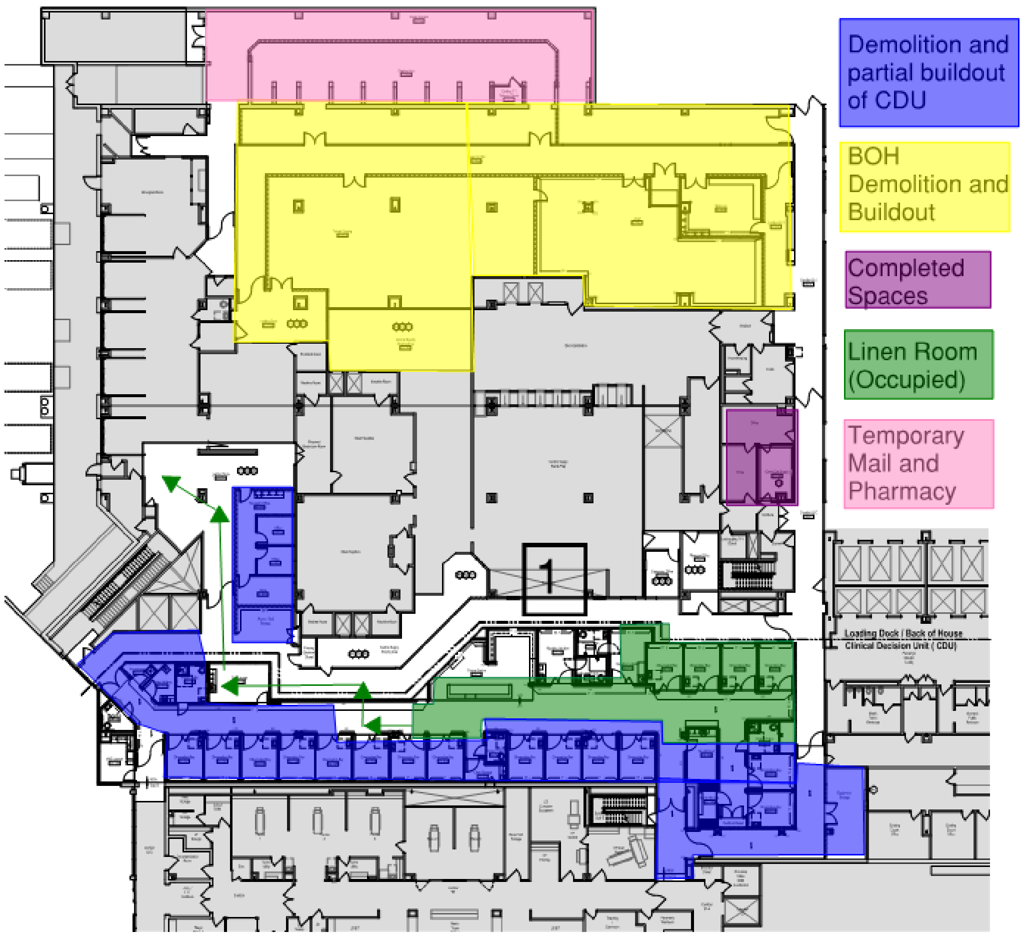


Figure 12: Relocated Pharmacy Phase 2 Plan

The third phase is detailed in Figure 13 and begins with the linen and mail rooms being moved into their permanent location, the old pharmacy. After its movement back into place, the back of house construction is complete except for the soiled corridor and staging space. This leaves only the pharmacy in its temporary location. Here, it is important to note that the soiled corridor walls have not been built yet, and soiled materials will still be able to pass through old soiled corridor hallway, which will be separated from the clean hallway during all phases. Also during this phase, the clinical decision unit will be completed to be turned over to the owner.

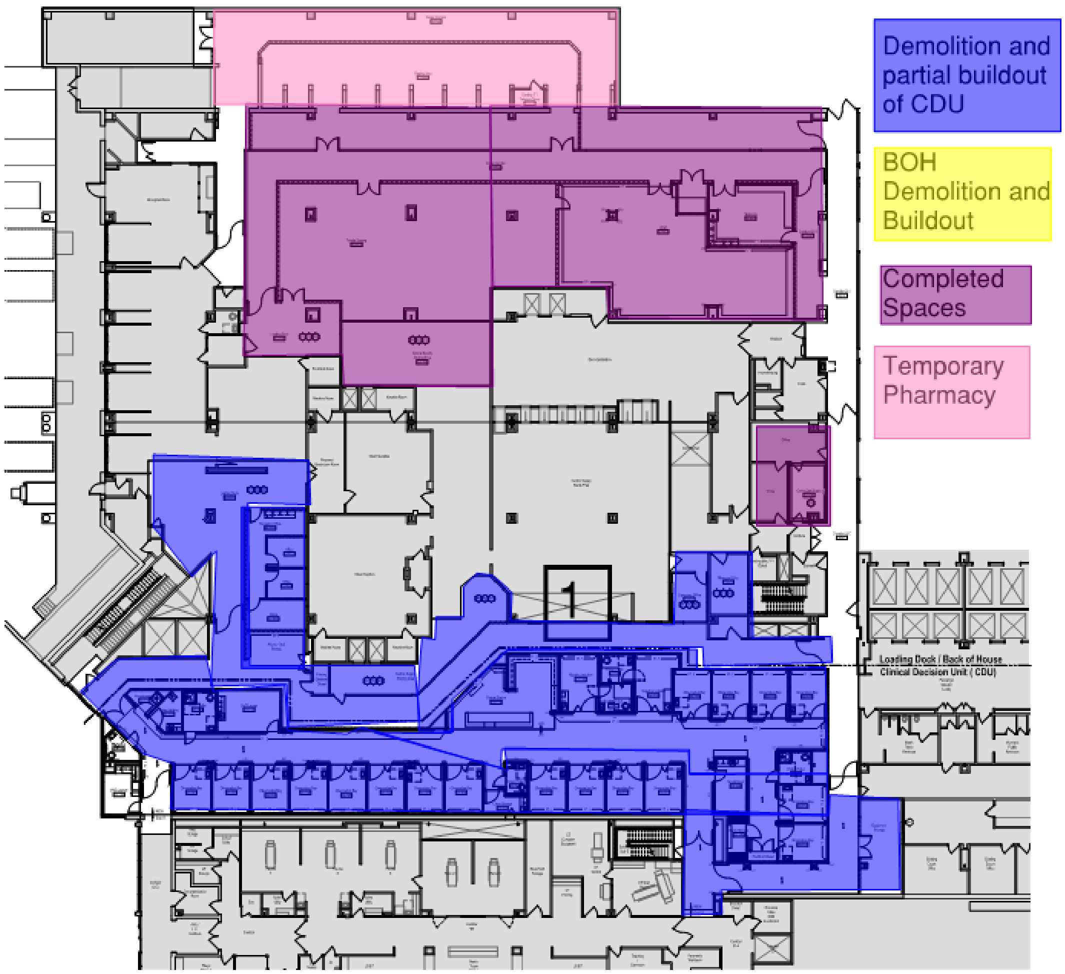


Figure 13: Relocated Pharmacy Phase 3 Plan

The final phase will commence as soon as the new pharmacy project is completed and the owner moves the pharmacy from the soiled corridor and staging area to its permanent location. After this is completed, the walls will be built to block off the soiled corridor from the staging area and buildout of the space including paint, ceiling, and accessories will be completed and inspected before being turned over to the owner. This is in contrast to the old phasing plan in which two different spaces: one in the back of house space and one in the CDU would have needed to be completed. Working on these two spaces at once would have caused some inefficiencies going back and forth.

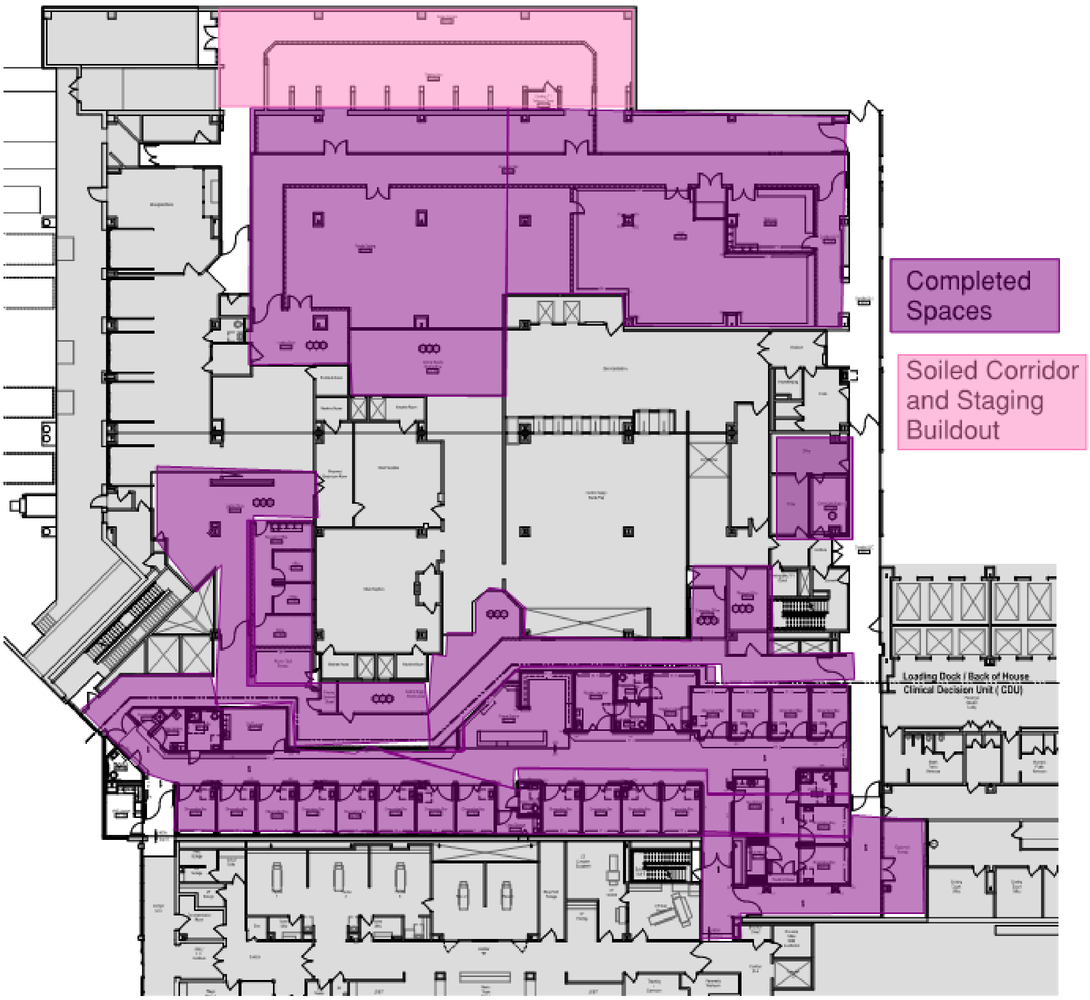


Figure 14: Relocated Pharmacy Phase 4 Plan

Overall, the phasing procedure for the pharmacy relocation option eliminates some of the need to move back and forth between spaces and return to spaces for rework. This phasing plan more clearly separated the CDU from the back of house space, which will help subcontractors plan materials and storage accordingly. It further creates a flexible option if the pharmacy project is further delayed where it would not impact ongoing operations for Turner's scope with the exception of the soiled linens, which is still operational during this time. For that reason, it seems clear that this phasing plan is more efficient for the workers as they complete the project.

3.5 Schedule Analysis

In order to focus on the tasks specific to the temporary relocation of the pharmacy, the original construction schedule has been recreated with only the tasks pertaining to and affecting the new mail room and linen rooms (old pharmacy) location. The clinical decision unit does impact work in some places, but has been condensed on this schedule to show the core relationships. As shown in the schedule in Figure 15, having the pharmacy relocated is crucial to the continuation of the construction schedule, as it is on the critical path and being controlled by the owner. Unfortunately, this schedule has been replaced and updated after the delay of the new pharmacy project. (This schedule, in its entirety, as well as a complete schedule with broken out clinical decision unit work, can also be found in Appendix B.)

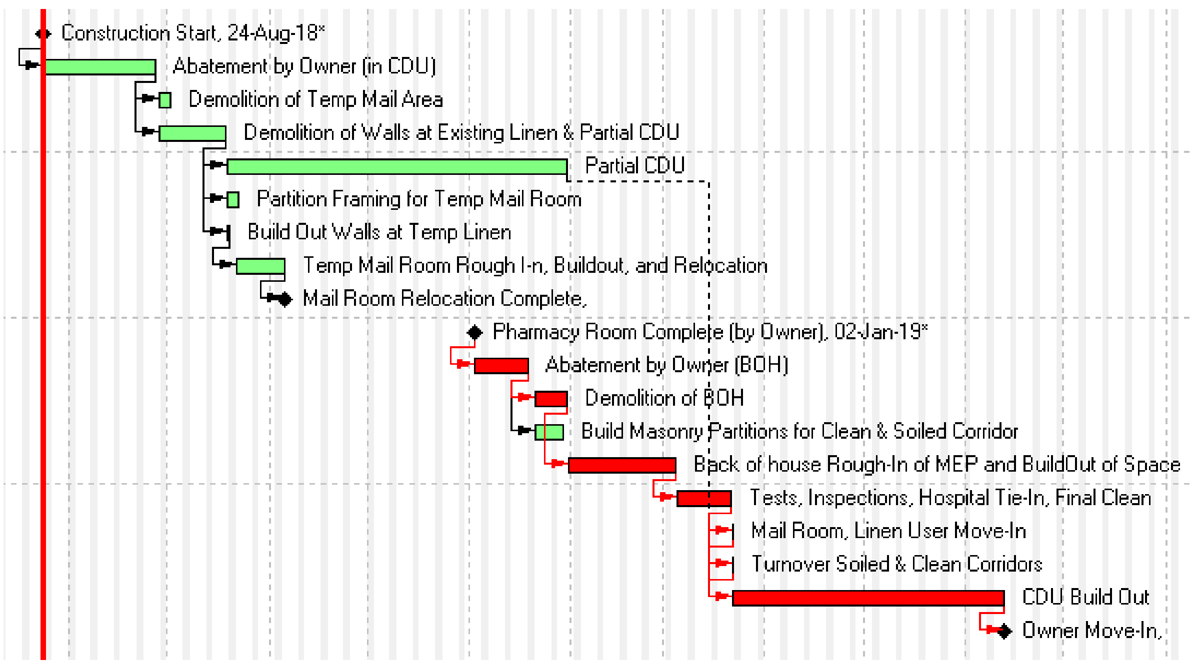


Figure 15: Original Back of House Pharmacy Space Schedule

The current information from the project team is that the pharmacy project is not scheduled to be completed until May 5, 2019. If changes were not made to the phasing plan or schedule (i.e. the project team were to just wait for the space to become available), the project will not be completed until October 15, 2019. As the construction schedule stands, this means that the completion date of the CDU would not be until October, which is an issue for the hospital when it comes to overcrowding and ensuring enough beds for their patients. This is depicted in the pharmacy delay schedule in Appendix B.

Because the project team was already well into the development of the project, they have chosen to amend this issue by also relocating the linen room to the pallet storage area. Although this altered the schedule enough to finish the clinical decision unit on time, it did not change the fact that the pharmacy needed to be relocated before the linen and mail rooms can move into the space. The demolition and build out of the current pharmacy space, relocation of mail and linen rooms into this space, and final build out of the spaces from which they were relocated will take a substantial amount of time because of the complexity of systems in these spaces. This restructured schedule results in the back of house space being completed October 15, 2019. This detailed schedule can be found in Appendix B.

However, if the project team had anticipated the delay of the pharmacy project, the schedule would have benefited from relocating the pharmacy rather than both the mail and linen room spaces. The following schedule not only ensures the completion of the CDU on time, but also ensures the completion of the entire project by May 30, 2019, which is two weeks earlier than the original the schedule.

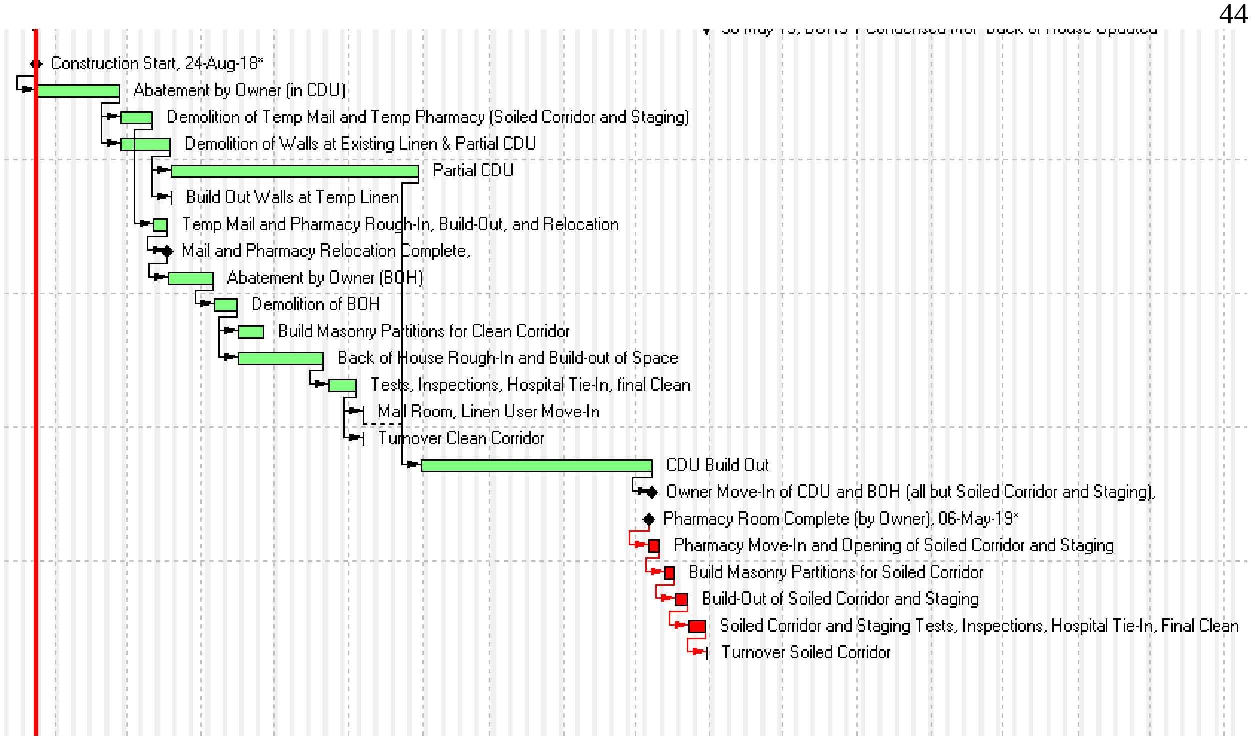


Figure 16: Updated Back of House Pharmacy Relocation Schedule

The first aspect of the schedule that saved time was the removal of the temporary linen room and mail room demolition and build out. In the current project schedule, these occur in separate locations and at different points in the schedule. In the new schedule, the temporary pharmacy and mailroom will be in the same location, which only requires one demolition and build out, rather than that of two separate spaces.

An important aspect of the schedule to note is that the CDU buildout activity has extended 10 days to accommodate for the equipment storage room that will now be included in that build out process. This allows the equipment storage room to be turned over with the rest of the clinical decision unit so that it can be utilized as needed during the time of opening.

Additionally, this schedule option allows the new linen space to be ready for move-in much earlier, making the relocation of the linen space unnecessary, but still allowing the CDU buildout to remain on schedule. Overall, this saves about two days total in the schedule.

It is also important to note the sequence for the soiled corridor / staging area: first, the necessary demolition will occur in the space. Then, basic rough in of the mechanical, electrical, sprinkler and lighting systems will occur so that they can be utilized by the temporary pharmacy and mail room, as they move into the space. These systems will remain in the space permanently, and once the pharmacy and mail rooms are complete and moved out, the finished such as new floor, walls, paint, ceiling, and hospital technology will be installed. This ensures that only limited work needs to be done once the pharmacy is relocated and the soiled corridor and staging area can be up and running as soon as possible.

The positive aspect of this schedule is that if the pharmacy relocation were to be delayed even further, the only space that would be occupied and in danger of being delayed is the soiled corridor and staging area. These two spaces are not crucial for the hospital to continue operation. This circumstance is unlike the original schedule that tied up the palette staging area and equipment storage, both of which are much more important to the function of the hospital than the soiled corridor and staging area.

Based on schedule alone, it is reasonable to recommend that the pharmacy relocation schedule created be utilized for the project. It is the shortest schedule (shorter than the original by two weeks and shorter than the current by 18 weeks). However, if the pharmacy would have been on time, the two weeks' worth of savings would not be enough to cover the cost of a pharmacy relocation. This is outlined in the next section.

3.6 Cost Analysis

The cost implication of relocating versus not relocating the pharmacy are outlined in Table 4. Based on cost alone, it would be beneficial for the project team to consider the relocation option: by relocating the pharmacy during the construction process, the project will save approximately $165,930.

Table 4: Pharmacy Relocation Cost Analysis

Cost	Original Location	Temporary Pharmacy	Delta
Moving pharmacy		$3,600	($3,600)
Moving linen	$1,000		$1,000
Construct temp pharmacy and mail	$4,471	$7,452	($2,981)
Building out temp linen space	$4,471		$4,471
General conditions	$148,480	$(18,560)	$167,040
Total Cost	$158,422	$(7,508)	$165,930

The first cost is the actual cost of moving the rooms. This entails packing the supplies and necessary items into boxes, moving them to their new location, and unpacking. It was assumed that the labor cost for one mover was $25/hr (Green), and the appropriate number of movers was assigned to the activity based on the schedule allowance for the move. It is important to note that the relocation of the mail room was not considered because this activity will occur in both situations and is therefore negligible in the cost comparison.

Additionally, the pharmacy relocation move will need to be planned in order to assure that all pharmaceuticals will still be able to be found and used during the daily activities of the hospital. For this reason, more movers and a higher rate of $30/hr was assumed. The movers will need to pack boxes shelf by shelf in an organized fashion, move them to the new space, and unpack them for proper organization. This is especially necessary for the well-being of the patients in the hospital.

Secondly, the build out of the spaces was considered. It was assumed that the build out would be necessary for the new space anyway (i.e., the mechanical and electrical rough-in, drywall, lighting, etc.). However, additional labor costs, based on the RS Means labor rate of $62.10/hr/laborer, was added to each of these to install any additional casework, shelves, equipment, or other necessities that may have been neglected by the movers while relocating to the space. These hours are also allocated towards any rework that may need to be done as a result of the use of the space before it will be used for its intended purpose.

The next line-item, general conditions, is a result of the schedule changes. The schedule for the pharmacy relocation is two weeks shorter than the original schedule, which saved two weeks of general conditions costs, which were calculated from Turner's original general conditions cost for the entirety of the project ($361,920 for a 39 week schedule). In the case of keeping the pharmacy in the same location, there will be additional costs for extending the schedule 16 weeks, while waiting for the pharmacy project to be completed, which are not included.

After compiling these costs, it is clear that the pharmacy relocation is currently the cheaper option. However, if the new pharmacy location would have been completed on time by the owner and the original construction schedule was being pursued, the costs of moving and building out a temporary linen room and extension of the general conditions costs would not have existed. Therefore, the project team was justified in choosing their original plan of action. It is important, though, for the project team and owner to anticipate these unforeseen circumstances when performing the project risk management analysis.

3.7 Comparisons and Final Recommendations

Overall, I would recommend that the project team consider relocating the pharmacy and altering the phasing plans to achieve the following savings:

- Cost: $165,930 in savings
- Schedule: 18 weeks in savings from current construction schedule (2 weeks from original)
- Phasing: more efficient

However, the team did not anticipate such a delay of the pharmacy. If the pharmacy would have been completed as originally scheduled, relocating the pharmacy space would not have been the best option, as it would have added significantly more cost.

Chapter 4

Analysis 2: Managing Project Conflicts through Portfolio Management

4.1 Problem Background

As organizations expand, including owners of a network of buildings, they reach higher levels of management needed for individual projects, simultaneously. They need to address the big picture by shifting focus to managing projects collectively, as a portfolio. At this point, the projects become investments that align with certain goals of an organization and create value. During the management process, risk, funding, timing, feasibility, and construction logistics are just some of the elements that must be considered by the owner. Additionally, portfolio management is important to owners because there are tools and technologies that have been developed to support decision-making at the portfolio level. However, this is a growing need that needs further study and industry response.

4.2 Problem Identification: Portfolio Management

The project management team at Unity Memorial Hospital is working on multiple renovation and addition projects simultaneously. This requires extensive coordination by the project teams with both the owner and other general contractors working on other projects. Although there are many more (approximately 20 at the current time), there are 4 contracts held by the owner that specifically require coordination with CDU construction:

- Air Handling Unit Installation
- Abatement of CDU Expansion
- Pharmacy Relocation Project
- Cancer Center Addition

These are pointed out on the Figure 17.

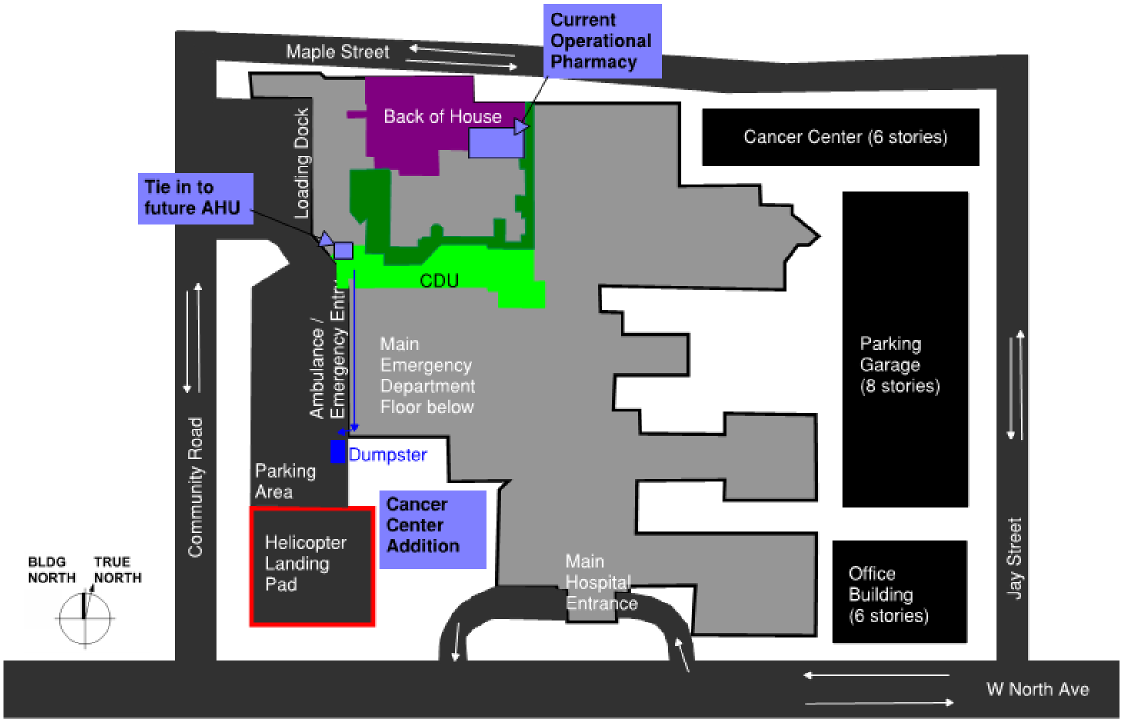


Figure 17: Locations of Additional Hospital Construction Contracts' Projects

The first project is the air handling unit contract. The mechanical systems for this renovation project will be sharing an air handling unit with other systems and renovations that are occurring in other parts of the hospital. For that reason, the owner has contracted directly with a mechanical company, McKamish, to install the air handling units that will be shared by two renovation projects.

Second, the pharmacy relocation project by another contractor is six months behind schedule. This is limiting Turner from performing the demolition and renovation of the current pharmacy space, as the pharmacy must remain fully operational throughout all of construction. The current pharmacy is planned to be renovated into the new mail room and linen room space.

Additionally, the owner holds a contract for asbestos abatement throughout the entire hospital, and this needs to occur before Turner's team can get into the spaces to start the demolition. Delays in abatement have caused the phasing of the project to change. The cancer center addition is just one of many other small renovations occurring in and around the hospital. These projects create challenges in coordination when it comes to the logistics of materials and lay down areas. Coordination and communication between all projects is necessary.

Through this analysis, the goal is to create a better strategy in managing these projects to achieve a more fluid construction sequence with better coordination and fewer delays. This will be assessed from the standpoint of portfolio management to determine how areas, such scope packages and financial conditions, have contributed to the sequence of construction renovations throughout the entirety of the hospital. This solution was chosen to incorporate the owner's point of view, as each individual contractor typically sees this only as an intrusion to their own project, rather than from an overall hospital-wide perspective.

4.3 Research: Industry Interviews

In order to gather information on portfolio management and how other hospitals are managing their projects, three project managers from hospitals were interviewed about their best practices of portfolio management. The following interview questions were used to guide the interviews.

- What factors are considered when scopes are being packaged for a portfolio?
- How do you manage the process for how projects and work are released for design and construction?
- How is risk determined for each project and how does that play a role in managing the packaging of the projects?
- What is the key to packaging scopes in a certain way versus splitting scopes into multiple packages?
- Are delivery methods considered when these packages are created?
- What roles do financial planning and cash flow play in packaging scopes?
- How do hospital logistics, staff, and workflow affect the organization of the package scope?

- How do you ensure that construction sequence stays efficient?
- In the case of my thesis project, how would you have gone about changing the portfolio management strategy to eliminate these issues?

The interviewees were project managers for healthcare related owner's ten years or more hospital-specific experience in order to get specific details relevant to the potential changes that could enhance the process at Unity Memorial Hospital. Representatives from Penn Medicine (Philadelphia), Unity Memorial Hospital, and UPMC (Pittsburgh) provided information of their own experiences and portfolio management strategies that work best to enhance the efficiency of their renovation projects across the hospital. Each individual had different suggestions on how improve the Unity Memorial Hospital project for better coordination and efficiency.

In the process of interviewing these project managers, it was derived that there are four main factors that impact the success of managing a portfolio of projects: contractor selection, funding, phasing/hospital logistics, and qualifications.

Table 5 summarizes how these project managers address contractor selection, funding, phasing, and qualifications in order to most effectively run and manage their projects, more specifically, their renovation projects. Each of these will be detailed in the following sections.

Table 5: Portfolio Management Interview Summary

	Penn Medicine	UPMC	UMH	Additional notes
Contractor Selection	Master agreement with firm for most renovations	Different phases may be picked up by different contractors	Almost all phases picked up by different contractors for purpose of competition	
Funding	One project / contract could have multiple funding sources	Fund phase by phase if there is a cash flow issue	Fund phase by phase if there is a cash flow issue	Typical that final decisions are made by financial department
Phasing / Logistics	Scheduling / phasing consultant to help coordinate with hospital operations	Responsibility of contractor (important during contractor selection)	Take on most responsibility of helping to phase projects and tell CM what they need to work around	Safety is always a concern is priority over ease of construction logistics
Qualifications	CM @ Risk – GMP; Based on previous Penn Medicine renovation experience	Design-Bid-Build or CM @ Risk; Based on previous phasing / logistics experience	CM @ Risk; Based on previous project-type experience	

4.4 Contractor Selection

First, contractor selection defines the contractors chosen to perform the work and by what means they are chosen. Based on the interview feedback provided, there are numerous approaches to this challenge. The chosen approach greatly affects the means by which an owner can manage their portfolio of projects.

One option for contractor selection that hospitals use is that they hire the same contractor for all of their renovation projects. This adds an element of value to the portfolio of projects because the contractor can more easily coordinate diverse parts of the hospital that they are working in without having to rely on another contractor to complete their work. This strategy can reduce potential delays to the projects which can save cost and reduce schedule delays. In which case, the portfolio, as a whole, is more robust for the hospital.

Another benefit to repeat work is the owner is able to build a relationship with this contractor. Building this relationship makes it much easier to work together, as the contractor likely understands the hospital logistics very well and knows which departments and staff they need to call in order to effectively communicate concerns or risks during hospital construction. This is also helpful for the portfolio because the owners' project managers do not always need to be as heavily involved and can rely on their experienced partner to ensure effective delivery.

Another option for contractor selection used for a portfolio, the option that Unity Memorial Hospital utilizes, is that they choose different contractors for each phase or scope of work because they believe that using different contractors helps to maintain competition. This competition has two elements: the first is cost, as the owner wants to ensure that they are getting fair prices for their work. Although they do not always take the lowest bid, they believe they receive better pricing by having different contractors compete to get each job.

In relation to achieving a better cost to complete aspects of the project, sometimes UMH will acquire contracts to run on their own. This is true for the abatement and the mechanical contracts that both affect the CDU project being run by Turner. The choice to run these on their own is a combination of how much workload that the owner's project managers have to manage in addition to the workload that the contractor is already experiencing. The biggest factor, however, is the cost. By taking these contracts on themselves, UMH avoids paying the mark-up that a construction manager would have charged them, as well as having a direct contact for smaller projects. However, the project manager for UMH must now coordinate across these two contracts when challenges, such as those seen in Turner's phasing plans arise.

The second element of competition surrounds the competition to perform better. They believe that having multiple contractors motivates them to stay on schedule and deliver better quality work to show than the others working within the hospital. Essentially, UMH believes this makes them work harder, because they are in constant competition for future work at the hospital. It also makes them compete to differentiate their performance, such as showing they can utilize better technology or processes than the other contractors. For example, Turner employed virtual reality, which will be discussed further in Chapter 6, to differentiate themselves from the other contractors during the proposal and interview process.

These elements of competition can introduce positive aspects to the portfolio; however, it also creates a strong lack of coordination among the contractors. The savings cost they achieve through competition could end up causing the project to incur more costs, such as the pharmacy project delay. This could have been reduced or avoided with better coordination among the contractors and owner. If there are multiple contractors working on multiple projects, it is much more difficult to coordinate between each of the projects and contractors. This tends to decrease the value of the portfolio, especially in the case that the owner needs to be much more involved in every single aspect of multiple construction projects. This takes away from their new construction

A third option that was discussed is a middle ground between the first two options. UPMC may have different contractors for different phases of a project, but they also strongly take into account that keeping the same contractor may also provide strong benefits to the project. Keeping the same contractor also minimizes the mobilization costs if the phases transition into each other.

For Unity Memorial Hospital, it is suggested to take an approach more similar to UPMC. This will still allow them to achieve some level of competition that they are seeking, but also takes into account the element of coordination that helps related projects to run more efficiently.

4.5 Funding

Second, funding is necessary for a project to be initiated. Depending on the financial structure of the organization, cash flow can limit a hospital's ability to complete a project. For this reason, hospitals will start phases one at a time under different contracts in order to be able to fund them. These contracts, as mentioned previously, can be given to different contractors or the same contractors.

One aspect of funding that was consistent among all three hospitals is that the projects first needed to be approved by the higher management of the hospital. Typically, this is done by each individual department keeping a list of their top-priority projects. They go through a high-level cost and schedule evaluation by the project managers for the hospital. This information is then provided to the upper management, who makes decisions with the financial branch of the hospital regarding which projects to release for design and construction. They do, however, consult the project managers and construction team for which parts of the project can be completed so that certain phases can be funded. From there, the team is tasked with selecting the team, managing, and coordinating the completion of each project.

The difference between each of the hospitals tends to be the timing by which the projects are released. For some hospitals it is yearly (projects get approved to move in May and a lot of the projects start to get kicked off in early July) and for some projects it is quarterly. This depends on the structure of the organization's financial planning team and not the project management team. This timing does, however, affect the coordination and phasing of projects. If projects are released yearly, they are likely larger contracts that include more work, and if projects are released quarterly or bi-yearly, they are likely smaller. If they are all smaller portions of work given to different contractors, there could be coordination necessary between the contractors if their phases or systems overlap and one contractor starts where another ended. The challenge to only funding projects on a yearly basis, is that the hospital needs to anticipate the needs for the next year, and if a project is suddenly in a rush to be completed, the financial window for funding may have already passed.

Although funding is something that the project team cannot necessarily control, it affects the total scope of their project portfolio. One suggestion for Unity Memorial Hospital is to be more aware and involved in the funding decisions. Additionally, the project team can control the contractors that handle the contracts, so it would be in their best interest to consider the size of the project, what phases will follow this contract, and the coordination that will be necessary when choosing their contractors.

4.6 Phasing and Logistics

Phasing and logistics is a concern when it comes to portfolio management because if the phases are separate contracts with different contractors, they must align certain logistical considerations to ensure efficient work and minimize impact to any ongoing operations. The output of one contractor will affect how the next contractor will pick up where they left off.

There are also two common themes between the project managers' views on phasing and logistics. The first is safety and the second is the continuation of the necessary hospital operations. These are both very important aspects to every hospital renovation project, as the patients in the hospital still require proper care and minimized negative impacts from construction. The doctors and nurses need to be able to do their jobs efficiently and the patients' safety must remain at the highest priority.

In order to ensure this, some owners have utilized a scheduling and phasing consultant that specializes in hospital renovation to be the liaison between the hospital operations staff and the general contractor. Although this is an extra cost to the project portfolio, this was recommended to ensure phases that are better suited to both the hospital operations and construction logistics. The hospital that utilizes this, Penn Medicine, also typically works with the same contractor for all their renovation projects. This consultant and the contractor doing the renovation have gotten used to working together, and it makes the phasing of the project much easier on the hospital. Although Unity Memorial Hospital does not necessarily use the same contractors, they would likely benefit from a phasing consultant because it would provide a consistent point person for the hospital staff to contact if there is a construction phasing-related issue. This consultant understands the hospital and would be able to intervene to fix the issue so that the hospital can continue to remain operational.

Other organizations put the phasing and logistics responsibility on the contractor after evaluating their qualifications and past-experience. For hospitals that employ this option of dealing with the phasing and continuation of hospital logistics, their delivery method and process by which they choose their contractors is extremely important. This will be discussed further in the Qualifications section of this chapter. For this option, however, the hospital managers are still very involved in the high-level phasing.

Finally, some owners, such as Unity Memorial Hospital, take on the most responsibility of helping to phase projects. Project managers know the hospital so well and typically their contractors do not. Project managers feel that it is part of their role as owner project managers to manage the phasing and coordination with the hospital. For this reason, they are tasked with the coordination between the contractors who take over different phases and parts of the hospital for renovation. Typically, their coordination process consists of getting these contractors in a room together to discuss the coordination and phasing issues, to work out solutions, and create updated schedules to account for any changes.

Unfortunately, it seems as though the hospitals' project management staff has a lot on their plate: as discussed, they tend to take on a lot of the smaller contracts themselves, so it is difficult for them to also coordinate among all of the contractors on site. For this reason, coordination can at times fall to the side and instead of meetings where the contractors can work out their problems together, the project managers have resorted to being the liaison between the contractors, which is often more time consuming and often less effective. This method tends to be less efficient and inducive of miscommunication.

To better manage their project portfolio from a phasing and logistics standpoint, it is suggested the UMH add a phasing and logistics consultant to their team or be stricter in coordination meetings between all of the contractors working in the hospital. Hopefully, this will eliminate phasing issues and allow the contractors to better communicate their issues to result in a more efficient way to complete the work.

4.7 Qualifications

Finally, delivery method is considered by these project managers because, although it is related to contractor selection, it takes into account how the contractor is engaged with the design team, procured, and reimbursed for their efforts. If the contractor is chosen based on the qualifications that they may already be familiar with other renovation projects in the building or at least hospital phasing and logistics, they are more likely to have a seamless phasing plan than a contractor that was chosen based on their lowest bid. This is why the construction manager delivery method is so popular among these hospital renovation projects.

However, the difference is the qualifications on which the owners base their selection. Some owners base their qualifications on if the contractor has completed other renovation projects in the building. This is important because the contractors generally will know who to contact, are familiar with the hospital's quality standards, understand the process of communication that the hospital utilizes, and these are all qualities that make the project go much smoother. Other owners only require a history of hospital phasing and logistics. These are also important qualities for a contractor, especially in situations that where the phases will run into each other and require high levels of coordination and communication with both the hospital staff and other contractors that may be doing work throughout the hospital. Also included in this is the ability to temporarily relocate spaces or move spaces. These skills help in the shifting of departments throughout the hospital, which is necessary in many renovation situations.

Some owners, such as Unity Memorial Hospital, do not take into account either of these, but instead care more about the project type. Some of their renovations are more medical-oriented, such as the emergency room space. Therefore, they look for contractors who are skilled in that project type, such as

Turner. In other situations, such as the pharmacy, where organization is necessary to maintain hospital operations, a different contractor was utilized with more experience in this department.

For Unity Memorial Hospital, it is suggested that they look for more contractors that understand their hospital and well as the phasing and logistics necessary to achieve project efficiency and coordination. This will help them to better manage and coordinate their portfolio of projects so that the contractors are well equipped with knowledge and experience to complete the project.

4.8 Final Portfolio Management Strategy Recommendations

In conclusion, it is suggested that UMH leverage ideas from these other hospitals in order to make their portfolio management, and therefore, their coordination processes, much smoother. Figure 18 shows the strategies considered with the bolded strategies being the suggestions for Unity Memorial Hospital.

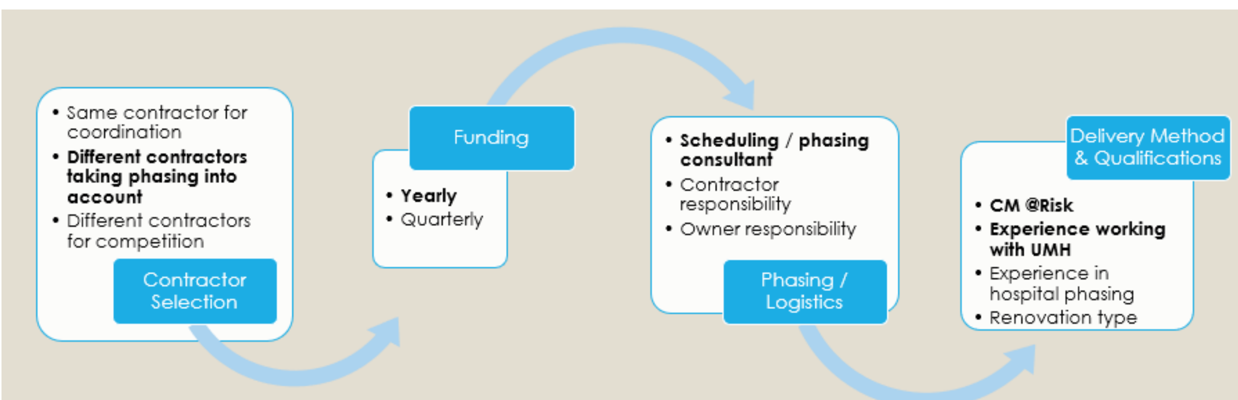


Figure 18: Portfolio Management Strategy

First, they should take into account the relationships between phases when choosing a contractor because it may be better for the project to keep the same contractor in place rather than bring in a new contractor for the purposes of competition. If the earlier phase is progressing successfully, they may be able to simply provide the new work as a change order that also streamlines the selection process. Secondly, although funding cannot necessarily be controlled, the project team should be aware of how funding can impact the size of the contracts put out for bid and that it may be easier for one contractor to be awarded and manage multiple small projects than it is for multiple contractors to manage many small ones. Additionally, phasing and logistics is an important aspect to making the project run smoothly and UMH may want to consider hiring a consultant that specializes in this to understand the hospital logistics thoroughly, especially if many different contractors are going to be used. Finally, UMH should reevaluate the qualifications they use to choose a contractor for their CM delivery method. The qualifications should center more the ability to coordinate with other contractors and with hospital staff.

Chapter 5

Analysis 3: Schedule Improvement through Prefabricated Systems

5.1 Problem Background

Prefabrication has become more and more common in the construction industry over the years. The ability to prefabricate depends on the design of the building and willingness of project members to perform the work. Prefabrication of a building has been proven to benefit a project's safety, quality, budget, and most importantly in this case, schedule and productivity (AE570).

In the Unity Memorial Hospital Renovation Project, there are approximately 3,000 linear feet of ductwork to be installed as well as plumbing piping, medical gas piping, electrical cable trays, and many other above ceiling systems. Prefabrication of racks with these systems installed off site will allow these systems to be brought into the building and installed more quickly and efficiently.

5.2 Problem Identification: Above Ceiling Systems Installation

Unity Memorial Hospital is on a strict schedule, with the renovation project to be completed by the end of June 2019, at the latest. This end date is expected to remain, even in light of the most recent delays caused by hospital logistics and other owner-held contracts. Because of these delays, the project team is looking for ways to shorten the schedule durations to achieve this end date.

Through this analysis, a potential solution that will be explored is the prefabrication of the above ceiling systems for the renovation project. This solution will also be helpful in fulfilling Turner's safety policy that "nothing hits the ground." Because all materials will be required to be brought in on racks, having them prefabricated and organized would allow for increased productivity.

5.3 Prefabrication Process

The current construction method begins with Turner taking over the space and immediately moving into the demolition phase of the project. After the demolition of the space, there is some time that is dedicated to ensuring that the designed system are coordinated with the current systems that are pre-existing above ceiling. From there, the materials will be brought on site for workers to install. However, this is not necessarily the most efficient method.

In an alternative strategy for above ceiling systems installation, the prefabrication process will begin before Turner can take over the space. In the time leading up to demolition of the ceiling and above ceiling systems, Turner can utilize laser scanning to determine the above ceiling conditions. This will need to be done after hours by an outside laser scanning company so that interruptions to hospital operations are minimized.

Having this data would allow Turner to begin coordinating and fabricating the systems to the correct size and configuration. These systems will then be assembled on racks, which, once on site, can be installed in larger runs requiring fewer connections, less labor on site, and increased speed as compared with on-site methods. Prefabricating the systems can occur as soon as the laser scanning is complete, so when demolition is complete, the racks can be delivered and installed. This concurrency of activity is where the largest portion of time in the schedule can be saved.

5.4 Design of Prefabricated Racks

The above ceiling systems shown in Table 6 and Table 7 will be the systems prefabricated and placed on the racks that will be installed above ceiling once demolition is complete. The difference between these two tables is that Table 6 shows the sizes of the systems that will be utilized in the main run of systems, while Table 7 shows the slightly smaller sized mechanical, electrical, and plumbing runs that will branch off the mains and into the individual patient rooms.

Because of the differences in pipe, conduit, and duct size, a typical size was assumed based on the construction documents and will be used for the calculations of the systems. This is also shown in the tables and will be used to create a typical rack for analysis purposes.

The systems in these tables include all the installation that Turner will be doing above the ceiling, with some exceptions. The first exception is the fire protection piping. This was left out of the prefabricated racks because of its unique layout for sprinkler coverage, which would not fit consistently within the prefabricated racks. The second exception is the sanitary line, which will be installed beneath the floor rather than above ceiling. The third is the return air and exhaust air ductwork. This does not run along the main corridor, so although the ductwork can be prefabricated, it will not be considered in this analysis.

Table 6: Systems for Prefabrication (Main Runway)

System	Typical Size
Mechanical Ductwork	30 x 12
Hot Water Piping to VAV (Supply and Return)	¾” (2)
Domestic HW	1 ½”
Domestic CW	2 ½”
Domestic HWR	½”
Vent Piping	3”
Medical Vacuum Piping	2”
Oxygen Piping	1”
Electrical Cable Tray	1.5’ Wide

Table 7: Systems for Prefabrication (Branches)

System	Typical Size
Mechanical Ductwork	10x4
Hot Water Piping to VAV (Supply and Return)	¾" (2)
Domestic HW	¾"
Domestic CW	¾"
Domestic HWR	½"
Vent Piping	3"
Medical Vacuum Piping	2"
Oxygen Piping	1"
Electrical Cable Tray	1' Wide

Finally, the patient rooms in the clinical decision unit are the most time sensitive to be completed. For this reason, the prefabricated racks for this analysis are focused on the CDU systems. If this is beneficial to the project schedule, it could be further scaled to include the back of house spaces. The CDU is shown in Figure 19.

The next step is the design of the racks themselves. The first consideration was how long the racks could be. For this analysis, the logistics of getting the racks into the building could be a key limiting factor. Luckily, the hospital's loading dock is directly adjacent to the space. The racks will be able to be unloaded at the loading dock and wheeled into the CDU space. During the time of installation, the interior walls in the CDU will have already been demolished to make way for the new layout, allowing the racks to come into the building without the need to make any turns, as depicted in Figure 19.

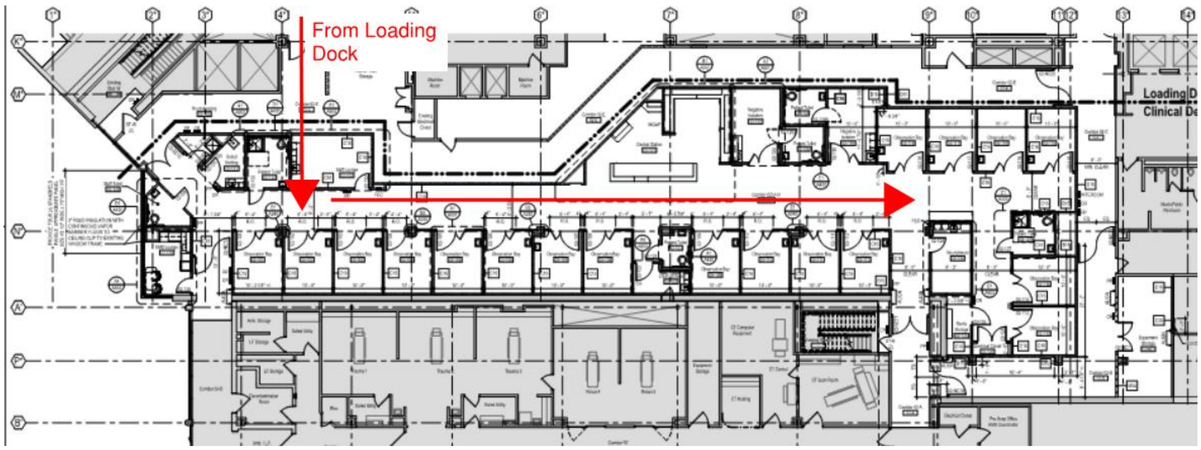


Figure 19: Unload Path of Prefabricated Racks

Because of the wide path into the space that wall demolition allows, the main prefabricated racks are able to span 20 feet. This is an ideal length because it is long and accounts for the standard lengths most systems come in, typically 10 foot intervals. Figure 20 shows an example design of what these main racks would look like, and the colors of the elements coordinate with those in Table 6. The assembly spans 20 feet with supports at five foot intervals.

The current depth of these racks is five feet; however, the plenum space available is 7’, so the assembly can be raised or lowered in the coordination process to align with the existing conditions found during the laser scanning phase of this analysis. This design also allows for the potential to add an additional rung for future MEP runs, if necessary. The total width of the assembly is 3.5’ to ensure access to the elements on the rack.

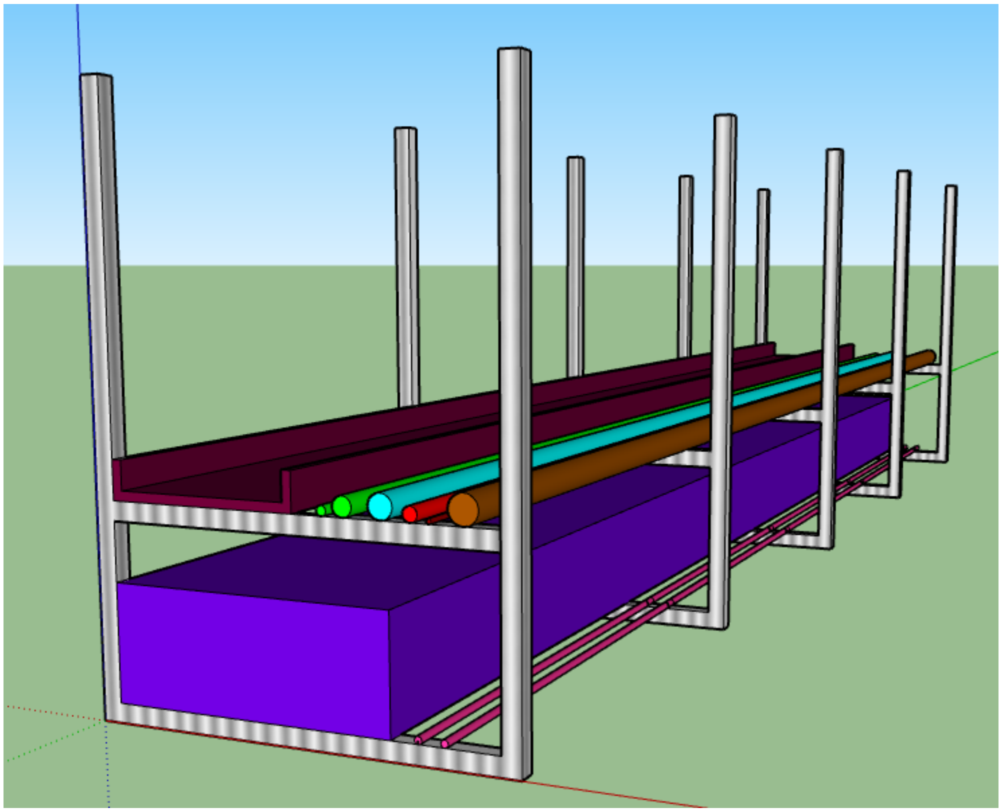


Figure 20: Isometric Main Rack Design

The branch racks, on the other hand, will hold elements from two patient rooms due to the termination locations. There are four pipes, hot and cold-water supply pipes, hot water return pipes, and vent pipes, that connect to the sinks that are located at the east wall of each patient room, whereas, the ductwork and the terminal unit hot water piping feeds the VAV boxes that are on the west side of each patient room. Finally, the medical gas piping runs to the patient headwalls on the south end of the patient rooms, and the cable tray is assumed to run from north to south across to the back of the room. Because of these locations, the branch rack will contain MEP runs from two adjacent rooms. This is depicted in Figure 21.

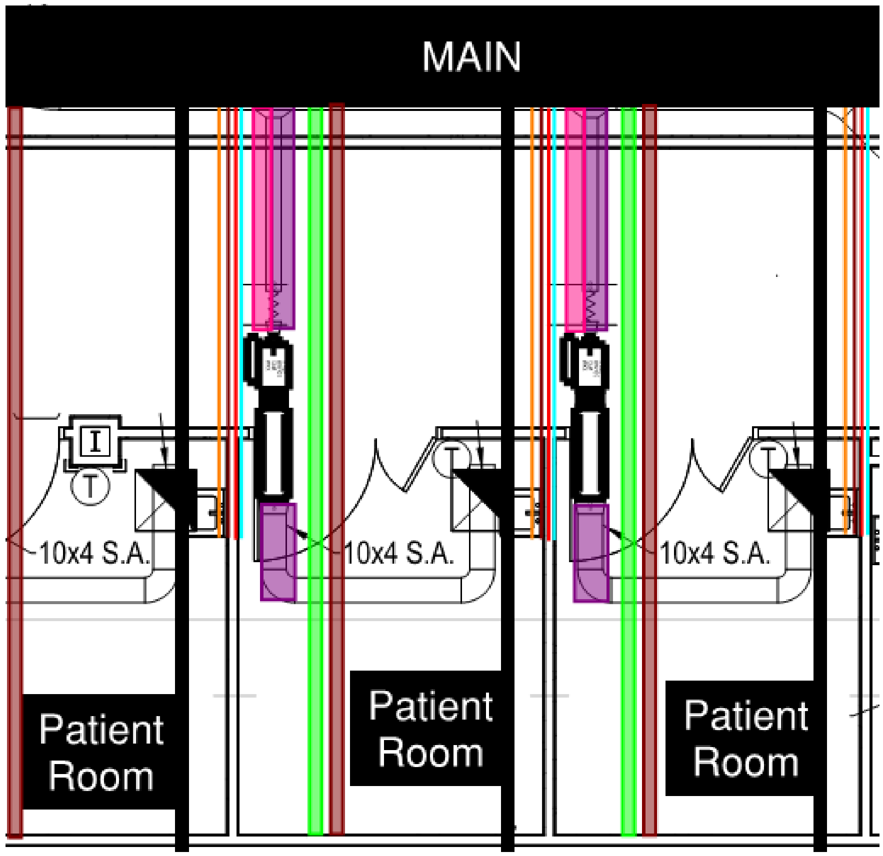


Figure 21: Plan View of Branch Racks

Once the ductwork leaves the VAV box, it must make two bends before terminating at the planned location for the diffuser. These two pieces will need to be installed separately and will not be a part of the prefabricated rack. Additionally, the VAV box can either be part of the prefabricated rack or be installed separately, depending on the existing conditions above the ceiling. One of the challenging aspects of including the VAV on the prefabricated rack is that the VAV boxes are being recycled from the demolition of other spaces. In that case, they would need to be made available and taken to the prefabrication shop on time in order to include them on the rack. Additionally, the necessary structural considerations would have to be made in order to ensure the racks could hold the weight of the VAV boxes. However, including them on the prefabricated racks would make installation much easier. For that reason, the VAV box is shown, in teal, in the prefabricated branch rack in Figure 22. The size of this rack is similar to the size of the rack of the main assembly in order to be wide enough to access both rooms. For height consistency, the depth of these racks is 5’, and the length of the rack is 25’, which is the length of the typical patient room. This length is needed for the medical gases to reach the south wall of the patient rooms.

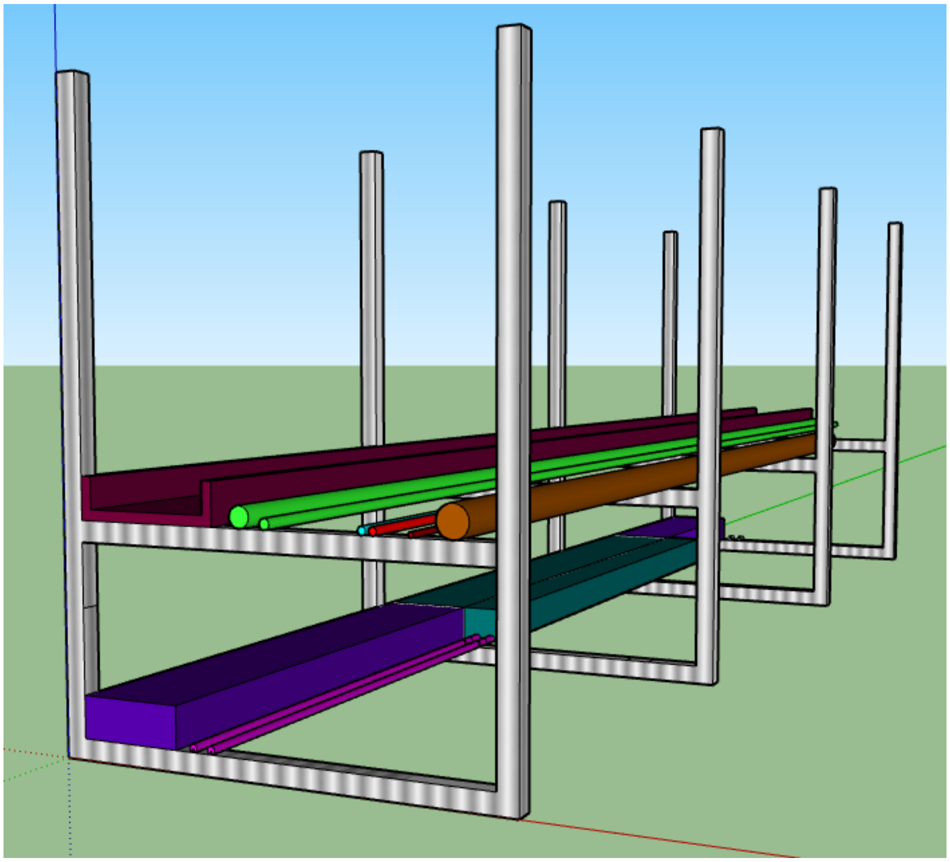


Figure 22: Isometric Branch Rack Design

5.5 Schedule Analysis

The first part of the scheduling analysis takes into account both the original construction schedule (Figure 23) and the current construction schedule (Figure 24). The full CDU-specific schedules can be found in Appendix C, and the full non-CDU-specific schedules can be found in Appendix B.

The original construction schedule breaks the CDU above ceiling rough-in into two separate parts due to the phasing of the project. This is because the linen room, which is in the middle of the new CDU, needs to remain in place during the construction sequence. This schedule relied heavily on the pharmacy relocation milestone. However, due to the delay of the pharmacy relocation project discussed in Chapter 3, a new schedule was created to temporarily relocate the linen room and complete the CDU all at one time.

Therefore, when implementing prefabrication of the above ceiling elements, the original schedule will not reflect the level of schedule decrease as the updated schedule being used. For this reason, the current project schedule was considered when implementing prefabrication on the project.

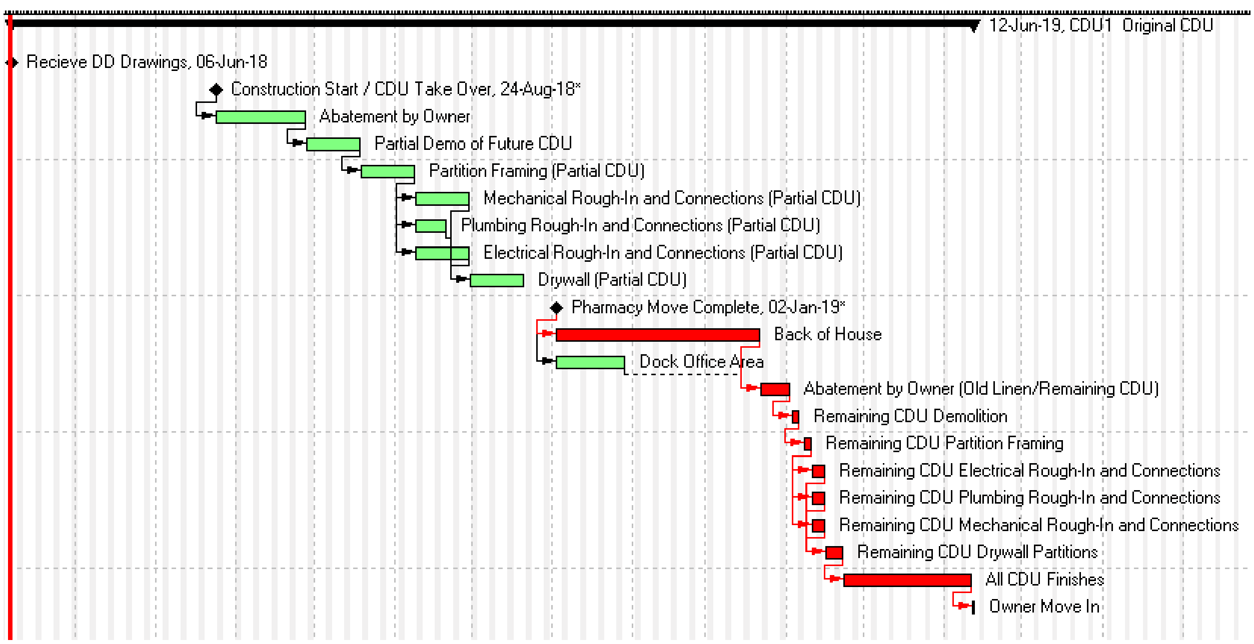


Figure 23: Original Construction Schedule Modified Specifically for CDU Activities

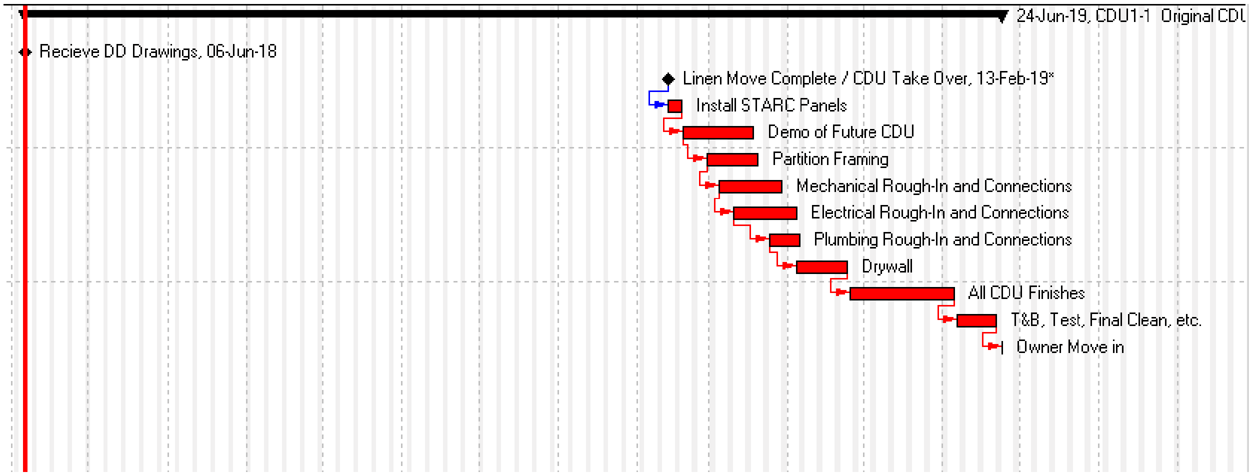


Figure 24: Current Construction Schedule Modified for CDU Activities

The activities on the current construction schedule include demolition of the current space, partition framing, and then the installation of all the mechanical, electrical, and plumbing systems. These include all of the above ceiling rough-in as well as the in-wall elements, final connections, and initial testing procedures. These activities will occur in succession moving from west to east across the CDU floor plan.

A duration of 15 days for the mechanical/electrical rough-in was used for the project schedule. It is assumed that this 15 day perioed includes four days for the main runs, nine days for the branches and connections within the rooms, one day for connections, and one final day for testing the system. The electrical rough-in was assumed to be similar, and the plumbing rough-in was a few days shorter because fewer final connections were necessary, as all pipes ran to the sink, which is very close to the main run of pipes.

After these systems are in place, drywall will be hung and finished, as well as the ceilings and remaining finishes for the space. This will be followed by the final tests, fixture installation, and cleaning before owner move-in. On the current schedule, the owner move in date is set to be June 24, 2019.

The schedule that was modified for prefabricated above ceiling racks is shown in Figure 25. This schedule starts much earlier, because of the laser scanning and off-site fabrication, which can start as early as the design development set of drawings. At this point in the design and construction process, the project team can make the decision to prefabricate the above ceiling systems. Once this decision is made, the project team can use laser scanning technology to scan the existing conditions above ceiling to analyze the system layouts for coordinating the layout and installation of the prefabricated racks. Once this plan is in place, the production process can begin. Even if this does not begin during the design development stage, there is flexibility for the racks to be prefabricated before the start of demolition on February 13, 2019. This is the date that the linen room will be fully relocated and demolition can begin.

Once demolition begins, the racks can be brought in through the loading dock and hung using a duct jack or forklift. To estimate the duration of this installation, the durations from the current project schedule was used as a baseline. It is assumed that prefabricated racks can be hung in half the time that it takes the hang individual pieces of ductwork. This is because the prefabricated racks are in longer sections and require fewer connections. Coordination is also removed from the sequence as an issue because all systems are being run simultaneously and the laser scanning step ensured that the dimensional coordination with the existing systems was already taken into account.

The duration to hang the prefabricated ductwork includes two days for the main runs and five days for the branches for a total of eight days. An additional three days were added to this duration for the excess installation on in-wall piping, pulling wires to specific locations, and small duct runs to the diffusers. Finally, one day for connections and one final day for testing the system were added to the schedule. After this total of 12 day duration for the systems’ rough-in, the schedule continues with drywall, ceilings, finishes, and finals testing and cleaning.

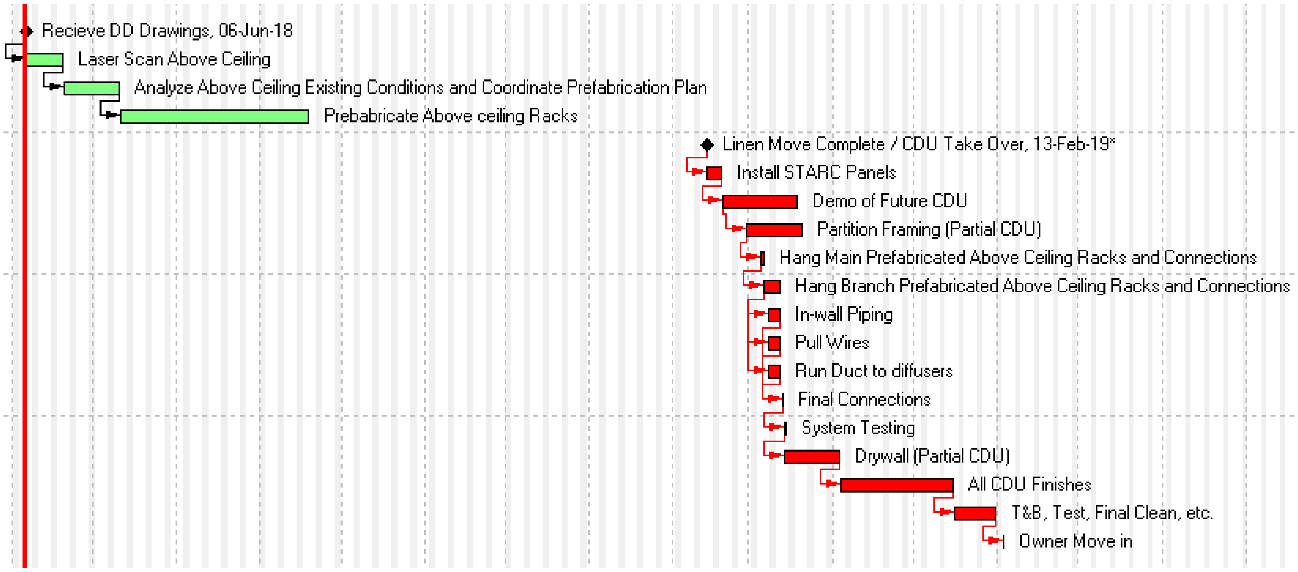


Figure 25: Current Schedule Modified for Prefabrication Analysis

With the implementation of prefabricated racks for the above ceiling systems, the scheduled date for owner move in is June 3, 2019. This is three weeks in schedule savings for the construction schedule.

5.6 Cost Analysis

The final consideration of this analysis takes the cost of laser scanning the space and prefabricating the racks for the above ceiling systems into account. There are four categories that reflect the difference in cost to these options. The first is the cost of the rack itself, which is more substantial than the hanging supports needed if the systems are not prefabricated. Without prefabrication, each element would go up individually; the rack allows for mass-installation of the above ceiling systems by only hanging one singular element: the prefabricated rack. According to RS Means 2018 Construction Cost Data, the metal bracing used for the racks will cost $1.50 per linear foot for both labor and materials. With supports every five feet of the run and each support needing 17 linear feet of metal, the total cost for all of the identified racks is $4,590.

The second element is the cost of install. This was calculated based on the typical sizes of pipe and duct size listed in Table 6 and Table 7. Because this rack is so much faster to hang and will take significantly less time, the cost of labor will be much reduced. This analysis assumed a 20% reduction in labor cost for the piping and ductwork included by using the prefabricated racks (Fishking). This reduction is reflected in Table 8. The labor costs were calculated using RS Means, and the breakdown of these costs can be found in the labor cost breakdown table in Appendix C.

The third element that is necessary for prefabrication is laser scanning. This is the most expensive portion of the prefabrication option because it requires special equipment and an additional party to do the work. Additionally, the laser scanning will likely need to be done during the off-hours of hospital operation to ensure minimum disruptions to the daily work. $30,000 is an assumed cost based on feedback from industry members.

Finally, the reduced schedule will save three weeks on general conditions costs which were calculated from Turner's original general conditions cost for the entirety of the project ($361,920 for a 39 week schedule).

Table 8: Cost Analysis of Prefabrication

	Original Cost	Prefabrication Cost	Delta
Cost of Rack	$0	$4,590	($4,590)
Labor Installation Cost	$59,482	$47,585	($11,897)
Laser Scanning	$0	$30,000	($30,000)
General conditions		($27,840)	$27,840
Total Cost	$59,482	$54,335	($5,147)

After calculating the total cost, it is clear that the prefabrication option is about equal to the original cost of traditional building methods. However, these general conditions cost savings are based on the assumption that the clinical decision unit is the only space included in the project renovation schedule.

When the back of house portion of the project is considered, these general conditions will not necessarily be saved, as the project schedule and critical path rely heavily on the pharmacy relocation discussed in Chapter 3. When the general conditions costs are eliminated from this cost comparison, the prefabrication option becomes over $22,000 more expensive.

5.7 Comparisons and Final Recommendations

Overall, the prefabrication of the systems improves the schedule by a total of three weeks, but will cost the project an additional $5,100, if analyzing the CDU only. It is recommended that the project stick with the traditional method of installing these systems due to the constant changes in planning and schedule. First, there are a number of milestones in the schedule that are controlled by the owner, not by Turner, that make coordinating difficult. An example of this is the pharmacy relocation and the decision to relocate the linen room. This is a change that would not have been anticipated by the project team and would have affected the planning of the prefabricated racks should they have already been in production. Unfortunately, it is likely that the schedule will be altered again due to the changes in hospital logistics. These schedule changes also have the capability to cut off the potential to unload the prefabricated racks into the space. Because of the multiple projects that would affect the coordination of prefabrication, it is not recommended for this project. Prefabrication would be better suited if Turner was coordinating all projects or if the entire renovation space were more repeatable (i.e., the back of house space were as repeatable as the CDU).

Chapter 6

Analysis 4: Virtual Reality's Effect on Value Engineering

6.1 Problem Background

The construction industry is getting more modern and technology savvy. Currently, virtual reality is being used for coordination, owner communication, and project marketing. However, value engineering is not something that has been directly identified by current contractors as a common benefit seen from the use of virtual reality, nor has it been studied by many researchers as an opportunity for growth and development.

6.2 Problem Identification

The value engineering for the UMH project was completed using a virtual reality program, called "Insite VR" to show the owner the differences in the value engineering options. Allowing the end user to explore these options while making decisions accelerated the process and reduced uncertainty about certain design options. The main value engineering scenario that was considered on this project was the patient headwalls. The virtual reality model was used to show three different patient headwalls to allow the doctors and nurses could use virtual reality to assess end usability. The owner was able to choose a final product based on their criteria of usability through feedback from the users, as well as cost.

However, Turner wishes that they were engaged even earlier in the design process so that more spaces could have been modeled and more value engineering could have occurred. Being brought on earlier would have given Turner more time to identify and propose different options for the Nurse's station, for example.

Overall, very little research has been done to document the benefits of virtual reality in the value engineering process. This could be part of the reason that it is not being utilized more broadly on projects:

the construction team is either involved too late or does not know about when and where virtual reality can be employed to support the value engineering process.

The purpose of this research is to identify how the industry is using virtual reality to improve their processes, with an emphasis on value engineering decisions. Interview questions will focus specifically on how the project teams integrate the use of virtual reality into their preconstruction and value engineering services. The goal is to utilize this information to begin to recognize and define the benefits of virtual reality for value engineering.

6.2 Literature Review

This literature review will define the necessary terms to continue with the interview research. These terms include virtual reality, augmented reality, and value engineering. The interviews with industry representatives will leverage these terms and how these are used on their projects. Clear and concise definitions of these terms are necessary to decipher how their examples of virtual reality uses relate to the topic of value engineering.

Additionally, the paper will start to define ways that virtual reality has been used in the AEC industry by organizing its applications into use cases, namely communication between the project team, design applications, construction applications, and value engineering applications. These instances serve as a starting point for the different ways that the industry members are utilizing virtual reality for value engineering and related decisions.

Finally, value will be defined as a part of the value engineering applications of virtual reality. This will aid in classifying how different virtual reality examples add value to the projects on which they are being used. Overall, this literature intends to provide the background information needed before the industry interviews.

6.2.1 What is Virtual Reality?

Virtual reality (VR) is an immersive and multi-sensory experience. It takes "real-time interactive graphics with three-dimensional models and a display technology to give the user the immersion in the model world and direct manipulation" (Mazuryk). The user can watch and manipulate the simulated environment in a similar manner to the way we act in the real world, which holds the benefit of being user friendly and intuitive rather, reducing the need for extensive computer and model knowledge.

Although the first idea of virtual reality was presented in 1965 (Mazuryk), it has only become more popular and attainable recently, as the gaming and entertainment industry has made it more accessible, affordable, and valuable to diverse markets. The gaming industry has also been a great push for quality in the virtual reality software and hardware. Often, the best VR tools used in the construction industry leverage the VR software that was originally developed for the purpose of gaming. Therefore, virtual reality has attracted more interest and the world has noticed its diversity in benefits of its application. Many industries have adopted virtual reality programs to benefit their businesses or research. Some examples include NASA's modeling of a virtual wind tunnel for aircraft studies, virtual experiences for medicine students in performing surgeries, and virtual skills training for athletes (Mazuryk). The AEC industry however, has primarily adopted it to achieve better communication within their project teams and to their clients (van den Berg M).

Before discussing how VR is utilized in this industry, defining the exact classification of virtual reality is important. Whyte (2002) argues that virtual reality has three defining characteristics:

(1) Interactive, enabling users to manipulate a design model.

(2) Spatial, with those models being represented in three spatial dimensions.

(3) Real-time, with feedback from actions given without noticeable pause.

Virtual reality is not to be confused with augmented reality., Augmented reality (AR) is a technology that presents a virtual world that enriches the world in front, often as an 'overlay' of information or visuals seen through a device. Virtual reality replaces the real world visually, with the full visual you see as a generated image. In terms of VR's defining characteristics presented by Whyte, augmented reality is different because it is not fully immersive. AR takes whatever the current reality is and adds to it or manipulates it. Figure 26 depicts the visual differences between these two terms to better define their differences.

Figure 26: Virtual Reality V Augmented Reality (Sol)

In addition, the display technologies is an important differentiator between virtual and augmented reality. As stated, VR is more of an immersive experience than AR. To view VR models, the construction industry mainly uses two different forms of display technology: immersive headsets or large scale displays, such as caves or walls (Kore). Figure 27 (Jacobson) and Figure 28 (Liston et al) show the viewing differences of the two immersive experiences. The first is high-performance immersive headsets:

Figure 27: Snapshot of VR Headset in use

The cave / wall display technologies require projectors and display screens or walls. These types of displays are most common in the scientific and professional communities, especially because they can accommodate multiple users at one time (Kore). This is most often what is used during a design review scenario. Additionally, Figure 30 shows an image of the Immersive Construction (ICon) Lab at Penn State University, which is frequently used by design and construction firms as well as the university to view projects before they are constructed.

Figure 28: Snapshot of project meeting in CAVE

Ultimately, the interactive, special, and real-time components of VR make it a valuable tool to be used for a number of different uses in the construction industry today. The following sections will analyze missed opportunities for the use of VR, as well as ways that VR has been implemented in the past in order to project what the future of VR in the AEC industry can be.

6.2.2 Virtual Reality for Communication and Coordination

The construction industry is leveraging a variety of technical solutions for communication and coordination, both during the design and construction phases of building. The need for communication starts with the designer, owner, and general contractor, and stems to the trade contractors. The larger the project and the more parties involved, the more important this communication process becomes. All parties must engage in the method of communication agreed upon so that information is not miscommunicated between parties. Miscommunicated information has the potential to affect the constructability, schedule, or cost of a project.

A paper entitled, "Focused Sharing of Information for Multi-Disciplinary Decision Making by Project Teams" written by Liston, Fischer, and Winograd at Stanford University discussed ways to enhance project team communication and decision-making abilities. First, the paper outlined why communication and information sharing are so important (Liston et al). The authors conclude that information sharing is vital to the growth and success of the industry and future investments should be made in the information infrastructure where possible. While this paper, written in 2001, identifies 3D Product Models and interactive workspaces (such as iRoom) as solutions to help implements a higher level of communication across parties, it fails to acknowledge the benefit that virtual reality brings to information sharing between parties in the construction industry.

One of the notable points made in this paper is that information sharing helps to anticipate future issues that may result during design or construction. Although not mentioned in the paper, this is something that VR can help with: by viewing the VR model collectively as a group, comments and discussions can result in changes to the project design to eliminate rework in the future (C. Bridgewater). Secondly, the paper mentions that the sharing of models and information enhances the consistency of the information or the model that is being shared (i.e. it holds the creating party more accountable for the correct information being passed along) (Liston et al). Again, the paper does not mention VR in this instance, but it can also be applicable in this situation by using it to communicate between different parties. Viewing and sharing the virtual reality model ensures that all contractors are on the same page with the design. It is very likely that the drawings can be interpreted differently, which is why the VR model can be a useful tool to decipher any ambiguities or uncertainties in the two-dimensional drawings.

The mentioned article is just one example that addresses the need for better communication on the jobsite, but does not mention virtual reality as a tool to improve coordination among parties. Ultimately, this type of research (and the need for improved information sharing abilities) has prompted additional investigation of new methods for information sharing. This exploration brought VR into the mix of tools implemented for communication among parties. The following sections identify examples as to how exactly the industry is using virtual reality to achieve this better communication across the project team.

6.2.3 Virtual Reality Applications in Design

Virtual Reality has proven to have a number of applications in the design sector of the building industry. Most critically, as mentioned previously, VR has emerged as a tool to enhance capabilities of communication and information sharing, which is both a challenge and a necessary component of the industry. This section details its applications during the design phase. Bridgewater identifies two ways that VR is employed to support design processes. One of the most common ways that virtual reality is used in the design phase is through the design process so that designers can visualize the spaces they are creating. A second common application for VR during design is so owners can review the design and make comments to enhance the design. These two applications, as well as others, are listed in Figure 29 (C. Bridgewater), which lists additional, less common, methods of implementing VR.

Design Phases	Preliminary and detailed design Lighting and ventilation simulations Data exchange Fire/safety/access assessments Scheduling and progress reviews

Figure 29: Applications of VR in the Design Phase

First, virtual reality helps designers to view their work in a more real environment to make the changes visually rather conceptually. Traditional forms of visualization used by designers include sketches, architectural drawings, mockups, or photomontages (van den Berg M). However, tools such as VR can create an immersive experience to visualize designs. For designers, this visualization tool provides a means to increase the creativity of the designers. The design data generated and saved by the VR system will allows designers to understand their designs three-dimensionally, which, in turn, allows them to make changes that they would not have otherwise seen or noticed (Chan).

One of the first examples of virtual reality being implemented in the design world is the Virtual Kitchen. This was a tool used mostly be interior designers at first in order to visualize their sketches. This was especially helpful to visualize the changes in colors, textures, and positions of objects. It allowed them to visualize these changes with a click of a button rather than reworking an entire sketch that may have taken them hours (Mazuryk). It was a nearly instantaneous method to interpret what the whole space would look like with each small change.

Since these first models, virtual reality has become much more popular, resulting in an increase in the quality of the colors and textures of building materials that can be seen in a virtual reality model. The most efficient means of importing these into the virtual reality model are through a rendering package that creates a very close image and texture to map it onto the surface of the modeled objects (Chan). For unique colors or textures, users have the ability to take photographs or samples of real objects, and scan them into the software. This makes the immersive experience more realistic and similar to the end product, which helps designers choose products and finishes for the job.

Project teams in the design phase are typically able to visualize basic models with low levels of detail. However, with increasing detail and accuracy, the model will appear more realistic. However, this added detail requires more time and effort by the team creating the model, as well as the right expertise, software, and hardware to be used. (Chan). Although some designers may not see this extra time and effort as necessary to have an extremely detailed VR model, this detail really benefits owners and end-users that want to visualize and comment on the end state of their building.

A higher quality model gives the owner a better feel for the space and they can better communicate with design professionals about their concerns or changes they want to make. For this reason, the most common use of virtual reality during the design projects is conducting design reviews with the owner and end-user (a photograph of a design review conducted at Penn State is shown in Figure 30 (Maldovan). This is especially true for owners who are novices in the building industry.

Figure 30: Design Review Meeting using ICon Lab at Penn State

These ideas are reflected in a paper entitled “Supporting Design Reviews with Pre-Meeting Virtual Reality Environments” and written by Marc van den Berg, Timo Hartmann, and Robin de Graaf. This paper evaluates some of the applications of VR in the design process. These applications center around the communication of project teams, specifically between the design team and the client. The purpose of their research is to define how virtual environments can be employed to communicate the design intent to clients while communicating feedback to design professionals (van den Berg M). The research and data collected was organized into one of three categories:

1) Exploration from a user perspective.
2) Participation in solution-finding.
3) Feedback on a design proposal.

Van Den Berg et al concluded that owners sometimes lack the confidence to speak up about a misunderstanding in the two-dimensional drawings; however, when they see the space built out virtually in front of them, they are able to visualize exactly what the space is going to look like in the future. VR takes the guessing and uncertainty out of viewing two-dimensional drawing sets. It was also found that viewing the VR model leads clients to feel more confident about the design that they are viewing and therefore more empowered to participate in problem-solving during the design process. Because these are the people that are going to be using the space, they have a more detailed understanding for how it will be used to provide better feedback to the design team regarding their vision for the space (van den Berg M). From the designer’s perspective, this experience of receiving client feedback helps in future designs of similar facilities. Through the questions that owners may ask, designers are able to adjust the way that they present information to owners or how they design certain aspects of a facility. The use of VR also helps to foster a good relationship between the owner and the designers because they are much more willing to hear the owners’ opinions and vice versa. This makes for a better coordinated and executed project.

Overall, design reviews that utilize a virtual reality model are a great method to take owner feedback into account and make the changes that will result in the owner's improved use of their space in the long run. Although design reviews are the most common use of VR in the design phase, it can also be used in other design and construction aspects.

6.2.4 Virtual Reality Applications in Construction

Although the virtual reality model often starts in the design phase, it can also be used in the construction process by a building in order to more effectively and efficiently build the space. Some of the potential applications of virtual reality during the time of construction are listed in Figure 31 (C. Bridgewater).

Area	Potential Applications
Site Operations	Rehearsing erection sequences Planning lifting operations Progress and monitoring Communications Inspection and maintenance Safety training and skills

Figure 31: Applications of VR in the Construction Phase

First, there are a number of design phase applications that affect the construction phase of a project. The first of these is that virtual reality implementation can reduce rework because with more owner input, the tendencies for changes once the work is in place is significantly lower (C. Bridgewater). The elimination of rework is conducive to a more fluid and efficient construction schedule.

Additionally, virtual reality has the ability to limit the number of physical mockups made on the job site. Typically, virtual mockups will suffice for any mockups with a visual intent (C. Bridgewater). However, if the mockup is needed from a constructability standpoint, such as ensuring no leaks, they may still be necessary. It is possible to do such mockups in place in order to eliminate the extra work associated with the mockup.

Safety is an important use for virtual reality in the construction realm. Although this may not be often considered as an important use of VR, safety is a necessary component of construction. Safety is instilled within workers through a variety of safety trainings, such as lectures, videos, or demonstrations; however, these are not always engaging for the workers, and their retention of the information they learn can be very low. Research by Rafael Sacks, Amotz Perlman, and Ronen Barak in their paper "Construction safety training using immersive virtual reality," proposed conducting safety training for workers in a virtual environment rather than exposing them to any construction hazards for the purpose of learning. This immersive, VR experience proved to be a better safety training experience than previously utilized teaching techniques (Sacks et al). Through VR, however, they are given the chance to assess situations and act on these decisions to achieve results. They are able to replay the situations and receive feedback on how they would be able to reach a better outcome, should this have been a real-life safety situation (Sacks). The VR system offers workers the exposure to hazardous situations similar to what they would be facing day-to-day on a job site.

The research developed as a part of this paper has shown the ways VR application for safety can be useful and improved the way that construction workers made safety decisions on the job site. However, it is not easy to implement this on construction sites for multiple reasons. First of all, training workers properly is more the responsibility of the subcontractor that is employing the workers. Typically, the general contractor or construction manager does not have a great responsibility in the training of workers, but instead ensures that they have been trained by their employer in some way. For this reason, it would have to be required via contract, which lessens the chance of implementation (Sacks). Additionally, the VR training system did not necessarily help the general safety aspects, such as wearing personal protective equipment and checking surroundings. These are basic aspects to safety that some workers forget about daily, even though they have been trained on the subject. Nonetheless, safety has shown to be a strong example of using VR to positively influence the construction process: a higher level of safety means fewer accidents on the construction site. Safety related issues can greatly impact project schedule and cost.

Virtual reality can also be used for simulations of the construction process, constructability, construction logistics, and site activities planning. Some of these methods were explained by C. Bridgewater, M. Griffin and A. Retik in their paper entitled, “Use of Virtual Reality in Scheduling and Design of Construction Projects.” (C. Bridgewater) First, it is believed that virtual reality can be applied to construction projects to help visualize the construction process for evaluation of its feasibility, as well as resource allocation and progress monitoring. It has the ability to give the construction team a better perception of the complexity of a project by allowing them to view the construction process step by step, and more easily identify the critical points that may impact the project schedule, cost, etc (C. Bridgewater).

The project team also will have the ability to use this VR construction model to consider different constructability scenarios, which could range from how the construction team would choose their sequence of activities, to how they would deal with an anticipated delay. They will be able to view this before construction to finalize planning and processes, as well as utilize it throughout the construction process to manipulate and change it based on where they are in the project schedule. If the schedule is delayed or off track, they can use it to reevaluate the construction process to get the project completed on time (C. Bridgewater).

Interactive collaboration is also an option for utilizing VR during construction. This will allow visualization of the site in real time. Using VR in real time would be especially helpful for larger projects, where it would be reasonable to use virtual reality to monitor more than just the construction processes and scheduling, but also the activities and progress of the equipment on site. It would be possible to check the different locations of construction equipment, as well as temporary facilities, to prevent delays on the project (C. Bridgewater).

A number of visualization tools for the construction manager's use have been utilized. However, there are still a number of challenges. One of the larger challenges that construction planners are running into when attempting to use virtual reality for their projects is that they are given an existing computer model from the designers that was meant for the designer's use. This means that the necessary information that will allow the construction manager to utilize the model for construction aspects, such as scheduling, may not be available (C. Bridgewater).

Additionally, VR can be useful in site organization to give the construction managers the ability to compare different alternatives for each point in the schedule for the facilities, equipment, and materials that need a location on site. This information and visualization of on-site construction helps the construction team to arrive at more efficient site planning solutions. They are able to evaluate this through every phase of construction, with the scheduled contractors that will have materials on site during each of those phases. This will help the specialty contractors to coordinate with each other, which should accomplish a more fluid construction experience (C. Bridgewater).

These are just some of the construction applications for VR, as there are a number of others that industry members have explained. These will be presented in the research portion of this chapter, and will be evaluated for their use in the design and construction industry. Construction companies are continuously finding new ways to implement VR to better their construction delivery, and it is important to build upon these ideas in order to build projects more efficiently.

6.2.5 Virtual Reality Applications in Value Engineering

Virtual reality has the potential to add value to a project through the means of value-adding measures, such as value engineering and value management. However, value must first be defined. Quantitatively, value is defined by the equation shown in Figure 32 (Atabay).

$$\text{Value} = \frac{\text{Function (desired performance)}}{\text{Overall costs}}$$

Figure 32: Value Equation

The desired performance, on the other hand, is something that needs to be defined by the owner. This desired performance can relate to any aspect of the project, whether that be the desired feel of the space through finishes, the desired performance of the building systems, the desired execution of construction, or the desired completion date of the project. The owner chooses the value that different materials or activities have based on what is important to them. To ensure all parties of the project team are aware of this, the owners must define their needs and goals of the project. These could include both value engineering and value management (Atabay).This, in turn, allows the project team to provide value through different aspects of the design and construction process.

Value engineering is a technique directed toward analyzing the functions of an item or process to determine "best value", or the best relationship between worth and cost. Typically, utilizing value engineering on projects can be used to gain the following benefits (Atabay):

- Cost reductions
- Schedule savings
- Quality improvements
- Detection of design deficiencies

Value engineering is not a technique for strictly cost cutting, but instead, it is used as a method to increase the value of a project based on what the owner defines as value (Atabay). This is where most people get confused between the line drawn between value engineering and value management.

Value management is another category of value that can be utilized by a project team. This typically involves improved designs that enhance the monetary value of the project. This does not necessarily take into account the owner's project goals for delivering or enhancing the project

(Tohooloo). Value management focuses on the outcome of a project and the cost of said outcome. However, unlike value engineering, this outcome is chosen and committed before value management process begins, which limits to options available for cost cutting. Through value management, the following outcomes can be achieved (Kostrzewa):

- Identify items that can be omitted.
- Identify items that can have their specification changed.
- Identify items that could be re-instigated later in the program, if the budget allows.

Value engineering and value management can be accomplished in a variety of ways using different tools and processes. However, there has not been research to convey the additional efficiency that virtual reality can contribute to this process.

6.2.6 Literature Review Conclusions

Overall, virtual reality is becoming more prevalent in the AEC industry, and new use cases are being discovered frequently. Although some of these applications were highlighted throughout this literature review, every company, region, team, and owner may have different ways of using this technology. For that reason, the industry research was conducted for further insight into how virtual reality can be used, especially to add value to the design and construction process.

6.3 Industry Interviews and Participants

In order to gather information on virtual reality and how industry members are using it to improve their value engineering practices, five industry professionals were interviewed regarding their value engineering, building information modeling (BIM), and virtual reality practices. The following interview questions were used as a guideline during the interview:

- What is your standard value engineering process or are there particular steps that you go through when looking at VE?
- What tools are you using to incorporate BIM on your projects?
- What is your knowledge / understanding of virtual reality as a part of the BIM process?
- Have you used virtual reality on projects before and in what way / for what purpose?
- What were the goals in using virtual reality on your past projects?
- What benefits did you see when using VR?
- Have you ever used VR for the value engineering process?
- How do you think this would be helpful/how was this most beneficial?
- How has virtual reality changed the way that value engineering is approached?
- When and how did you start incorporating virtual reality into the value engineering process and was it something that was planned and how so?
- What criteria determine if virtual reality is used on a project?
- What do you see is the largest benefit to virtual reality in the value engineering experience?
- What do you see is the biggest challenge to using virtual reality in the value engineering experience?
- In your experience, where are the best applications for this? (Finishes? Systems? Spatial design? Etc.)

The interview participants represent a range of people were chosen with different backgrounds and experiences with virtual reality. The focus was to identify different parties that have direct experience with using virtual reality in value related discussions during the preconstruction process. Some of the industry members' positions focus specifically on implementing virtual methods of designing and constructing, and may work on a number of projects at a time, while others are project managers working with owners and a specific project on a day-to-day basis. All individuals have a different take on virtual reality and their opinions and points of view are taken account in the interview analysis. Table 9 outlines some background on the individuals that were interviewed.

Table 9: Virtual Reality Interviewee Information

Design / Construction	Title	Location
Construction	Interiors/SPD Procurement Manager	Pittsburgh, PA
Construction	Virtual Design & Construction Engineer	Boston, MA
Construction	Senior Project Manager	Columbia, MD
Construction	Director of Virtual Design and Construction	Bethesda, MD
Design	Director of Virtual Design and Construction	Arlington, VA

6.4 Interview Results: How VR Adds Project Value

In order to organize the information obtained from the interviews, a mind map was created with different categories derived from the interview questions, each containing information on how virtual reality can be used to add value to the design and construction process of a building. Each of the categories contains a number of subtopics. These encompass the differing opinions of interviewees on the topics, specific examples relating to that category, and considerations made by industry members as a part of using virtual reality to add value to a project.

Originally, the goal of this research was to identify how virtual reality can be used in value engineering practices. However, during these interviews, many of the conversations began to range from value engineering, to value management, and to other forms of value. For this reason, the objective of the following information focuses on how virtual reality can add overall value to a project rather than just value engineering, which is much more specific.

The categories and relationships that have been formed as a result of the interviews can be visualized using Figure 33.

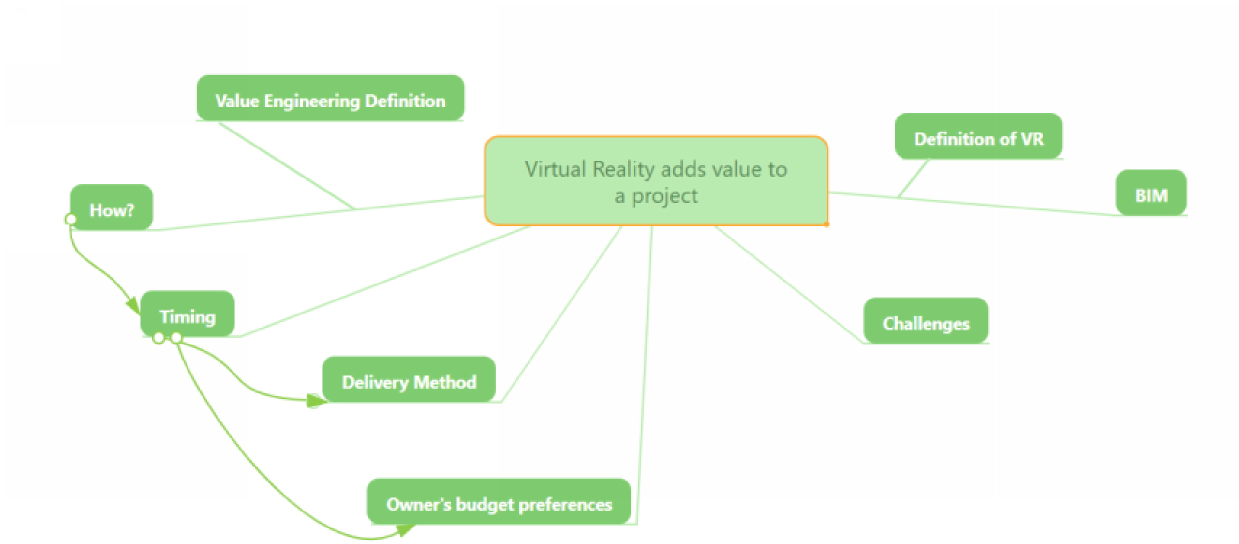


Figure 33: Virtual Reality Adds Value Mind Map

The focus of Figure 33 is how exactly virtual reality adds value to a project. But, first, it is important to understand what is defined as value by the participants. As previously stated, value engineering was originally the research priority. However, as interviewees were answering questions, it became apparent that the industry members had different understanding and use of the phrase value engineering, most of which had slight differences from the definition provided in the literature review research. Additionally, when addressing virtual reality, the topic strayed away from value engineering and into value management and ways that value, in general, it added through the use of VR.

Value management is a term that was discussed at length in an interview with senior project manager,. Once the term was identified, it was noticed that other interviewees were using the definitions of value management and value engineering interchangeably. To differentiate the two terms, the senior PM made the following statement:

"Value engineering, by definition, is a substitution of something of equal or better value, quality, or performance. In other words, if you have a better and cheaper way to do this, with better performance. We use the term value management in the industry as the words for value engineering that is done way too loosely. I would say most "value engineering" is value management, which is getting something cheaper that looks just the same."

In addition to this statement, there was discussion among the other interviewees about the timing of value engineering. Value engineering is typically something that should occur as soon as possible in the design process; value management, on the other hand, typically deals with finishes towards the end of the project. Although timing will be discussed directly in a later section, it is important to consider the difference, by definition, in timing between value engineering and value management.

Figure 34 is a representation of this information that resulted from the mind mapping exercise used to organize the interview information.

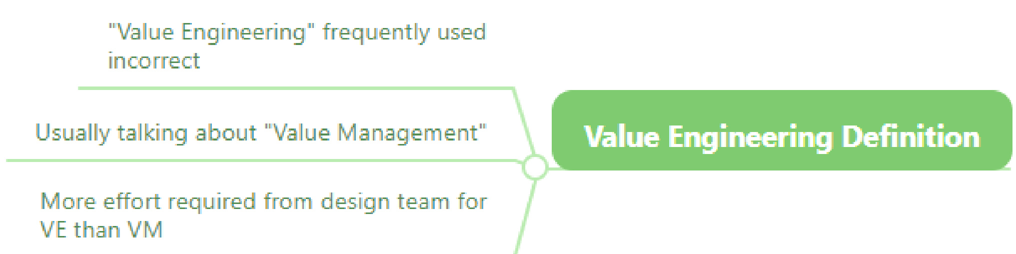


Figure 34: Value Engineering Definition Mind Map

For these reasons, it has been decided to include all iterations of value in this research. Moving onto how exactly virtual reality is used to achieve value in the design and construction environment, three categories have been defined and are reflected Figure 35 in the relevant section of the mind map.

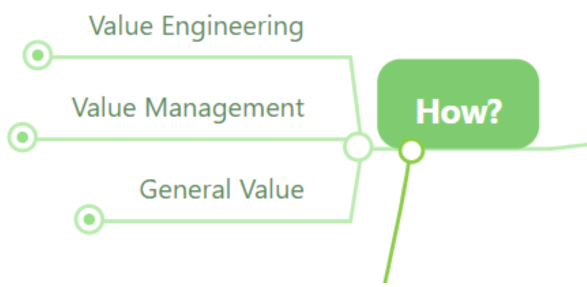


Figure 35: Three Ways Value is Achieved Using VR

The first category that was analyzed is value engineering. It was a very common statement among the interviewees that virtual reality is used for value engineering on a project by project basis. The opportunity really needs to present itself in order for virtual reality to be considered for the true definition of value engineering of a project. This is because most value engineering applications do not necessarily deal with visual concepts, but instead more equipment and system based applications.

Figure 36: How VR Helps to Achieve VE Mind Map

However, there were a few examples that were provided by the interviewees that demonstrated that virtual reality can definitely be applicable and useful in the value engineering process. The first is the patient headwall example that was used for the Unity Memorial Hospital Project. The virtual reality model was used to show three different patient headwalls so doctors and nurses could use virtual reality to determine usability. The owner was able to choose a final product based on their criteria of usability and cost. Chapter 1 provides more detail as to how virtual reality provided value engineering for this project.

The next example was provided by the design representative. Using virtual reality, they were able to engineer a solution to a lighting issue. This took place in an office where the client was concerned about having proper lighting levels in the middle of the room, because of how tall the cubicle walls were. Instead of installing more lighting, which would have been an added cost to the owner, they developed a mirror that was able to reflect enough light to the cubicles. The model in virtual reality was able to provide a visual that confirmed the lighting levels and visual impact were acceptable by the owner. If this would not have been able to have been modeled, the owner likely would have spent the money to install additional money to ensure proper lighting levels.

Next, value management was analyzed as a category of value that virtual reality has the opportunity to enhance. The largest application discussed that fits into this category is the ability of the owner to choose finishes for certain spaces. These include, but are not limited to paint, carpet, tile, casework, exterior facades, ceilings, and accessories. Using the VR software, owners are able to choose between a variety of finishes based on the way they will look in the space and are able to truly evaluate how important these finishes are, depending on their cost. Using the software, they are sometimes able to determine that two products are so similar that it does not make sense to spend the extra money for one over the other. However, there were varying opinions as to whether the virtual reality representation of these materials was sufficient to choose materials based on the model alone.

Figure 37: How VR Helps to Achieve Value Management Mind Map

First and foremost, the opinions were largely dependent on the individuals' familiarity with using the modeling and virtual reality tools. The industry members who are project managers had the tendency to say that that the finishes portrayed in the virtual reality program were not quality enough for the owner to choose based on the virtual image alone, while the virtual design and construction focused industry members were confident in choosing, not all, but certain finishes using the model. This is more than likely due to the fact that virtual design and construction-oriented industry members are more well-versed in the tools and programs available for virtual reality. The programs that produce higher quality rendered spaces are typically more difficult to use. Many cannot easily import and manipulate a design model; therefore, they take skilled individuals to operate such software tools. The combination of the higher quality tools and having the ability and skill level to use them properly makes for the ability of owners to better choose finishes for a space.

A strong example of this was brought up in an interview with one VDC profession, as he stated:

it definitely does depend on the tools you're using and the skill level. In Pittsburgh, for example, they have a VR set up, and it does some pretty cool things, but the software that they use and the expertise they have available limits them to looking at Sketch-Up models. With that, you get accurate spaces, proportions, and sizes and can feel like you're in the space, but you're never going to get away from that cartoon-y look Sketch-Up has. This is in contrast to some of the more advanced tools out there, which require an advanced user.

He further provided a set of side by side images; the first is the VR image and the second is a real life photograph of the as built space. This shows how similar VR can get to real life if the right software is utilized.

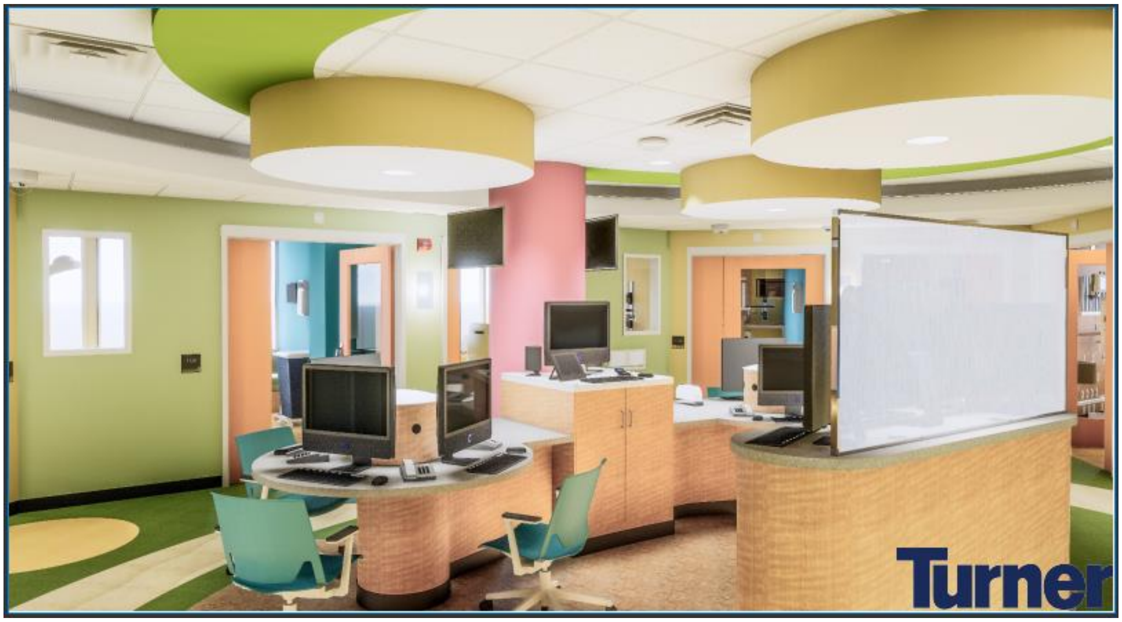


Figure 38: Virtual Reality Image of Nurse's Station

Figure 39: As Built Photograph of Nurse's Station (Photo by Matt Wargo)

However, even the more skilled VR users caution that it is important to get physical samples for the owners to approve. This is because some owners can be incredibly particular with the way their spaces look. If they are building an addition or a building that is a part of a network or campus of other buildings, they may want the materials to match exactly.

Something that was not mentioned during interviews but is important to address in addition to the quality of the software and users of the software, is the quality of the hardware and equipment being used. There is a decent amount of hardware required to run virtual reality systems: computers must have a high enough operating capacity, if projectors are being used, they must be able to portray the 3D images, and the goggles must sync with the other hardware and software properly. The hardware also contributes to the visual quality of the model and will affect the way that finishes and spaces are perceived by the user.

Additionally, the type of materials has a lot to do with the perception of the material in the virtual model. One of the examples that was brought up by another VDC expert was selecting or matching a particular stone. The colors provided by the quarries are always a little bit different, so it is important to work with the quarry and ensure the color is exactly what the owner is looking for, especially if they are trying to match a color that is already existing.

The final, and most broad, category that addresses the ways that virtual reality can add value to a project is through general value. This category is identified as general value because these are not instances that directly save the project costs on choosing a certain product, finish, system, or piece of equipment, but instead, the virtual reality model is utilized to save costs that cannot be quantified directly, such as site planning, user group visualization, inspections, and bidders meetings.

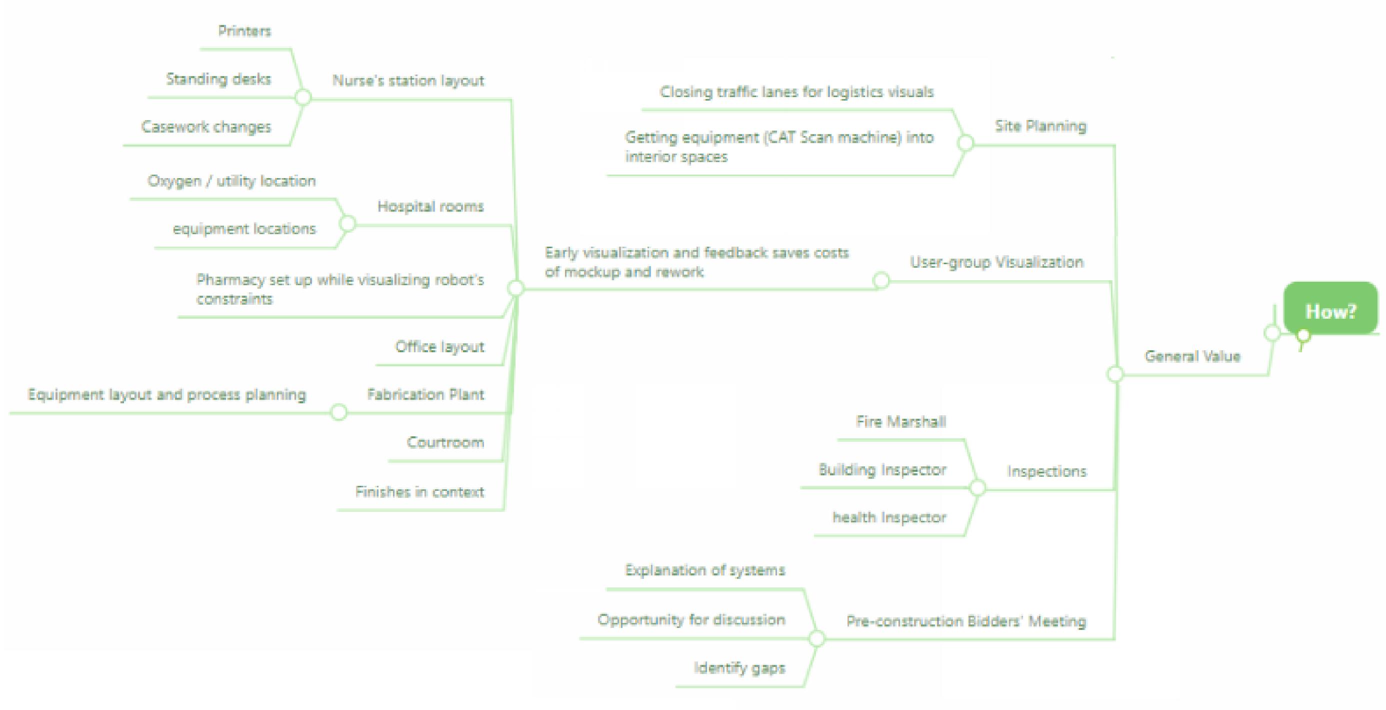


Figure 40: How VR Helps to Achieve General Project Value Mind Map

The first example of how VR can add general value to a project is using the software for site planning. VR allows the contractors to visualize how they are going to use the spaces available during the contraction process. This adds value to the project because it ensures the contractors ability to execute their plans methodically and visually. One example that was given during the interview process was using virtual reality to view the site and the impacts that may be encountered if the project team were to shut down a lane of traffic. Another example was using virtual reality to model the way in which a project team can get a large piece of equipment into the building and maneuver it down a maze of hallways and into its proper location.

Although these applications were not discussed in great detail, they are definitely aspects of construction management that can benefit from virtual reality. For one, with accurate dimensions, the model will be able to determine the tolerances for wall placement before the wall is built. It will help to think proactively while building the walls to accommodate the equipment that will need to be brought in through the space. Not only is it important to be sure that large pieces of equipment can get into the building, but if the walls and floors are finished, it is important to find a way to navigate the equipment through the building without causing any damage and requiring rework in the spaces that the equipment may scratch. In the long run, utilizing this tool can save the project the costs of rework or even needing to remove walls or windows to get equipment into the space.

As far as the site planning example is concerned, this is great for owners who may be building on a campus or putting an addition on their building to visualize the construction process and how it can impact their day-to-day activities during construction. It can be utilized to visualize student safety: what areas will need to be blocked off or require an overhead net to catch any debris. Or, it can be used to visualize parking that may stop being available to the user groups during a renovation. Coordinating with owners when it comes to site logistics, phasing, and planning is very important, as was the case for the Unity Memorial Hospital project.

One of the most common ways that virtual reality is used in practice is through end-user visualization. This enables early visualization of the space by end users, such as doctors and nurses in a hospital, the future inhabitants of an office space, the engineers of a fabrication plant, or even judges in a courtroom. These individuals, using virtual reality, can see the space before it is constructed to provide feedback and changes that they would like to make. This minimizes the amount of rework that would have needed to be done if they would not have seen the space until it was constructed and wanted to make changes after the work was in place.

In addition to decreasing the costs of changes and rework, the cost of mockups is also something that can be saved during this process. Many times, designers will specify request mockups to be reviewed and approved by the owner and designer before the project team can continue with construction. Virtual reality provides the ability to visualize many systems and layouts to avoid the costly mockup process.

Although the interviewees provided countless examples of how they have used virtual reality for end-user visibility purposes, a few examples are very noteworthy: The first example is how a nurse’s station was modeled and visualized in virtual reality to allow the nurses who would be using the space to make comments on its layout and use. A visual of the virtual reality model is provided in Figure 41. Some of the comments that the nurses made on this space included the location of the printers, where the standing desks should be located for better view of the patient rooms, and some casework changes to reflect the number of files that they needed. The modeling of this space was especially important for this project because this nurse’s station was repeated over thirty times throughout the hospital. If the nurse’s stations were built and changes needed to be made, each of the thirty stations would have needed changed. Additionally, the original mock-up of the space made was built out of foam core and cardboard to help the nurses visualize the space; however, many of the nurses still did not feel confident in how the space would look. This led the team to the VR model, which was extremely helpful for feedback, but also to validate the user experience.

Figure 41: Virtual Reality Model of Nurse's Station

Another example of user visualization in VR was provided by the designer, who worked on modeling this courtroom. Although an older example, it is still a great example of the types of spaces that can benefit from visualization. One of the main reasons that this project was targeted for virtual reality use is the multiple iterations of physical mockups that would have been needed to be built to ensure a number of criteria, such as the judge's bench being high enough to see the entire court room, safety and security, and lighting conditions. Courtrooms are typically built out of plywood as a mockup in an offsite warehouse before the final design is approved. However, VR's visualization capabilities have eliminated this need, saving the cost and time the physical mock-up would have taken. The virtual reality model is shown in Figure 42 (Maldovan).

Figure 42: Virtual Reality Model of Courtroom

Another example, provided by an owner's VDC leader, was a pharmacy layout that allowed the end-user to visualize and critique their space. This was especially helpful for them because the project team was also able to model the constraint of the robot that would be placed in the space. Through the VR model, the client was able to visualize how it would move around the space and place it in such a way to maximize efficiency and ensure the room would be big enough to house it. They were able to place certain cabinets in certain locations where they knew that they would need them based on the robot's location.

Inspections are a very new example of how virtual reality can add value to a project. Essentially, this process did not start out as something intentional. It started with the owner's request to be able to visualize and comment on the layout of their future space, similar to that examples cited as a part of the user-group visualization topic. However, as more and more detail was put into the model by the virtual design team, it became very simple to add in the last few details in order for it to look exactly like the finished product. Once this was realized by a member of the project team, they decided to allow the fire marshal, building inspector, and health inspector to view the space with the goggles, identifying anything that would become an issue in the future if the building were to be constructed as shown in the virtual reality model.

Although it is something that not many people have utilized, it has great potential for growth, especially once contractors realize its benefits. The information regarding this topic was gathered from the interview with one of the construction VDC experts. He has only worked on a few projects that have utilized this function of virtual reality, but was very passionate in stating his first experience, as he believed that it was a big step for virtual reality and its use and benefits for the construction industry.

After viewing it, the inspectors identified needed changes, such as changing the color of the exit signs, adding strobelights, altering the height of the hand wash sinks, and moving control panels. These are typical changes for inspectors to flag at the end of construction projects, so they are not detrimental to the project; however, they definitely would have added extra time, labor, and materials at the end of the project. The VDC manager confirmed that spending the extra time and effort to detail out the model in VR was absolutely worth it. He estimated that it took about 80 hours of an engineer’s time to create the model, totaling only a few thousand dollars. This is significantly less money than what it would have cost the project to change all of the exit signs that were the wrong color. This example, along with the fact that this process has paid off on other projects, shows that it adds significant value to the project.

Finally, VR has also added value to construction projects during preconstruction bidders’ meetings for specialty contractors. Before the specialty contractors have the opportunity to put their bid together for the project, they all sit in the room together while the general contractor runs through the model to identify the systems, scopes, etc. It allows the specialty contractors to ask questions about the design, make suggestions, and open the opportunity for discussion of the design. In the long run, with buy-in from the parties, there is potential to identify scope gaps or identify design challenges that may need to be altered before construction. Although this is not something that is used consistently because it requires a design far enough along for a model to be created and imported into a VR software, it is something that has proven to be beneficial, adding value to the project. Additionally, this is something that can be accomplished using a 4D BIM model; however, contractors have gained benefits when this occurs in VR by having a better understanding of the building and can put together a more reasonable estimate.

Through the interviews, a number of useful ways to utilize and incorporate virtual reality on design and construction projects have been uncovered, all of which have provided value to the project through means of value engineering, value management, or just general value-added objectives. However, in addition to how VR adds value, other information from the interviews was also uncovered, such as the impact of schedule, delivery method, and budget have on the ability to use VR for added value.

6.4.1 Interview Results: Schedule's Effect on VR

Schedule and timing are important factors in the way that virtual reality can be utilized on a project to add value. Timing is important because it addresses when team members are brought on to give input on the development of the project and when a model will be produced.

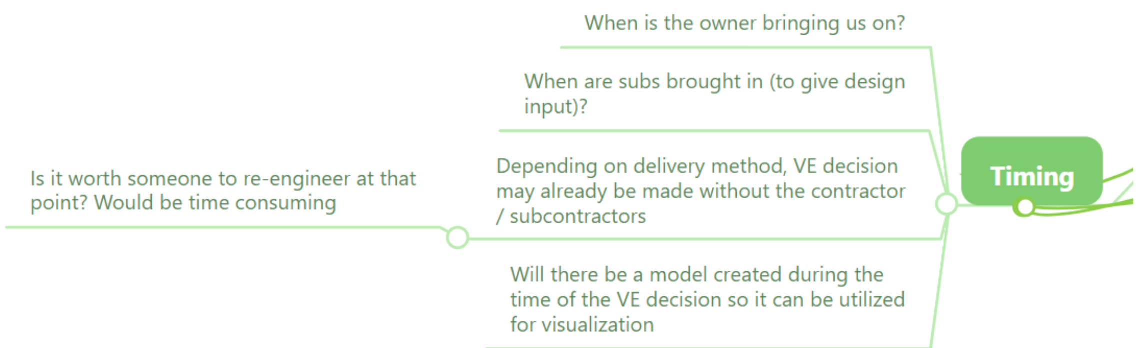


Figure 43: Timing Mind Map

First, the timing of value-related decisions is important. It is much more beneficial if value decisions are made as early as possible on a project. This idea is reflected in Figure 44. The chart depicts that as the project and the design move forward, it becomes more and more costly to make changes, while if these decisions were to be made as early in the project as possible, through the means of reviewing virtual reality models, for example, the cost to changing the design is significantly lower. This is because the cost of rework or changing systems is non-existent in the early stages of the project, but once materials have been ordered and work has been put in place, changing it adds materials and labor costs. It would also push back the schedule, especially if the new solutions' materials require an extensive lead time.

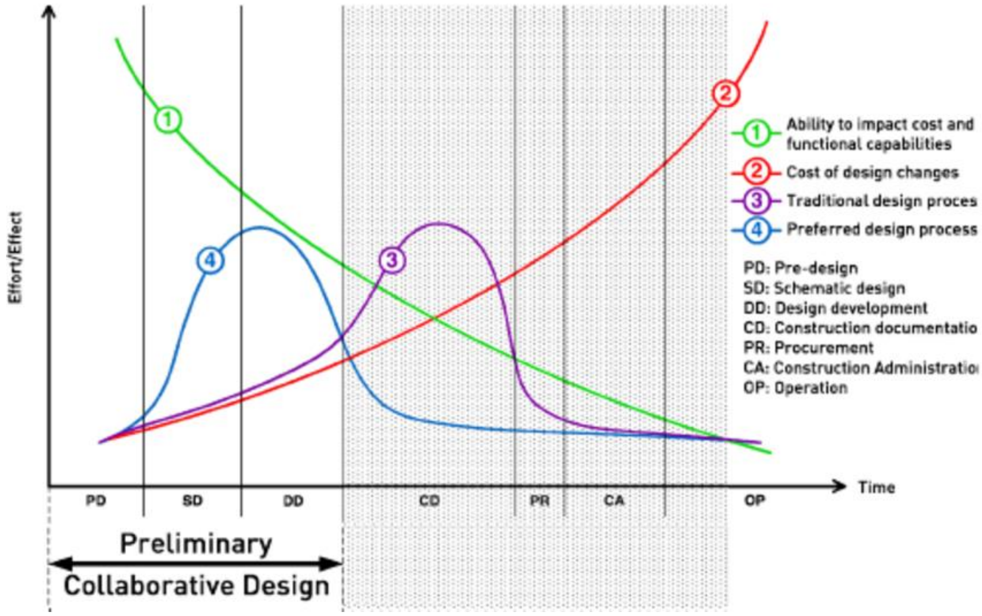


Figure 44: Optimized Plans Cut Down on Costs (Jones et al)

Ideally, value decisions would be made early, but there are some key factors and decisions that are made during the beginning stages of the project that affect when these value decisions can be made. In order to make the best value engineering decisions, it is important to have feedback from more than just the owner and the design team. Depending on the delivery method, which will be discussed in more detail in the following section, the contractor and subcontractors will likely be brought on later than the designer. This may be a missed opportunity for their input on the constructability and function of the systems within the building, which is also a missed opportunity for additional value engineering. Having these parties involved in the design process early on allows them to provide constructive feedback to the design, which is why the timing of the process is so important.

If the contractor or subcontractors see a major concern with an aspect of the design already decided and implemented by the designer, they will likely have the opportunity to value engineer the system on their own; however, to re-engineer the entire system based off one small value adding aspect may not be worth the time in the long run. If the design is already passed the point of making that particular decision, the owner misses out on having additional value to their project.

In order for virtual reality to be utilized early on in the design process as a means of adding value, a model is important to get the process started. The issue could be that the model is not developed far enough to use because it is too early in the design process. In this situation, if there were to be something that would be beneficial to visualize during the decision-making process, such as the shape of the building or the location of a curtain wall, a model will need to be created before virtual reality can be an option for visualization. A model can be made in a virtual reality software; however, it is typically more beneficial and efficient for the model to begin in Revit with the designer, especially when it comes to the first steps of the building, such as its exterior shape and look. When considering the ability that a project team has to utilize virtual reality to add value to their project and their decision making process, timing is a big factor.

6.4.2 Interview Results: Delivery Method's Effect on VR

Because timing is so influential on the value engineering process, it is ideal for contractors to be on board as early as possible. For this to be possible, the selection of a delivery method is very important. Figure 44 in the previous section, also shows that the preferred design process, i.e. an integrated project delivery (IPD) delivery method, allows more of the decisions to be made between the schematic design and the design development stages, rather than the traditional (design-bid-build) delivery method where more effort is needed by the team in the construction documentation phase. Making value engineering decisions early on, whether virtual reality is being used or not, is best for the success of the value of the building. However, if virtual reality is a tool that the owner knows that they want to implement, the following information should be considered when a delivery method is chosen for their project.

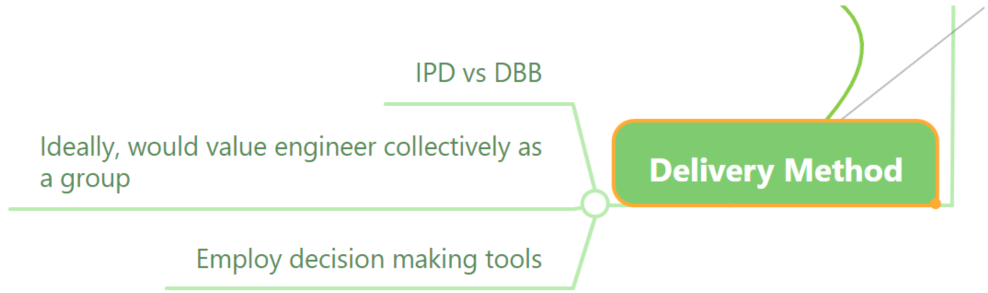


Figure 45: Delivery Method Mind Map

One of the main differences between a preferred design method, such as IPD and design-bid-build is the level of integration and collaboration associated with them. In an IPD, the members of the team help to choose other members to ensure that they are able to work together well for the duration of the project. These teams, because of their high level of collaboration, are more likely to produce better value engineering solutions for the project. In addition, if virtual reality is a method that they choose to incorporate into their value engineering process, the team will be better equipped to make this happen. Having an IPD delivery method means that whatever party is better equipped to do something takes on that risk, so the most skilled VR users would be in charge of this; it does not have to be put in the hands of the general contractor or designer to run this process. Overall, an IPD delivery method would produce more collaboration for value and better quality models, visuals, and information to make it an easy process for the owner and other parties involved.

During the design-bid-build delivery method, the designer is the only party making design decisions. Because these decisions are made without the input of the contractors or subcontractors, there are not very many considerations made for value engineering options in the beginning stages of design. In contrast, the IPD delivery method allows group collaboration for better value designs and keeps potential options for value open. They are able to employ decision-making tools as a group in order to achieve this. For example, set based design is an example of a tool that allows all parties to have their point of view recognized and make the best decision for the team. It does this by keeping design options flexible for as long as possible during the development process. Instead of choosing a single point solution upfront, this method identifies and explores various options, eliminating less-valued choices over time.

For these reasons, IPD, or at least a more integrated and collaborative delivery method, is recommended for high quality value engineering. The owner will be able to be involved from the very beginning as a part of the team and help make these value engineering decisions, depending on the information that the team provides them with. In regards to the virtual reality aspect of value, this can easily be utilized when visualization is a necessary component of the value decision.

6.4.3 Interview Results: Budget's Effect on VR

The owner's budget preferences have the ability to affect the way that value engineering is approached. Based on what the owner's funding needs are, contracts and budget may not allow the chance to use virtual reality to help value engineer the building. This is something the owner may want to take into account before the project begins, depending on their project goals.

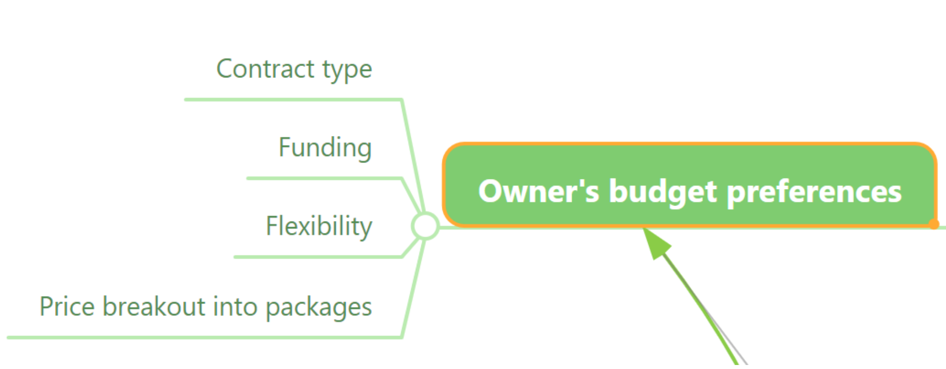


Figure 46: Budget Mind Map

First, different contract types have different levels of design flexibility, meaning that under a contract like a GMP, the cost of the project will be capped at a maximum price that the owner will pay. However, it is encouraged to save costs where possible. Typically, these contracts include a shared savings clause to push the contractor to value engineer throughout the design and construction process. On the other hand, a contract such as a lump sum provides a fixed price for the set work shown in the drawings. This type of contract does not incentivize contractors to work towards a better value project. For this reason, virtual reality as a means of adding value to a project is way less likely in the lump sum contract scenario.

Additionally, each contractor has different policies on how they charge for different value engineering services. If an owner wants to use VR for a specific value engineering application, it should be written into the contract to ensure that the owner will not incur additional charges for this. The contractors that spoke of this during the interview included the VR model as a part of their value engineering service because they understand how beneficial it is in the long run. However, if a contractor is not very experienced using virtual reality, they may charge the owner additional costs in order to use it. This cost may drive the owner away from using virtual reality in the value engineering process.

The price per package may also affect how if virtual reality is used for value engineering. Often times, when the owner receives a GMP and it is over budget, they will look at the packages individually to see where they are spending more than anticipated. If they are spending more money on something that is more “behind the scenes” such as MEP systems, then VR will likely not be used in the value engineering decisions to change the systems and cut costs. However, if excess money is being spent on interiors or finishes, this is a visual concern and something that the project team may utilize VR for in order to make decisions on what changes to make to the space.

A project owner is not typically using these aspects to decide on a project type. However, they should be aware of how their decisions may affect their value engineering experience.

6.4.4 Interview Results: The Challenges of VR

Across the interviews with the industry members, there were a number of challenges associated with the utilization of virtual reality and how it is used on projects, whether that be for value engineering, value management, or just general value adding activities.

Figure 47: Challenges Mind Map

The first challenge that contractors identified is not having an accurate model, or even a model at all, to work with. Typically, for this process, the designer is responsible for providing an accurate and detailed design model. However, depending on the architect's contract with the owner, the designer may not have a model or the architect may not be required to have a sharable model. Although this is less and less common as we move into the age of BIM and supporting technology, this situation may occur. This provides a challenge to the contractor if they want to use VR because they would then have to model the building from scratch on their own. Depending on the size of the building, this may take more time than what it is worth, depending on the goals for the future uses of the model.

Additionally, another challenge that the industry faces when it comes to implementing virtual reality in their practice is the labor investment necessary for it. Virtual reality programs require technically savvy employees who are passionate enough about doing it to keep learning to programs and testing out new things. Typically, a high skill level is necessary in order to use some of the more advanced software programs that will produce better quality models. This issue bleeds over into the hardware and software investments. These are not typically expensive as long as they are continuing to add value to the company projects. However, if they are not managed and used properly, they could be an inefficient and ineffective use of time. Skilled VR users are necessary to first, find the right VR solutions that meet the projects' and the company's goals and second, ensure that there is a return on investment.

One of the biggest challenges that the interviewees face is getting the owners on board with using virtual reality. Every owner is different and has different opinions: although some are very interested in using VR, others are more skeptical, and this is for a number of reasons. First, some owners are confused and do not understand what virtual reality is or what the benefits of it can be. This decreases their likelihood of buy in to using it on their projects. Additionally, some owners just do not like change or trying new things. They are traditional and do not see the value adding components to new technology. Third, some owners believe it would be too expensive and do not consider the pay off in the long term. Finally, some owners are afraid to extend the schedule or increase cost due to allowing their end users to make too many significant changes when the reality is that when you allow them to make changes earlier enough, these aspects of the project should not be affected. Overall, the goal with owners is to get to the point with them where they ask to use it because they understand the value that it adds. Many of the contractors have a goal to educate owners on the positive effects of using VR on their projects.

The comfort level of people actually using the VR headsets has also presented itself as an issue for owners. First, some people do get queasy depending on the flickering and the refresh rate of the model, which bothers some people more than others. Occasionally, people are embarrassed or feel they understand enough to watch on the screen without the immersive experience that VR provides. If the owner does not want to use it, it is not something that can be forced on them; however, it is not productive to make a model that the owner does not want to use.

A final challenge that some contractors struggle with is when exactly virtual reality should be used, i.e., what can be communicated with an immersive VR model that cannot be communicated through a 3D model review. Because of this, it is important for the project team to go into a project with a plan in mind of how they want to utilize VR.

These challenges are faced by contractors as they use VR method, especially to improve value on a project. None of these challenges are severe enough to stop the research and implementation of VR. Additionally, with more and more emerging technology, these challenges will not be difficult to resolve.

6.4.5 Interview Results: How BIM Adds Value

In talking to the industry members, they came up with a number of examples to add value to the projects on which they were working; however, they were not technically methods that incorporated virtual reality. This speaks to one of the challenges that is faced in the industry, that some individuals are not necessarily fully educated on what exactly VR is and how it can be utilized for efficiency and value. One industry member in particular used the terms “virtual reality” and “augmented reality” interchangeably when, as discussed in the literature review, they are very different. Others took the term virtual reality to mean anything having to do with BIM or BIM implementation, however, VR is just one tool to implement BIM on a project.

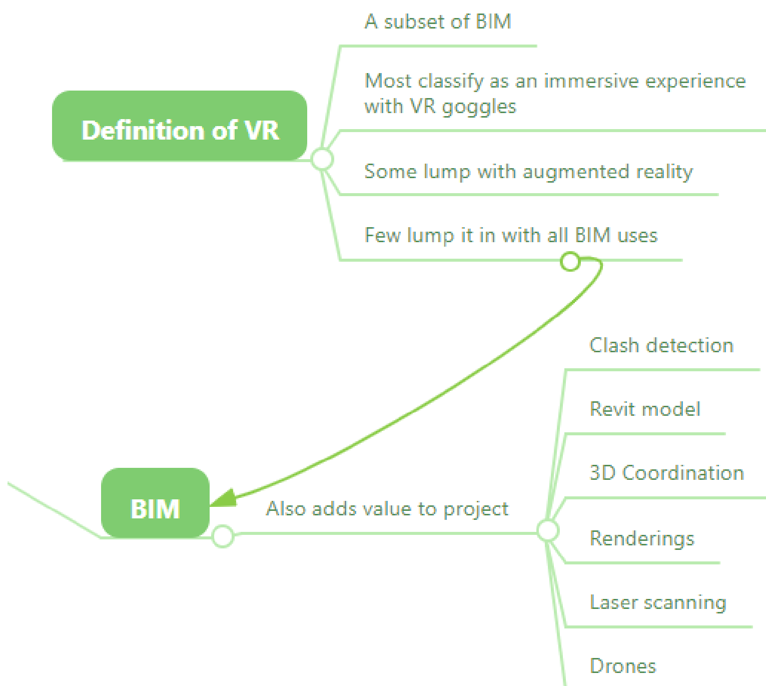


Figure 48: Definition of VR as a Subset of BIM Mind Map

Nonetheless, the interviewees provided valuable feedback as to how they are using other tools, not just virtual reality, to add value to their projects. These range from laser scanning to drones to renderings and are listed in Figure 48. With a well-executed BIM plan, the project team can easily incorporate VR as a BIM use for the duration of the project.

6.5 Conclusions

In conclusion, virtual reality has the potential to expand and add value to construction project, whether that be for uses in value engineering, value management, or other ways to add value more broadly. However, it is important for the owner and the project team to realize that the timing for which value decisions are made, the delivery method used, and the anticipated budget of the project can affect and potentially limit the available performance of virtual reality. If virtual reality is being used on a project, the project team should anticipate the challenges before putting additional work into a high-quality VR model because the challenges may diminish the time and effort already put into it. Finally, the project team should evaluate how the VR model can interact with other BIM uses. Virtual reality is an up and coming tool that will revitalize the future of the construction industry.

Chapter 7

Mechanical Breadth: Air Handling Unit Re-Size

7.1 Introduction

The ductwork for this project runs to the new air handling unit being installed by a separate contract held by the owner, rather than the old air handling unit currently being used for the space. Because the air handling unit is addressed under a different contract, the assumption is that the reason for a new air handling unit is to account for the new spaces added to the scope of work. Because much of the space went from storage areas to patient care rooms, this places higher load on the air handling unit, requiring a larger size to account for this.

The following analysis identifies two new system possibilities: VAV with reheat or active chilled beams to service only the new spaces created as a result of this renovation project. This allows the current air handling unit to still service the other spaces around the hospital without upgrading its capacity to a new air handling unit. A cost analysis will decide whether one of the new systems should be implemented or if it is better for the owner to continue with their plan for a new air handling unit to service all spaces.

7.2 System 1: VAV with Reheat

The first system suggested is the system that is already in place in the hospital. The only difference would be that a smaller air handling unit to account for the added load and spaces would be utilized in addition to the current air handling unit. This system is shown in Figure 49 (Reheat Systems), which depicts how the new air handling unit will bring in outside air as well as recycle some returned air to go through preheat and cooling coils before being ducted to the VAV boxes at each room/space. The VAV boxes will then reheat the air, which is originally cooled for dehumidification, to supply the space with proper temperature air. The reheat coil is supplied by hot water piping from the existing boiler that is assumed to have the capacity necessary for these extra units.

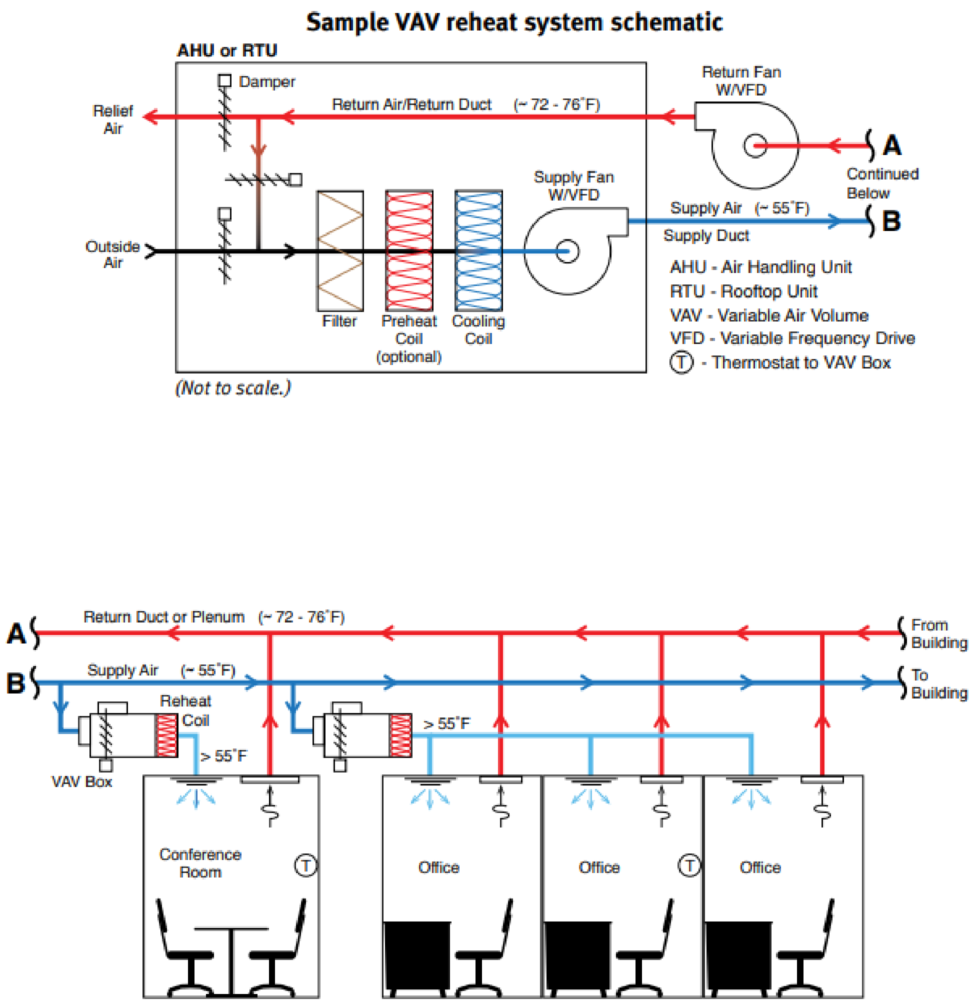


Figure 49: VAV Reheat System Diagram

In order to size the air handling unit necessary to take care of the VAV boxes in the new space, TRACE700 was utilized to input the rooms and their required internal heating and cooling conditions, including people, lighting, and miscellaneous equipment. TRACE700 utilizes the ASHRAE Standard 62.1 2004/2007 to predict the heating and cooling air change parameters for each room type inputted into the system. The main rooms types include hospital rooms, corridors, offices, and storage rooms. The output of the program provided the heating and cooling demand for the spaces as well as the airflow necessary to maintain the system. These demands will be used to size and price the air handling unit necessary for the space. The airflow necessary is 4,375BTU. Figure 50 show the outputs provided by TRACE700.

AIRFLOWS

	Cooling	Heating
Diffuser	4,375	1,332
Terminal	4,375	1,332
Main Fan	4,375	1,332
Sec Fan	0	0
Nom Vent	1,967	1,302
AHU Vent	1,967	1,302
Infil	0	0
MinStop/Rh	1,332	1,332
Return	4,161	1,156
Exhaust	1,752	1,126
Rm Exh	215	176
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

Figure 50: TRACE700 Air Handling Unit Airflow Output

The benefits to this system first include that it is already the system that the hospital and their maintenance staff is used to using. This eliminates any confusion between using multiple types of systems. Additionally, an air handling unit recovers some return air from the space, which helps for energy efficiency because the heat from this air means that the air handling unit needs to do less work to heat the outside air before it is duct to the VAV boxes.

7.3 System 2: Active Chilled Beams

The second system that could be installed in place of the air handling unit and VAV boxes is a dedicated outside air unit (DOAS) that preheats and cools the air before ducting it to active chilled beam units that either heat or cool the air before dispersing it into the space. The four-pipe system requires both hot and cold water to be run to the chilled beams in order to either heat or cool the air as necessary for the space. A diagram of the system is shown in Figure 51 (Chilled Beams).

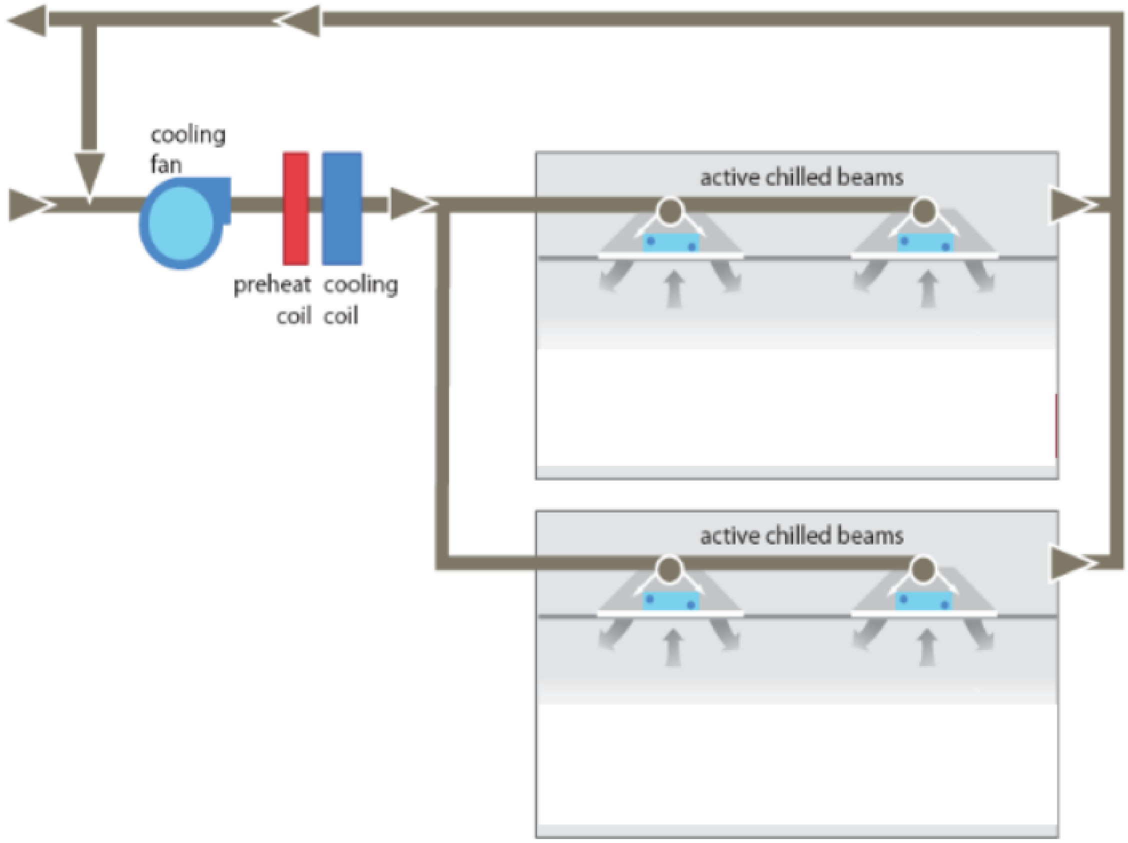


Figure 51: 4-Pipe Active Chilled Beam System Diagram

Similarly to the air handling unit and VAV system, TRACE700 was utilized to input the rooms and their required internal heating and cooling conditions, including people, lighting, and miscellaneous equipment. The output of the program provided the heating and cooling demand for the spaces. These are broken out into the main and auxiliary cooling and heating, the main being the DOAS system that initially cools or heats the outside air and auxiliary being the chilled beams themselves. The airflow necessary through each of the pieces of equipment is 2,028 CFM. This is the criteria for which the DOAS unit will be sized and priced.

AIRFLOWS

	Cooling	Heating
Diffuser	2,028	2,028
Terminal	2,028	2,028
Main Fan	2,028	2,028
Sec Fan	0	0
Nom Vent	1,967	1,996
AHU Vent	1,967	1,996
Infil	0	0
MinStop/Rh	2,028	2,028
Return	1,814	1,814
Exhaust	1,752	1,782
Rm Exh	215	215
Auxiliary	15,843	0
Leakage Dwn	0	0
Leakage Ups	0	0

Figure 52: TRACE700 DOAS/Chilled Beam Airflow Output

One of the benefits of this system is that it utilizes all outside air, which is healthier for the patients in a hospital, because it decreases the change that any germs or harmful air will be moving throughout the hospital. Additionally, the chilled beams themselves do more of the heating and cooling than the DOAS unit that feeds air to the chilled beams; therefore, so the DOAS unit will be much smaller than the air handling unit.

However, there are some negatives to using this system. One being that more chilled beams would be needed than VAV boxes. Some VAV boxes serve multiple storage rooms in the back of house space, but chilled beams will be needed for each room, and some rooms will even need to have more than one, depending on the size of the room. Additionally, the VAV boxes only require hot water to reheat the air. The chilled beams will also require cold water for when the air needs cooled.

7.4 Cost Analysis

The cost analysis of these two options were compared with the option being pursued (to replace the air handling unit with one that has a higher capacity), reflected in Table 10. The costs for the air handling units, demolition costs, DOAS, and chilled beams were found using RS Means 2018 Construction Cost Data; however, the costs for running hot and cold water to the chilled beams and VAV boxes were derived as a result of the project estimate, as this was assumed to be more accurate than the RS Means costs. The size and required airflow of the new air handling unit was shared by the owner to ensure an accurate cost of the upgraded air handling unit.

The VAV boxes were not priced as a part of this cost analysis because the VAV boxes that were being used for the space originally will be relocated and reused based on the new room layout. Additionally, the number of chilled beams was estimated to be 120 units based on the number of diffusers in the space.

An additional consideration is that the duct sizes are different, and therefore, will be different prices, as the ducts for a chilled beam system are much smaller than a VAV system. This is because the airflow is much smaller for a 100% outside air system. The duct sizes for the main ducts were calculated using ASHRAE Standards to be 26x26 for the air handling unit and VAV system and 18x28 for the chilled beam system. These calculations were combined with the takeoffs and average duct size from the construction documents. The branch ductwork sizes were estimated based on this information. The prices are shown in Table 10, and the calculations can be found in Appendix D.

Table 10: Cost of Air Supply Options

	AHU Upgrade	New AHU for CDU	DOAS System for CDU
Old AHU Demo	$600.00		
AHU	$139,000.00	$18,300.00	
DOAS			$9,150.00
Chilled Beams			$201,600.00
Run Cold Water to Chilled Beam			$86,750.00
Run Hot Water to Chilled Beam/VAV	$76,250.00	$76,250.00	$86,750.00
Ductwork	$52,970	$52,970	$36,530
Total	$92,570.00	$71,270.00	$334,030.00

7.5 Conclusions

Between the two new systems suggested, the new air handling unit with VAV boxes is better suited for the space. Although a DOAS system provides outside air that is better for the environment of the patients, this is at a significantly higher cost to the project. Not only would it be a higher initial cost, as shown in Table 10, but it would also be a higher operating cost, as all of the outside air will need to be heated during the process. This is an additional energy cost that will continue to affect the operation of the building.

From there, the owner can choose between adding an additional air handling unit to account for the added load in the spaces or upgrading the air handling unit that is already in place. What would come into question is the state of the current air handling unit. Unity Memorial Hospital is a very old building, which can mean that the air handling unit has the potential to be out-of-date and starting to run inefficiently. This is information that would be necessary in order to make this decision because if the air handling unit were to be older, the hospital would be correct in taking this opportunity to remove the old air handling unit and replace it with a new one.

Chapter 8

Acoustics Breadth

8.1 Introduction

The emergency room expansion project boarders the current emergency room, which will remain operational. This means that much of the demolition and construction work will be completed on the other side of the main wall from patient emergency rooms. In order to ensure that these patients are not disrupted at any time, it is important that this wall is reinforced acoustically so the patients are not hearing loud construction noises fromthe other side of the wall. This is depicted in the hospital layout in Figure 53.

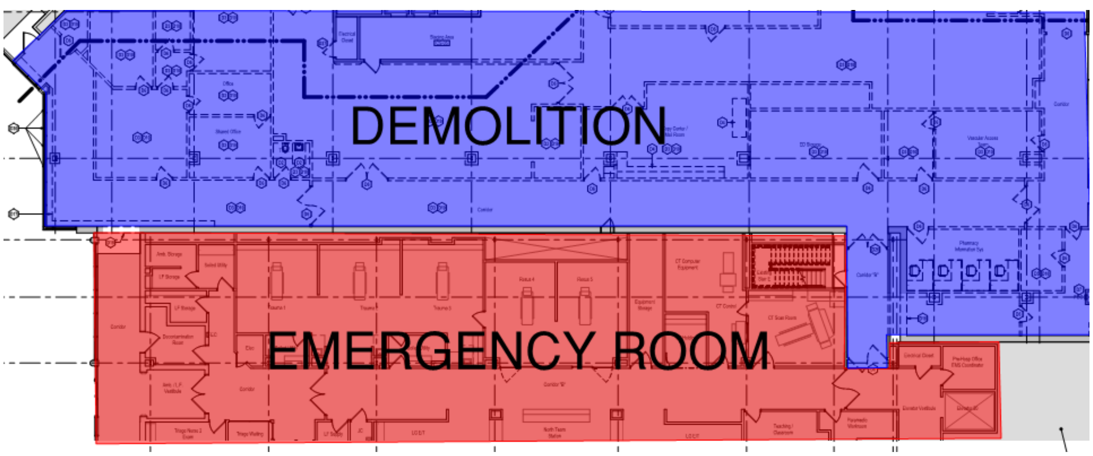


Figure 53: Demolition and Emergency Room Spaces

The following analysis will determine the noise that will be heard in these emergency room spaces based on the noise that will be generated during the construction of the emergency room expansion and the sound that the current wall type will allow to travel through the space. Research will identify ways to acoustically reinforce the walls shared with the current emergency patient rooms if necessary. A sound transmission analysis will be completed to find the Sound Transmission Class (or STC) for partition options, which will reveal the best options acoustically for sound insulation. Cost will also be a factor in choosing these options.

8.2 Demolition Sound Output

In order to identify the sound output of construction demolition, the construction documents were referenced for the demolition activities that will be performed in the space. Then, the tools with relatively loud sound levels that are relevant for these activities were evaluated for their use and sound output. These can be found in Table 11, and originated from a sound level data base (Berger). Due to the frequency, location, and schedule for these activities to take place, it is assumed that the maximum noise that will occur is 94.1 dB. This is the sum of the sound output of the following tools/activities: Sawzall, yelling voices, shop vacuum, and sledge hammer.

Table 11: Relevant Sound Outputs for Demolition Activities

Tool	Sound Output (dB)	Use
Sawzall	88	REMOVE EXISTING CASEWORK AND CORRESPONDING BULKHEAD
Sledge Hammer	91	REMOVE AND DISPOSE EXISTING PARTITION
Grinding Wheel	84	SAWCUT SECTION OF EXISTING CONCRETE WALL
Hammer Drill	95	REMOVE AND DISPOSE OF EXISTING MASONRY CMU
Sawzall	88	REMOVE EXISTING CEILING AND CEILING MOUNTED EQUIPMENT
Floor Sander	61	REMOVE EXISTING FLOORING IN ITS ENTIRETY - INCLUDING ADHESIVE
Shop Vacuum	88	GENERAL CLEANING
Voices Yelling	78	GENERAL NOISE

8.3 Performance Analysis

The first aspect of the performance analysis is the calculation of the amount of sound that the receiving rooms, i.e. the current emergency rooms, will receive based on the construction noise, which is estimated to be 94.1 dB. For this calculation, the equations and diagram referenced in Figure 54 were utilized.

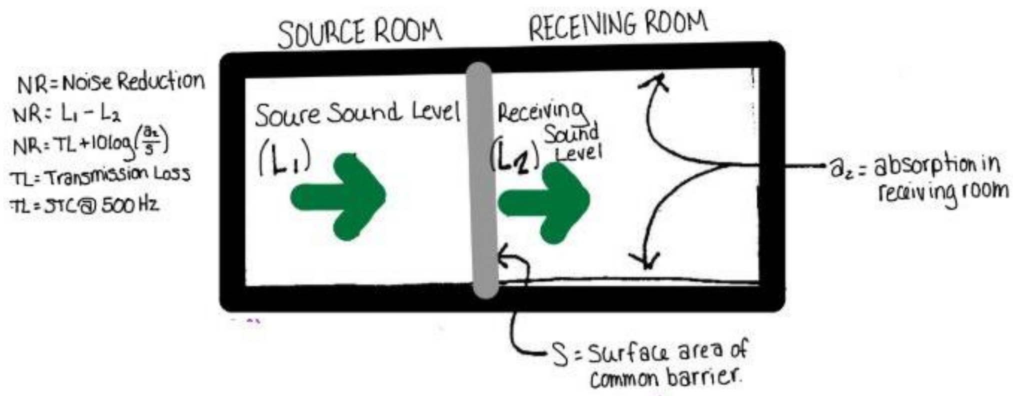


Figure 54: Acoustics Analysis Sound Transmission Diagram

The first piece of information that was necessary for this analysis is the transmission loss. At a frequency of 500Hz, the transmission loss (TL) is equal to the sound transmission class (STC). For simplicity of this calculation, a 500Hz frequency was assumed and the STC referenced in the drawings was utilized as the TL value. This STC value is shown in Figure 55. Because this is an existing wall and the exact wall type was not called out as a part of the drawings, this wall type was assumed, as this is the wall type that will be used between the patient rooms.

INTERIOR PARTITION SCHEDULE - GROUPS A - L (LIGHT GAUGE METAL FRAMING)																	
	CONSTRUCTION DATA							TOP TERMINATION			RATED PARTITIONS			ACOUSTICAL PERFORMANCE			
TYPE	OVERALL PARTITION DEPTH	GWB THICKNESS	FRAMING SIZE	METAL GA.	STUD SPACING	DETAIL AT TOP	DETAIL AT BASE	STUDS TO STRUCTURE	GWB TO STRUCTURE	INSULATION TO STRUCTURE	SMOKE PARTITION	FIRE RATING (HRS)	FIRE TEST	SOUND INSULATION	STC RATING	STC TEST	NOTES
C15	4 7/8"	5/8"	3 5/8"			TC1	BC1	•	•	•	-	1	UL U419	•	49	SA-870717	FIRE STOP

Figure 55: STC Value of Partition

Additionally, the absorption of the receiving room was found using the table of absorption values (site) and a typical-sized emergency room. Once the absorption value and the surface area of the common barrier were acquired, these numbers, along with the transmission loss, were used to find a noise reduction of 49.98dB. This was used to calculate a receiving sound level of 44.11dB in the occupied emergency room.

According to the World Health Organization guidelines, the background noise level in a patient's hospital room should not exceed 35 dB during the day, which means that the 44.11dB calculated is too loud for the space according to the World Health Organization. For this reason, acoustics reinforcement options were considered (Jerlehag).

8.5 Acoustics Reinforcement Options

One option for additional reinforcing is to build an additional wall layer of insulation, studs, and gypsum wall board. This will increase the STC by 6, after using the same equations for the necessary calculations, this brings the receiving sound level in the emergency rooms to 38.11dB, which is still higher than the suggested 35dB (Expert). In addition, this would be a permanent addition to the hospital and likely something that the hospital does not want to pay for.

The second option is a temporary sound attenuation fire blanket, which can increase the STC of the assembly by 11 (Thermafiber). This brings the calculated receiving sound level in the emergency rooms to 33.11dB, which is lower than the suggested 35dB. This is a temporary option that can be removed at the end of the project. This option will also take significantly less time to install than building an additional wall for acoustics reinforcement. It is the best option to limit the amount of construction noise heard in the emergency rooms. A summary of the STC values and receiving sound levels can be found in Table 12.

8.6 Cost Analysis

Table 12 shows a breakdown of the cost per square foot of each option as well as their STC values and receiving sound level for the room. The costs utilize RS Means 2018 Construction Cost Data and include the labor for installation of the assembly as well as the overhead and profit that the owner will pay.

Table 12: STC and Costs for Acoustical Reinforcement

	STC	Receiving Sound Level	Additional Cost Incurred (per square foot)
Current Wall	49	44.11	$0
Additional insulation and GWB	55	38.11	$5.75
Temporary Sound Attenuation Fire Blanket	60	33.11	$1.28

8.7 Conclusions

As the additional insulation and gypsum wall board is significantly more expensive than the temporary option with less acoustical reinforcement, this is not necessarily the best option. Because the sound attenuation blanket acoustically reinforces the rooms best, this is the ideal option for the hospital to pursue. However, it has been noted by various sources that hospitals do not typically follow the World Health Organization's suggestion to limit the background noise to 35dB. Peak levels in hospitals have reached over 75dB, and have continued to increase over the years (Jerlehag). For this reason, it is not suggested to pursue the temporary sound attenuator, as only the north set of emergency rooms will be affected. The hospital can fill their other rooms first, and use the north rooms only once others are filled to minimize the impact of the noise.

Chapter 9

Conclusions and Final Recommendations

Analysis 1: Phasing Analysis of Temporary Pharmacy Relocation

The first analysis that was completed improved the phasing of the project by temporarily relocating the pharmacy space. This was done by analyzing how a temporary pharmacy relocation would aid in a more fluid construction plan, a shorter construction schedule, and lower cost. The outcome of this analysis proved this to be a recommended course of action for the project, as the new phasing plans separate the clinical decision unit work from the back of house work for better work flow, the schedule saves 2 weeks on the original schedule and 18 weeks on the current schedule, and it saves $165,930 in construction costs.

Analysis 2: Managing Project Conflicts through Portfolio Management

It was concluded that UMH can evaluate contractor selection, phasing and logistics, delivery method, and funding to better enhance their project and portfolio management strategy. Contractor selection can be improved by using different contractors but take phasing and coordination into account when awarding contracts. Funding, although cannot be changed without direction from the organization’s financial department, has an impact on how often contracts are awarded. Yearly is ideal in order to put larger scopes within a contract. To better the phasing and logistics aspect of managing these projects, it is suggested that UMH hire a schedule and phasing consultant. Finally, to better qualify their contractors, UMH should continue to hire construction managers with experience working at UMH.

Analysis 3: Schedule Improvement through Prefabricated Ductwork

Laser scanning and prefabrication was proposed as an option to gather information on the existing conditions and assemble prefabricated racks for the above ceiling systems. It was concluded that although 3 weeks of schedule time would be saved, the potential hospital-caused logistics challenges limit the flexibility of the installation of the system. Additionally, the costs saving seen in this analysis will only be seen if the CDU were to be independent of the back of house renovation. For these reasons, this analysis was not recommended for the project team to consider.

Analysis 4: Virtual Reality's Effect on Value Engineering

The research conducted on virtual reality proved that there are a number of applications for value engineering, value management, and adding general components of value to a project. It also showed the impacts that delivery method, schedule, and budget have on virtual reality and how it can be used on a project. Finally, the challenges of using virtual reality were identified.

Chapter 10

MAE / ABET Requirements

10.1 MAE Requirements

As part of the Architectural Engineering Integrated Master's Program, students take additional masters classes and demonstrate their knowledge of the coursework by relating ideas and research to their thesis projects. The main Masters classes that will be useful during the analysis of Unity Memorial Hospital's Clinical Decision Unit and Emergency Expansion are AE 570: Production Management in Construction (Fall 2018), AE 572: Project Development and Delivery Planning (Spring 2018), and AE 597: BIM Execution Planning (Spring 2019). Below describes the Master's classes which will be incorporated into the senior thesis and how their concepts will contribute to the analyses.

AE 572: Project Development and Delivery Planning

This course focuses on how the construction industry utilizes different types of project delivery methods and contracts. This information was utilized, especially in Analysis 2: Portfolio Management, to provide insight into how the delivery methods and contract types play a role in the portfolio management process. This information was also utilized in Analysis 4: Virtual Reality's Effect on Value Engineering to analyze the effect that different delivery methods and timing of contractor involvement have on the timing of value engineering and how this affects when and how virtual reality can be utilized.

AE 570: Production Management in Construction

Production analysis and lean construction tools are covered in depth in this class. These concepts are primarily used in Analysis 3: Schedule Improvement through Prefabricated Ductwork. These planning concepts were utilized to ensure proper organization and delivery of prefabricated ductwork.

AE 597: BIM Execution Planning

This course focuses on BIM planning through a variety of mediums and how they are utilized in today's construction industry. This course helped to gain insight on the research topic of virtual reality and how it can be utilized for value engineering.

10.2 PSU AE – ABET 2.3

One of the largest constraints presented by this building project is the phasing for which construction needs to occur. The most prominent reason for this is the various contracts for other renovation work around the hospital that need to be coordinated. This is addressed in the phasing analysis. This analysis presents new phasing plans, schedule, and cost analysis to advise a better phasing plan for the project. Additionally, the portfolio management analysis identifies additional strategies to better manage and coordinate the various contracts for renovation within the hospital.

10.2 PSU AE – ABET 2.4

This project specifically addresses the section related to public health safety and welfare. This is because this is a hospital renovation project in which the quality of the air and the space is important to address because of the poor immune systems of the patients in the hospital. It is important that the construction activities do not affect the patients, which is why the phasing analysis (Analysis 1) is so critically planned. Additionally, both of breadth topics address this importance, as the mechanical breadth takes into account the quality of the air being supplied to the space and the acoustics breadth ensures that the current emergency room space adjacent to construction will not be interrupted by the construction noise.

Appendix A

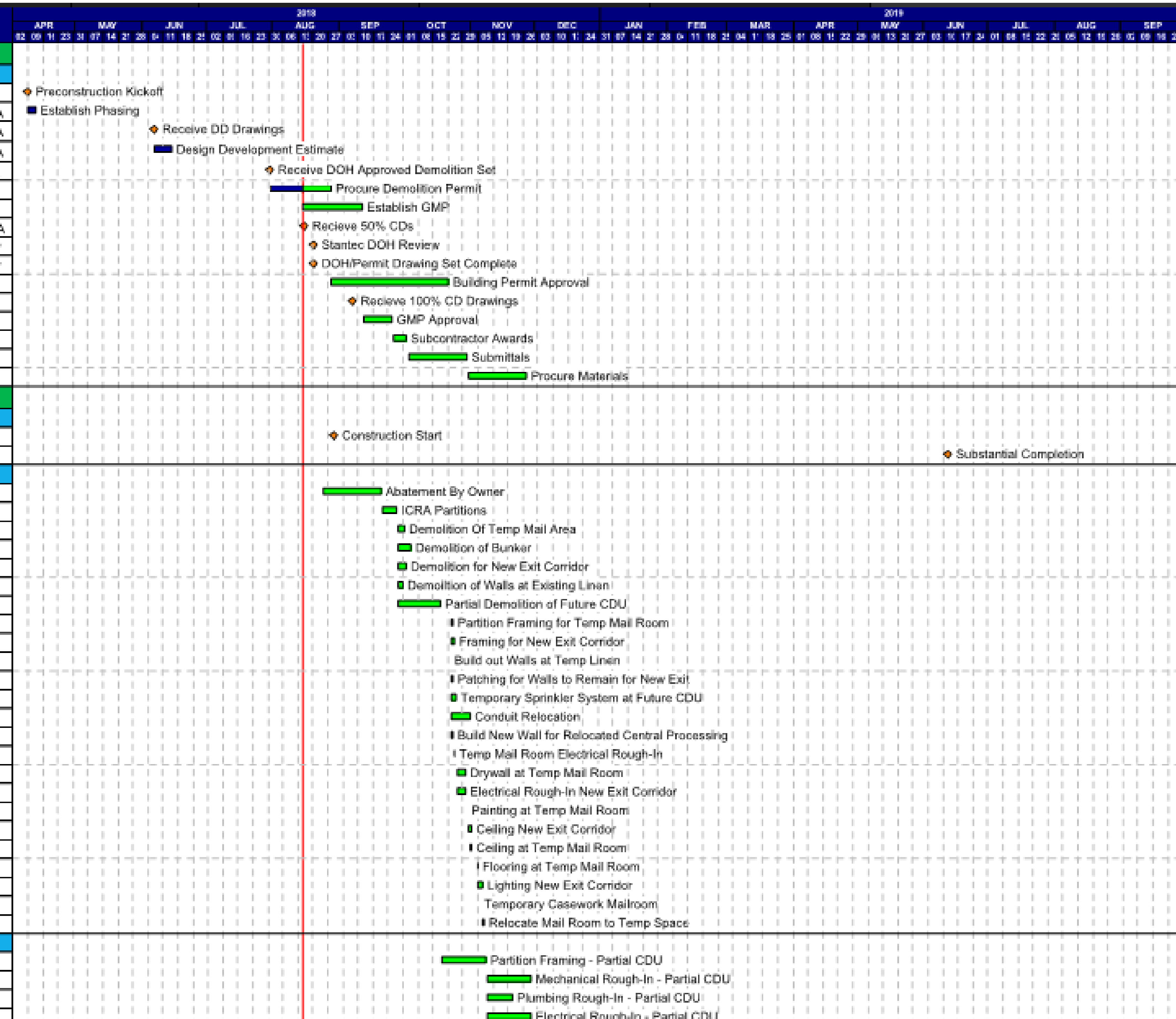
Project Background

A.1 RS Means Square Foot Cost Estimate

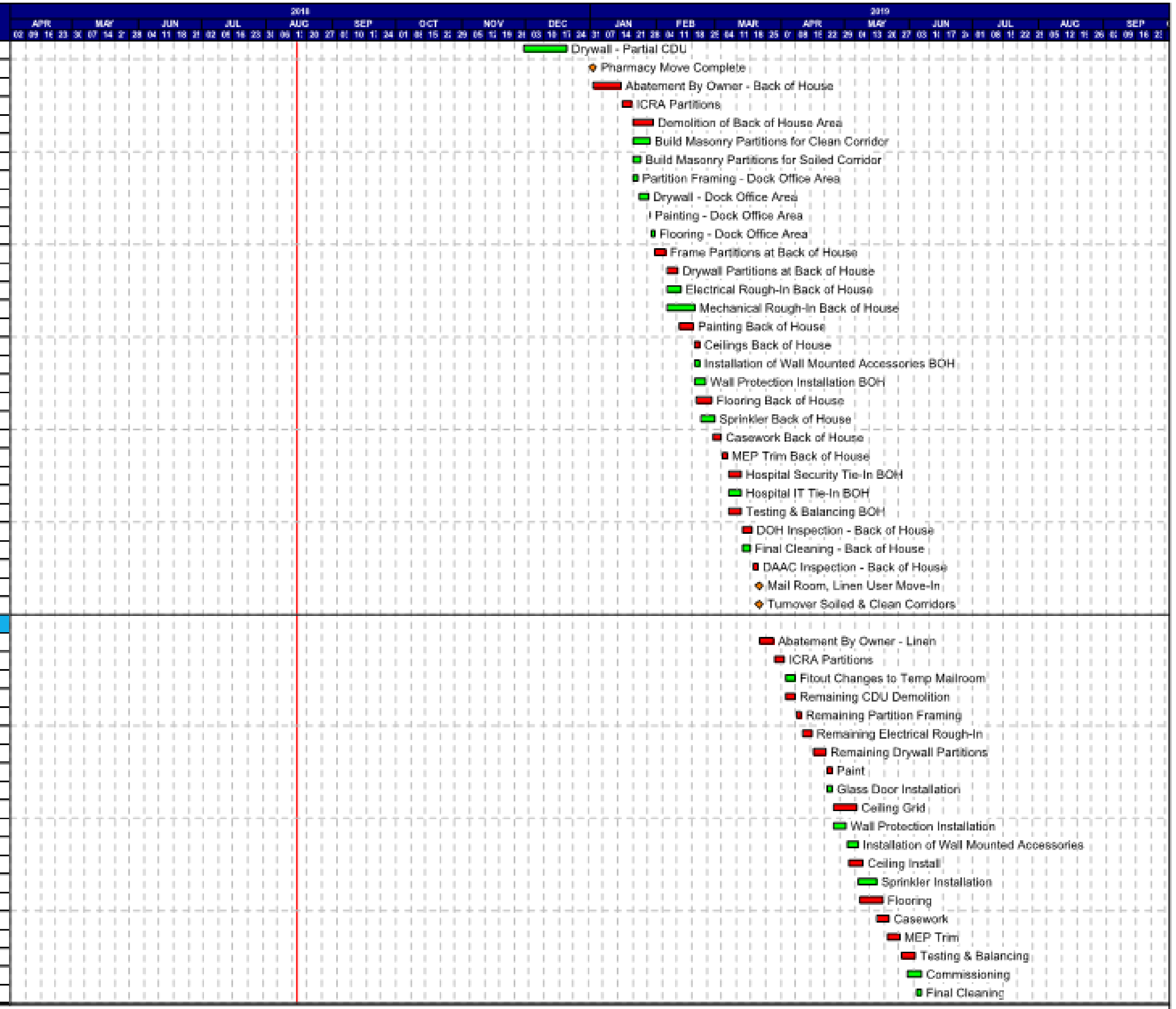
Unity Memorial Hospital Square Foot Estimate					
Perimeter	1500		Assume not applicable		
SF Area	26000				
Story Ht	12		Assumed		
Square Foot Estimate Breakdown per RS Means page 148-149					
			Total Cost/SF	Total Cost	
Substructure	Not Applicable to Renovation				
Shell	Not Applicable to Renovation				
Interiors	17.40%		$63.95	$1,662,570.00	
Conveying	Not Applicable to Renovation				
Plumbing	10.90%		$40.06	$1,041,495.00	
HVAC	22.30%		$81.95	$2,130,765.00	
Fire Protection	1.60%		$5.88	$152,880.00	
Electrical	12.70%		$46.67	$1,213,485.00	
Equipment/Furnishings	16.40%		$60.27	$1,567,020.00	
Total percentage	81.30%		$298.78	$7,768,215.00	
Cost per square foot of RS Means	$367.50				
Cost per square foot based on renovation %	$ 298.78				
Total Interior New Construction Cost	**$ 7,768,215.00**				
Demolition Cost					
Average demolition cost	$6	/sf			
Total Demolition Cost	$ 156,000.00				
Total Project Cost					
Total Cost Per Square Foot	$ 304.78				
Total Cost	$ 7,924,215.00				
Total Project Cost Based on Turner's Estimate					
Total Cost Per Square Foot	$ 197.00				
Total Cost	$ 8,636,542.00				

A.2 Original Schedule

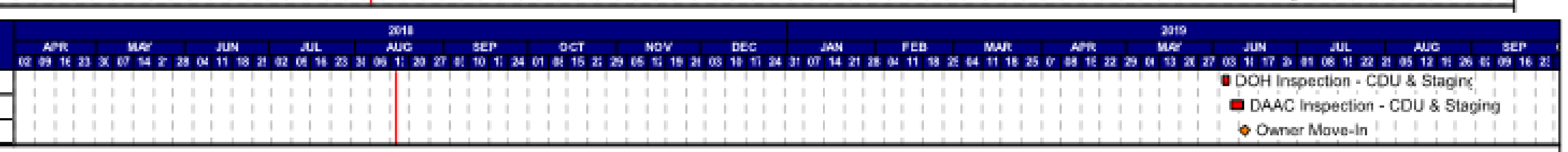
Act ID	Description	Orig Dur	Rem Dur	Early Start	Early Finish
PRECONSTRUCTION					
1000	Preconstruction Kickoff	0	0	09APR18 A	
1010	Establish Phasing	5d	0	09APR18 A	13APR18 A
1020	Receive DD Drawings	0	0		06JUN18 A
1030	Design Development Estimate	10d	0	07JUN18 A	15JUN18 A
1670	Receive DOH Approved Demolition Set	0	0		30JUL18 A
1990	Procure Demolition Permit	30d	10d	31JUL18 A	29AUG18
1050	Establish GMP	20d	20d	15AUG18 A	12SEP18
1040	Recieve 50% CDs	0	0		15AUG18 A
1060	Stantec DOH Review	0	0		20AUG18 *
1070	DOH/Permit Drawing Set Complete	0	0		20AUG18 *
1080	Building Permit Approval	40d	40d	28AUG18	22OCT18
1470	Recieve 100% CD Drawings	0	0		07SEP18 *
1090	GMP Approval	5d	10d	12SEP18	26SEP18
1100	Subcontractor Awards	5d	5d	26SEP18	03OCT18
1110	Submittals	20d	20d	03OCT18	31OCT18
1120	Procure Materials	20d	20d	31OCT18	28NOV18
CONSTRUCTION					
Overall Construction Tracking					
1130	Construction Start	0	0	29AUG18	
1140	Substantial Completion	0	0		12JUN19
Early Demo CDU & Back Corridor					
1150	Abatement By Owner	20d	20d	24AUG18	21SEP18
1160	ICRA Partitions	5d	5d	21SEP18	28SEP18
1170	Demolition Of Temp Mail Area	2d	2d	28SEP18	02OCT18
1180	Demolition of Bunker	5d	5d	28SEP18	05OCT18
1270	Demolition for New Exit Corridor	3d	3d	28SEP18	03OCT18
1290	Demolition of Walls at Existing Linen	1d	1d	28SEP18	01OCT18
1950	Partial Demolition of Future CDU	15d	15d	28SEP18	19OCT18
1190	Partition Framing for Temp Mail Room	2d	2d	23OCT18	24OCT18
1280	Framing for New Exit Corridor	3d	3d	23OCT18	25OCT18
1300	Build out Walls at Temp Linen	1d	1d	23OCT18	23OCT18
1310	Patching for Walls to Remain for New Exit	2d	2d	23OCT18	24OCT18
1350	Temporary Sprinkler System at Future CDU	4d	4d	23OCT18	26OCT18
1360	Conduit Relocation	8d	8d	23OCT18	01NOV18
1400	Build New Wall for Relocated Central Processing	2d	2d	23OCT18	24OCT18
1200	Temp Mail Room Electrical Rough-In	1d	1d	25OCT18	25OCT18
1210	Drywall at Temp Mail Room	3d	3d	26OCT18	30OCT18
1320	Electrical Rough-In New Exit Corridor	3d	3d	26OCT18	30OCT18
1220	Painting at Temp Mail Room	1d	1d	31OCT18	31OCT18
1340	Ceiling New Exit Corridor	3d	3d	31OCT18	02NOV18
1230	Ceiling at Temp Mail Room	2d	2d	01NOV18	02NOV18
1240	Flooring at Temp Mail Room	1d	1d	05NOV18	05NOV18
1330	Lighting New Exit Corridor	3d	3d	05NOV18	07NOV18
1250	Temporary Casework Mailroom	1d	1d	06NOV18	06NOV18
1260	Relocate Mail Room to Temp Space	2d	2d	07NOV18	08NOV18
Linen & Mail Buildout, CDU Start, Soiled Corr					
1600	Partition Framing - Partial CDU	15d	15d	19OCT18	09NOV18
1630	Mechanical Rough-In - Partial CDU	15d	15d	09NOV18	30NOV18
1640	Plumbing Rough-In - Partial CDU	8d	8d	09NOV18	21NOV18
1650	Electrical Rough-In - Partial CDU	15d	15d	09NOV18	30NOV18



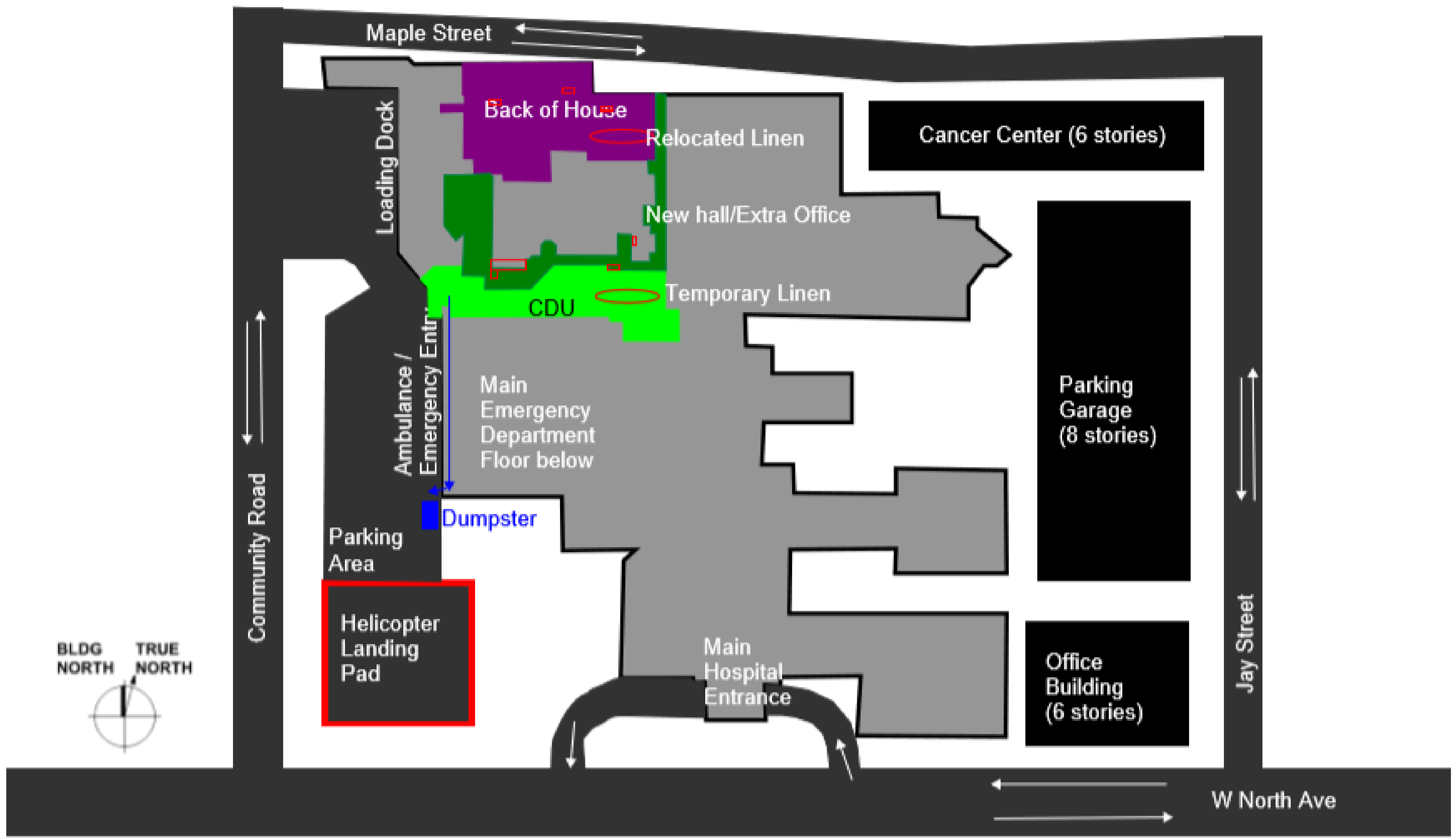
Act ID	Description	Orig Dur	Rem Dur	Early Start	Early Finish
1610	Drywall - Partial CDU	15d	15d	30NOV18	21DEC18
1680	Pharmacy Move Complete	0	0		02JAN19 *
1880	Abatement By Owner - Back of House	10d	10d	02JAN19	16JAN19
1370	ICRA Partitions	3d	3d	16JAN19	21JAN19
1380	Demolition of Back of House Area	8d	8d	21JAN19	31JAN19
1390	Build Masonry Partitions for Clean Corridor	7d	7d	21JAN19	30JAN19
1620	Build Masonry Partitions for Soiled Corridor	4d	4d	21JAN19	25JAN19
1690	Partition Framing - Dock Office Area	3d	3d	21JAN19	24JAN19
1710	Drywall - Dock Office Area	3d	3d	24JAN19	29JAN19
1700	Painting - Dock Office Area	1d	1d	29JAN19	30JAN19
1720	Flooring - Dock Office Area	2d	2d	30JAN19	01FEB19
1410	Frame Partitions at Back of House	4d	4d	31JAN19	06FEB19
1420	Drywall Partitions at Back of House	4d	4d	06FEB19	12FEB19
1440	Electrical Rough-In Back of House	5d	5d	06FEB19	13FEB19
1450	Mechanical Rough-In Back of House	10d	10d	06FEB19	20FEB19
1460	Painting Back of House	5d	5d	12FEB19	19FEB19
1430	Ceilings Back of House	5d	3d	19FEB19 A	22FEB19
1500	Installation of Wall Mounted Accessories BOH	3d	3d	19FEB19	22FEB19
1520	Wall Protection Installation BOH	4d	4d	19FEB19	25FEB19
1510	Flooring Back of House	6d	6d	20FEB19	28FEB19
1490	Sprinkler Back of House	5d	5d	22FEB19	01MAR19
1530	Casework Back of House	2d	2d	28FEB19	04MAR19
1480	MEP Trim Back of House	3d	3d	04MAR19	07MAR19
1540	Hospital Security Tie-In BOH	5d	5d	07MAR19	14MAR19
1550	Hospital IT Tie-In BOH	5d	5d	07MAR19	14MAR19
1560	Testing & Balancing BOH	5d	5d	07MAR19	14MAR19
1570	DOH Inspection - Back of House	3d	3d	14MAR19	19MAR19
1960	Final Cleaning - Back of House	2d	2d	14MAR19	18MAR19
1580	DAAC Inspection - Back of House	3d	3d	19MAR19	22MAR19
1590	Mail Room, Linen User Move-In	0	0		22MAR19
1660	Turnover Soiled & Clean Corridors	0	0		22MAR19
CDU Buildout					
1870	Abatement By Owner - Linen	5d	5d	22MAR19	29MAR19
1730	ICRA Partitions	3d	3d	29MAR19	03APR19
1930	Fitout Changes to Temp Mailroom	3d	3d	03APR19	08APR19
1970	Remaining CDU Demolition	3d	3d	03APR19	08APR19
1750	Remaining Partition Framing	3d	3d	08APR19	11APR19
1790	Remaining Electrical Rough-In	3d	3d	11APR19	16APR19
1740	Remaining Drywall Partitions	5d	5d	16APR19	23APR19
1840	Paint	3d	3d	23APR19	26APR19
1860	Glass Door Installation	3d	3d	23APR19	26APR19
1820	Ceiling Grid	7d	7d	26APR19	07MAY19
1850	Wall Protection Installation	4d	4d	26APR19	02MAY19
1780	Installation of Wall Mounted Accessories	4d	4d	02MAY19	08MAY19
1830	Ceiling Install	5d	5d	03MAY19	10MAY19
1810	Sprinkler Installation	8d	8d	07MAY19	17MAY19
1770	Flooring	8d	8d	08MAY19	20MAY19
1760	Casework	5d	5d	16MAY19	23MAY19
1800	MEP Trim	5d	5d	21MAY19	28MAY19
1890	Testing & Balancing	5d	5d	28MAY19	04JUN19
1900	Commissioning	5d	5d	31MAY19	07JUN19
1910	Final Cleaning	3d	3d	04JUN19	07JUN19



Act ID	Description	Orig Dur	Rem Dur	Early Start	Early Finish
1920	DOH Inspection - CDU & Staging	3d	3d	04JUN19	07JUN19
1980	DAAC Inspection - CDU & Staging	3d	3d	07JUN19	12JUN19
1940	Owner Move-In	0	0	12JUN19	



A.3 Site Logistics Plan



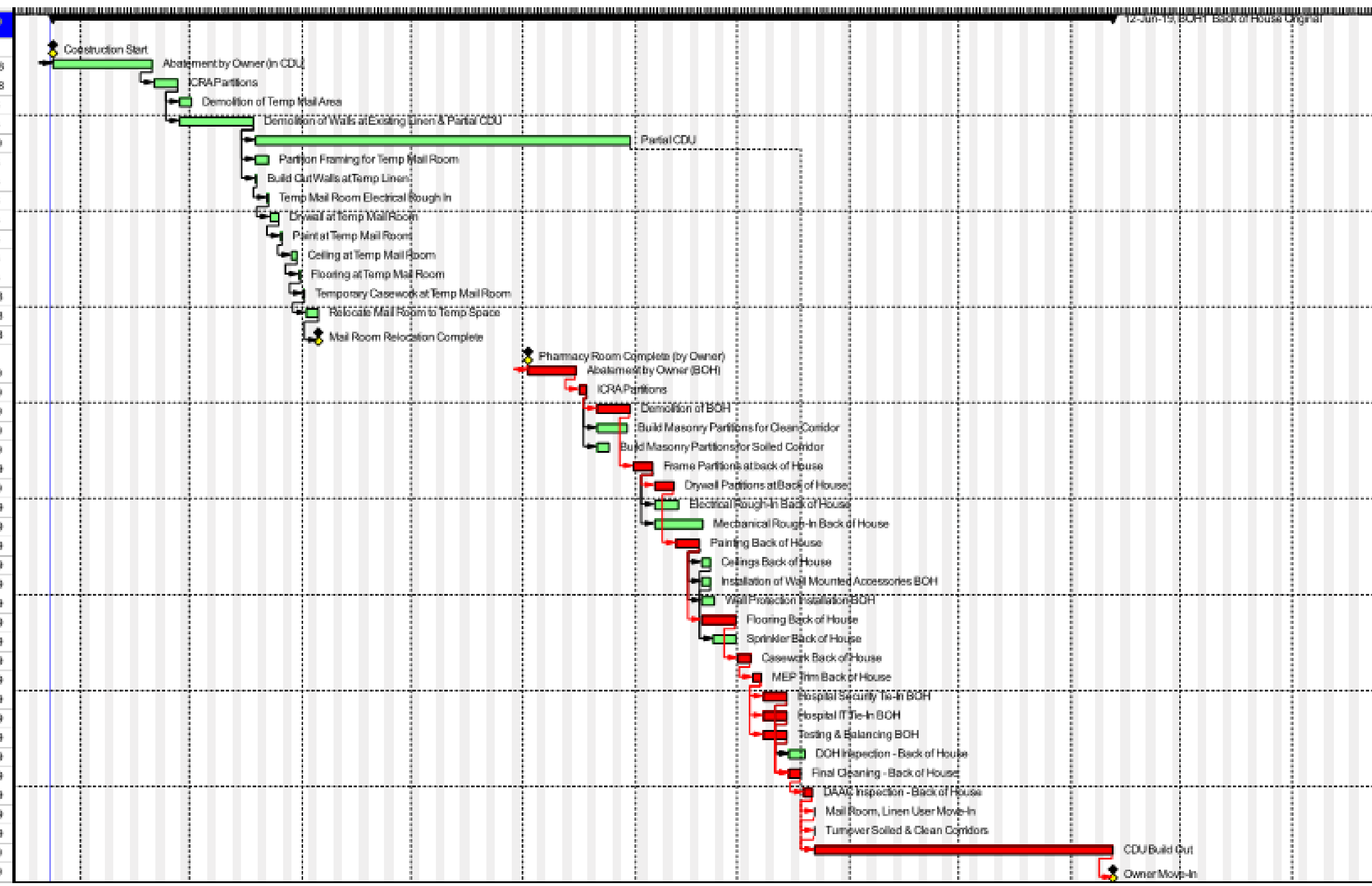
Unity Memorial Hospital
Existing Site Plan

Appendix B

Temporary Pharmacy Relocation Schedules

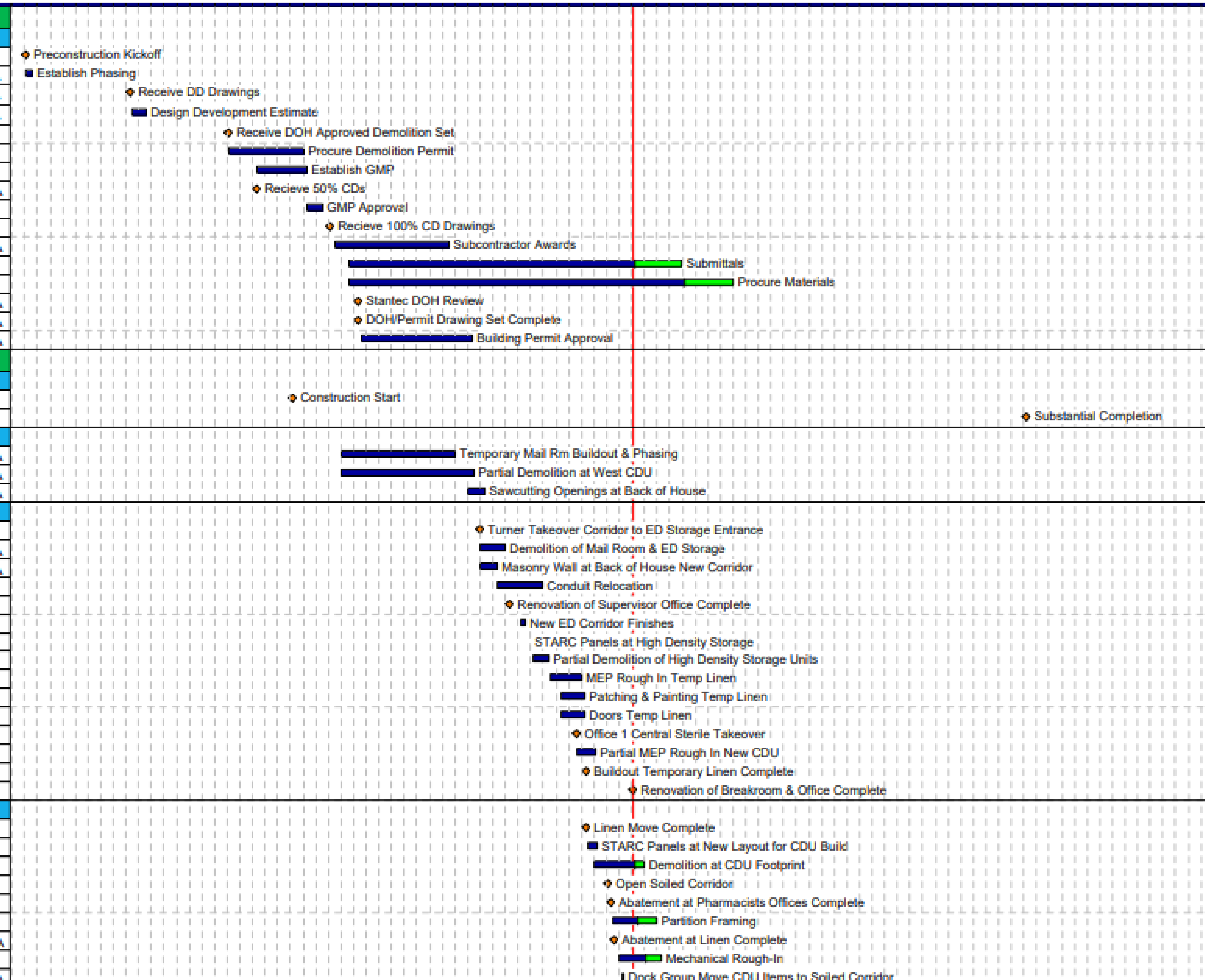
B.1 Original Schedule Simplified for Pharmacy Relocation

BOH1	Back of House Original	209	24-Aug-18	12-Jun-19
A1000	Construction Start	0	24-Aug-18*	
A1010	Abatement by Owner (in CDU)	20	24-Aug-18	20-Sep-18
A1011	ICRA Partitions	5	21-Sep-18	27-Sep-18
A1020	Demolition of Temp Mail Area	2	28-Sep-18	01-Oct-18
A1030	Demolition of Walls at Existing Linen & Partial CDU	15	28-Sep-18	18-Oct-18
A1033	Partial CDU	74	19-Oct-18	30-Jan-19
A1035	Partition Framing for Temp Mail Room	2	19-Oct-18	22-Oct-18
A1040	Build Out Walls at Temp Linen	1	19-Oct-18	19-Oct-18
A1050	Temp Mail Room Electrical Rough In	1	22-Oct-18	22-Oct-18
A1060	Drywall at Temp Mail Room	3	23-Oct-18	25-Oct-18
A1070	Paint at Temp Mail Room	1	26-Oct-18	26-Oct-18
A1080	Ceiling at Temp Mail Room	2	29-Oct-18	30-Oct-18
A1090	Flooring at Temp Mail Room	1	31-Oct-18	31-Oct-18
A1100	Temporary Casework at Temp Mail Room	1	01-Nov-18	01-Nov-18
A1110	Relocate Mail Room to Temp Space	2	02-Nov-18	05-Nov-18
A1115	Mail Room Relocation Complete	0		05-Nov-18
A1120	Pharmacy Room Complete (by Owner)	0	02-Jan-19*	
A1130	Abatement by Owner (BOH)	10	02-Jan-19	15-Jan-19
A1131	ICRA Partitions	3	16-Jan-19	18-Jan-19
A1140	Demolition of BOH	8	21-Jan-19	30-Jan-19
A1150	Build Masonry Partitions for Clean Corridor	7	21-Jan-19	29-Jan-19
A1160	Build Masonry Partitions for Soiled Corridor	4	21-Jan-19	24-Jan-19
A1170	Frame Partitions at back of House	4	31-Jan-19	05-Feb-19
A1175	Drywall Partitions at Back of House	4	06-Feb-19	11-Feb-19
A1180	Electrical Rough-In Back of House	5	06-Feb-19	12-Feb-19
A1190	Mechanical Rough-In Back of House	10	06-Feb-19	19-Feb-19
A1200	Painting Back of House	5	12-Feb-19	18-Feb-19
A1210	Ceilings Back of House	3	19-Feb-19	21-Feb-19
A1220	Installation of Wall Mounted Accessories BOH	3	19-Feb-19	21-Feb-19
A1230	Wall Protection Installation BOH	4	19-Feb-19	22-Feb-19
A1240	Flooring Back of House	8	19-Feb-19	28-Feb-19
A1250	Sprinkler Back of House	5	22-Feb-19	28-Feb-19
A1260	Casework Back of House	2	01-Mar-19	04-Mar-19
A1270	MEP Trim Back of House	3	05-Mar-19	07-Mar-19
A1280	Hospital Security Tie-In BOH	5	08-Mar-19	14-Mar-19
A1290	Hospital IT Tie-In BOH	5	08-Mar-19	14-Mar-19
A1300	Testing & Balancing BOH	5	08-Mar-19	14-Mar-19
A1310	DOH Inspection - Back of House	3	15-Mar-19	19-Mar-19
A1320	Final Cleaning - Back of House	2	15-Mar-19	18-Mar-19
A1330	DAAC Inspection - Back of House	3	19-Mar-19	21-Mar-19
A1340	Mail Room, Linen User Move-In	0	22-Mar-19	22-Mar-19
A1350	Turnover Soiled & Clean Corridors	0	22-Mar-19	22-Mar-19
A1360	CDU Build Out	59	22-Mar-19	12-Jun-19
A1370	Owner Move-In	0		12-Jun-19

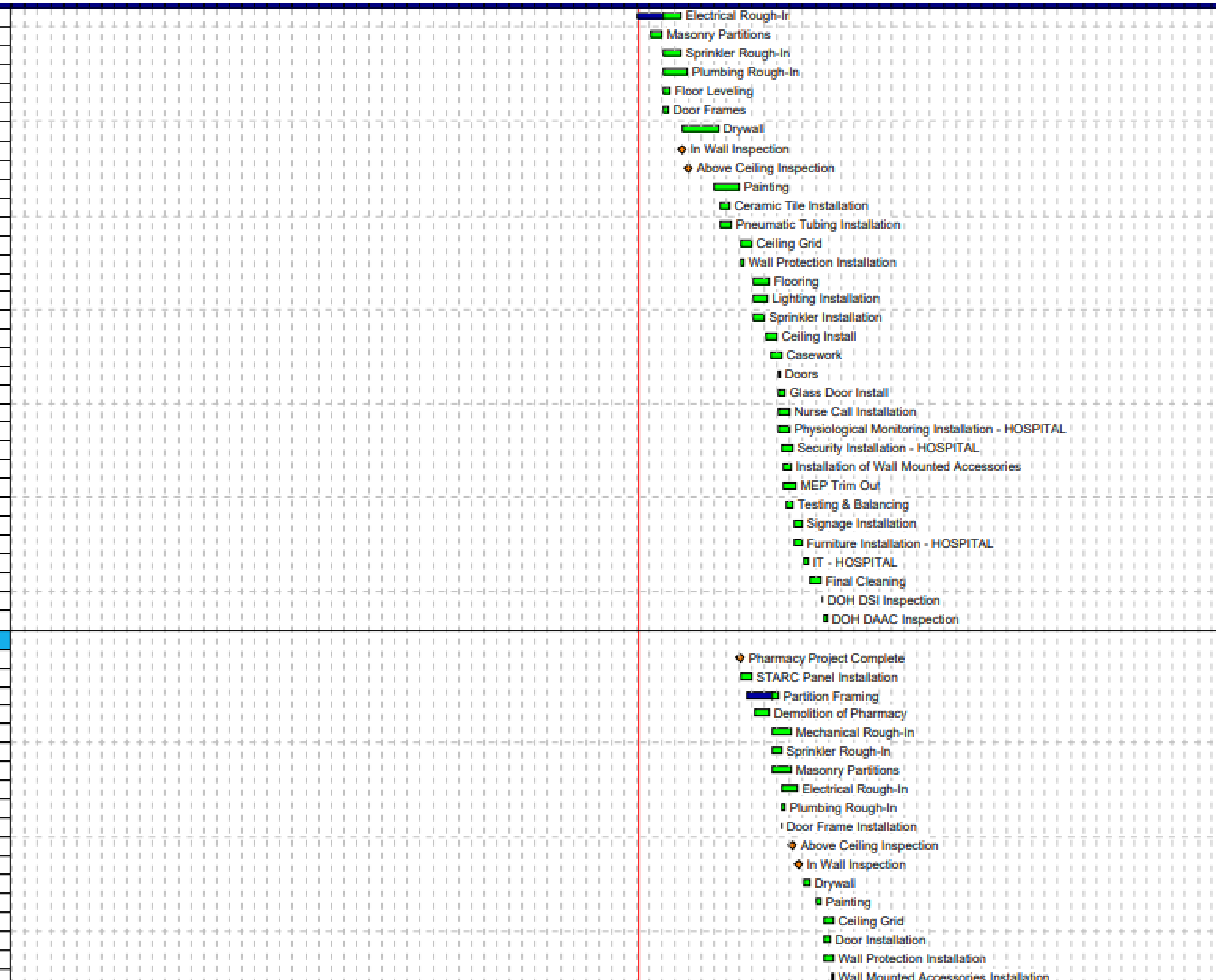


B.2 Current Construction Schedule Adopted After Pharmacy Delay

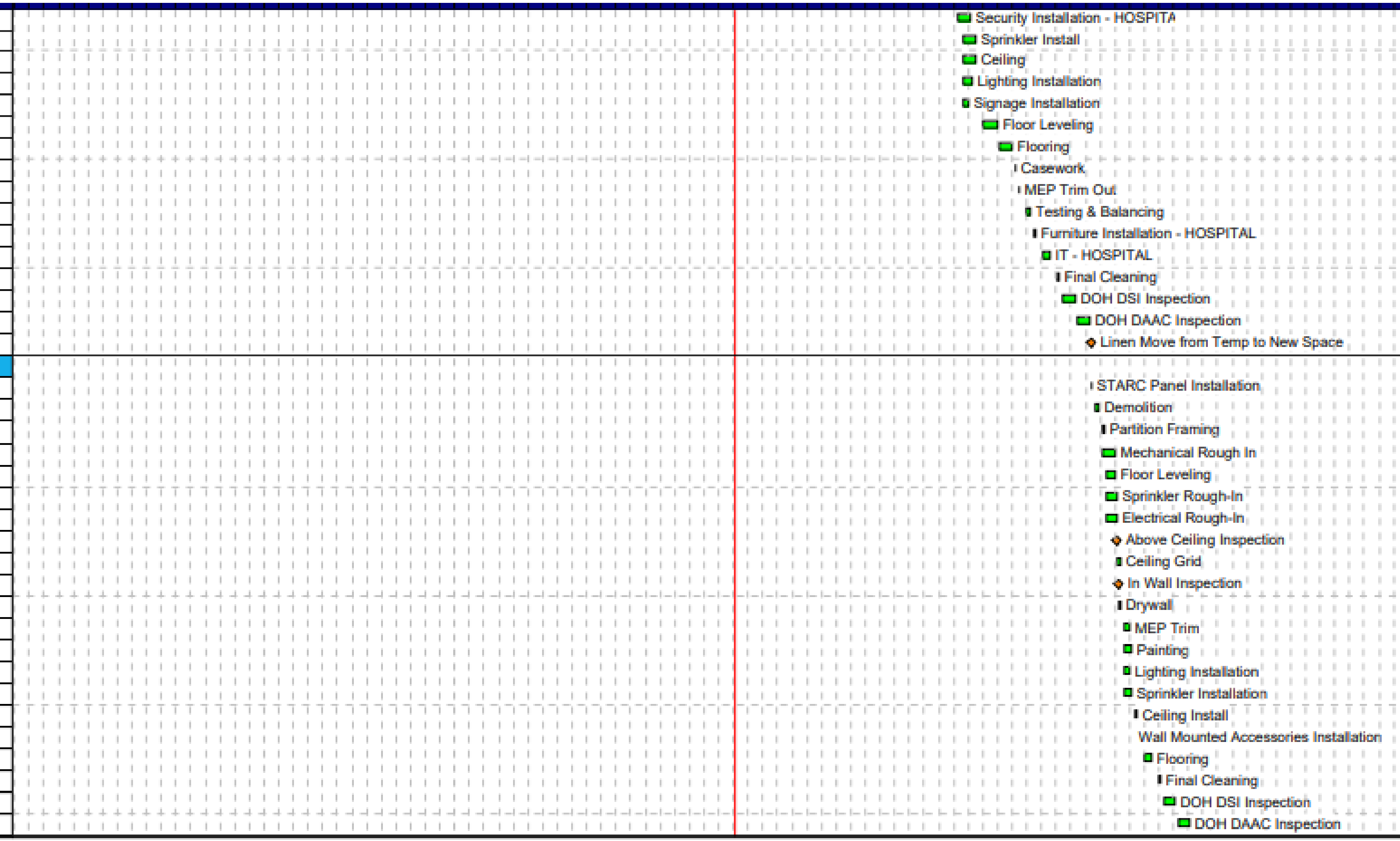
PRECONSTRUCTION				
1000	Preconstruction Kickoff	0	09APR18 A	
1010	Establish Phasing	5d	09APR18 A	13APR18 A
1020	Receive DD Drawings	0		06JUN18 A
1030	Design Development Estimate	10d	07JUN18 A	15JUN18 A
1670	Receive DOH Approved Demolition Set	0		30JUL18 A
1990	Procure Demolition Permit	30d	31JUL18 A	11SEP18 A
1050	Establish GMP	20d	15AUG18 A	12SEP18 A
1040	Recieve 50% CDs	0		15AUG18 A
1090	GMP Approval	5d	12SEP18 A	21SEP18 A
1470	Recieve 100% CD Drawings	0		24SEP18 A
1100	Subcontractor Awards	5d	27SEP18 A	30NOV18 A
1110	Submittals	20d	05OCT18 A	08APR19
1120	Procure Materials	20d	05OCT18 A	06MAY19
1060	Stantec DOH Review	0		10OCT18 A
1070	DOH/Permit Drawing Set Complete	0		10OCT18 A
1080	Building Permit Approval	40d	12OCT18 A	13DEC18 A
CONSTRUCTION				
Overall Construction Tracking				
1130	Construction Start	0	04SEP18 A	
1140	Substantial Completion	0		15OCT19
Early Demo CDU & Surrounding Areas				
1150	Temporary Mail Rm Buildout & Phasing	1d	01OCT18 A	03DEC18 A
1160	Partial Demolition at West CDU	1d	01OCT18 A	14DEC18 A
1640	Sawcutting Openings at Back of House	10d	10DEC18 A	20DEC18 A
Central Sterile Changes & Temp Linen Buildout				
1170	Turner Takeover Corridor to ED Storage Entrance	0	17DEC18 A	
1300	Demolition of Mail Room & ED Storage	10d	17DEC18 A	31DEC18 A
1630	Masonry Wall at Back of House New Corridor	8d	17DEC18 A	27DEC18 A
1340	Conduit Relocation	8d	26DEC18 A	21JAN19 A
1190	Renovation of Supervisor Office Complete	0		02JAN19 A
1360	New ED Corridor Finishes	4d	08JAN19 A	11JAN19 A
1230	STARC Panels at High Density Storage	1d	14JAN19 A	14JAN19 A
1220	Partial Demolition of High Density Storage Units	5d	15JAN19 A	24JAN19 A
1240	MEP Rough In Temp Linen	4d	25JAN19 A	11FEB19 A
1250	Patching & Painting Temp Linen	3d	31JAN19 A	13FEB19 A
1260	Doors Temp Linen	3d	31JAN19 A	13FEB19 A
1180	Office 1 Central Sterile Takeover	0	08FEB19 A	
1310	Partial MEP Rough In New CDU	8d	08FEB19 A	19FEB19 A
1200	Buildout Temporary Linen Complete	0		13FEB19 A
1210	Renovation of Breakroom & Office Complete	0		11MAR19 *
CDU Buildout				
1270	Linen Move Complete	0		13FEB19 A
1280	STARC Panels at New Layout for CDU Build	3d	14FEB19 A	20FEB19 A
1290	Demolition at CDU Footprint	8d	18FEB19 A	18MAR19
2290	Open Soiled Corridor	0		25FEB19 A
2320	Abatement at Pharmacists Offices Complete	0		27FEB19 A
1320	Partition Framing	10d	28FEB19 A	25MAR19
2310	Abatement at Linen Complete	0		01MAR19 A
1350	Mechanical Rough-In	12d	04MAR19 A	28MAR19
2300	Dock Group Move CDU Items to Soiled Corridor	1d	05MAR19 A	07MAR19 A



1330	Electrical Rough-In	8d	11MAR19 A	04APR19
1510	Masonry Partitions	5d	18MAR19	25MAR19
1370	Sprinkler Rough-In	8d	25MAR19	04APR19
1380	Plumbing Rough-In	10d	25MAR19	08APR19
1400	Floor Leveling	4d	25MAR19	29MAR19
1490	Door Frames	3d	25MAR19	28MAR19
1420	Drywall	15d	04APR19	25APR19
2160	In Wall Inspection	0		04APR19
2170	Above Ceiling Inspection	0		08APR19
1450	Painting	10d	22APR19	06MAY19
2150	Ceramic Tile Installation	4d	25APR19	01MAY19
2340	Pneumatic Tubing Installation	5d	25APR19	02MAY19
1430	Ceiling Grid	5d	06MAY19	13MAY19
1480	Wall Protection Installation	3d	06MAY19	09MAY19
1410	Flooring	8d	13MAY19	23MAY19
1570	Lighting Installation	7d	13MAY19	22MAY19
2200	Sprinkler Installation	5d	13MAY19	20MAY19
1440	Ceiling Install	5d	20MAY19	27MAY19
1390	Casework	5d	23MAY19	30MAY19
1500	Doors	2d	27MAY19	29MAY19
1530	Glass Door Install	4d	27MAY19	31MAY19
1540	Nurse Call Installation	5d	27MAY19	03JUN19
2330	Physiological Monitoring Installation - HOSPITAL	5d	27MAY19	03JUN19
1550	Security Installation - HOSPITAL	5d	29MAY19	05JUN19
1460	Installation of Wall Mounted Accessories	3d	30MAY19	04JUN19
1720	MEP Trim Out	5d	30MAY19	06JUN19
1580	Testing & Balancing	3d	31MAY19	05JUN19
2130	Signage Installation	2d	05JUN19	10JUN19
2210	Furniture Installation - HOSPITAL	3d	05JUN19	10JUN19
1560	IT - HOSPITAL	3d	10JUN19	13JUN19
1970	Final Cleaning	3d	13JUN19	20JUN19
1590	DOH DSI Inspection	1d	20JUN19	21JUN19
1600	DOH DAAC Inspection	1d	21JUN19	24JUN19
Back of House & Linen Buildout				
1610	Pharmacy Project Complete	0		06MAY19 *
2250	STARC Panel Installation	1d	07MAY19	13MAY19
1650	Partition Framing	5d	10MAY19 A	28MAY19
1620	Demolition of Pharmacy	8d	14MAY19	23MAY19
1680	Mechanical Rough-In	8d	24MAY19	04JUN19
1700	Sprinkler Rough-In	5d	24MAY19	30MAY19
1800	Masonry Partitions	8d	24MAY19	04JUN19
1660	Electrical Rough-In	8d	29MAY19	07JUN19
1690	Plumbing Rough-In	3d	29MAY19	31MAY19
1780	Door Frame Installation	2d	29MAY19	30MAY19
2190	Above Ceiling Inspection	0		04JUN19
2180	In Wall Inspection	0		07JUN19
1760	Drywall	5d	10JUN19	14JUN19
1770	Painting	4d	17JUN19	20JUN19
1740	Ceiling Grid	5d	21JUN19	27JUN19
1790	Door Installation	3d	21JUN19	25JUN19
1830	Wall Protection Installation	5d	21JUN19	27JUN19
1840	Wall Mounted Accessories Installation	2d	26JUN19	27JUN19

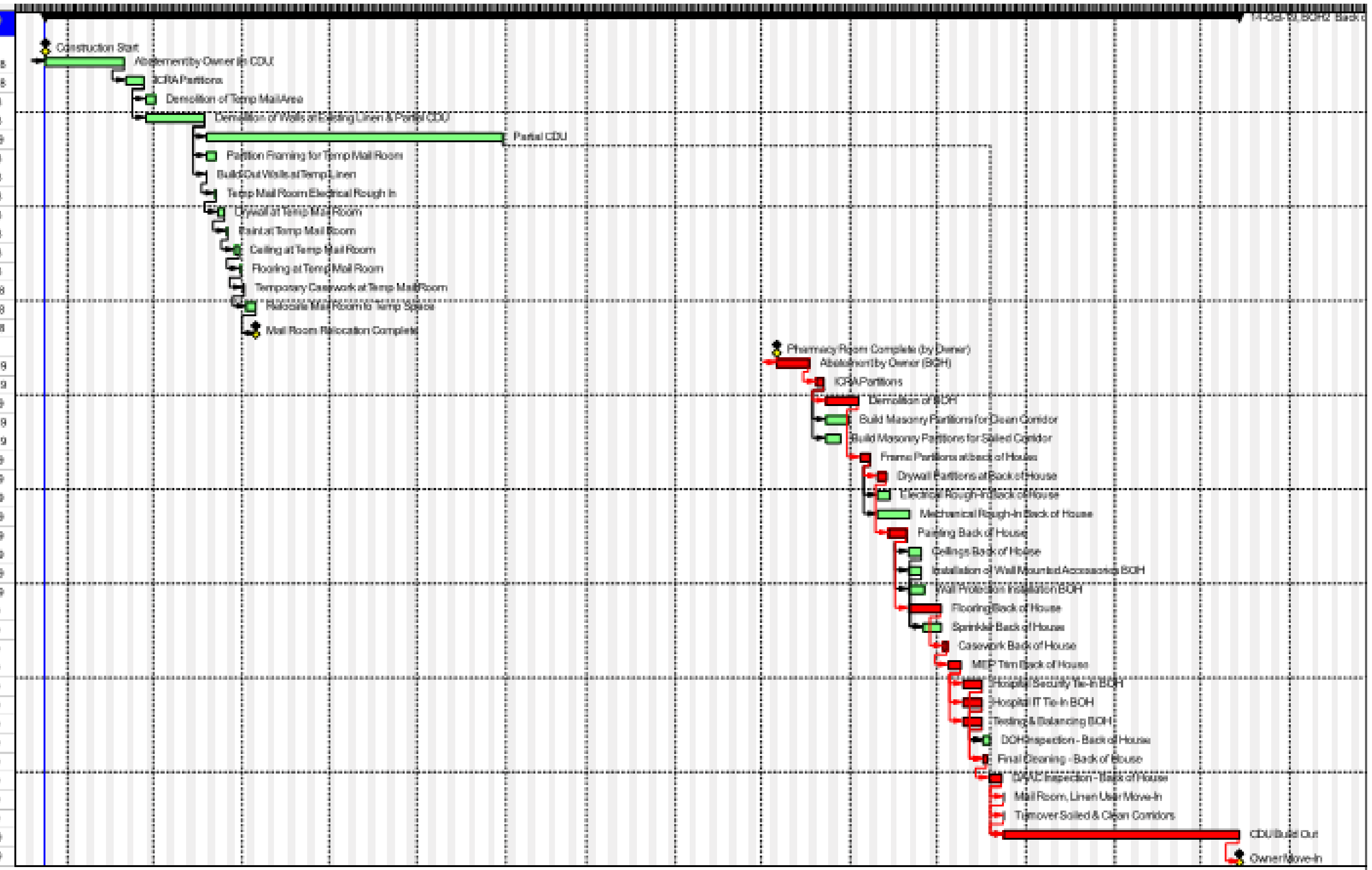


2020	Security Installation - HOSPITAL	5d	26JUN19	02JUL19
1730	Sprinkler Install	5d	28JUN19	05JUL19
1750	Ceiling	5d	28JUN19	05JUL19
2100	Lighting Installation	4d	28JUN19	03JUL19
2120	Signage Installation	2d	28JUN19	01JUL19
1810	Floor Leveling	6d	08JUL19	15JUL19
1820	Flooring	5d	16JUL19	22JUL19
2220	Casework	2d	23JUL19	24JUL19
1710	MEP Trim Out	2d	25JUL19	26JUL19
2240	Testing & Balancing	3d	29JUL19	31JUL19
2230	Furniture Installation - HOSPITAL	2d	01AUG19	02AUG19
2010	IT - HOSPITAL	5d	05AUG19	09AUG19
1960	Final Cleaning	3d	12AUG19	14AUG19
1980	DOH DSI Inspection	5d	15AUG19	21AUG19
2000	DOH DAAC Inspection	5d	22AUG19	28AUG19
1850	Linen Move from Temp to New Space	0	29AUG19	
Pallette Storage				
2030	STARC Panel Installation	1d	29AUG19	29AUG19
1950	Demolition	2d	30AUG19	02SEP19
1860	Partition Framing	2d	03SEP19	04SEP19
1870	Mechanical Rough In	5d	03SEP19	09SEP19
2050	Floor Leveling	3d	05SEP19	09SEP19
2060	Sprinkler Rough-In	4d	05SEP19	10SEP19
2080	Electrical Rough-In	4d	05SEP19	10SEP19
2270	Above Ceiling Inspection	0		09SEP19
1930	Ceiling Grid	3d	10SEP19	12SEP19
2070	In Wall Inspection	0		10SEP19
2260	Drywall	2d	11SEP19	12SEP19
1880	MEP Trim	2d	13SEP19	16SEP19
1920	Painting	3d	13SEP19	17SEP19
2090	Lighting Installation	2d	13SEP19	16SEP19
2140	Sprinkler Installation	3d	13SEP19	17SEP19
1940	Ceiling Install	3d	18SEP19	20SEP19
2110	Wall Mounted Accessories Installation	1d	18SEP19	18SEP19
1910	Flooring	5d	23SEP19	27SEP19
2040	Final Cleaning	2d	30SEP19	01OCT19
1890	DOH DSI Inspection	5d	02OCT19	08OCT19
1900	DOH DAAC Inspection	5d	09OCT19	15OCT19



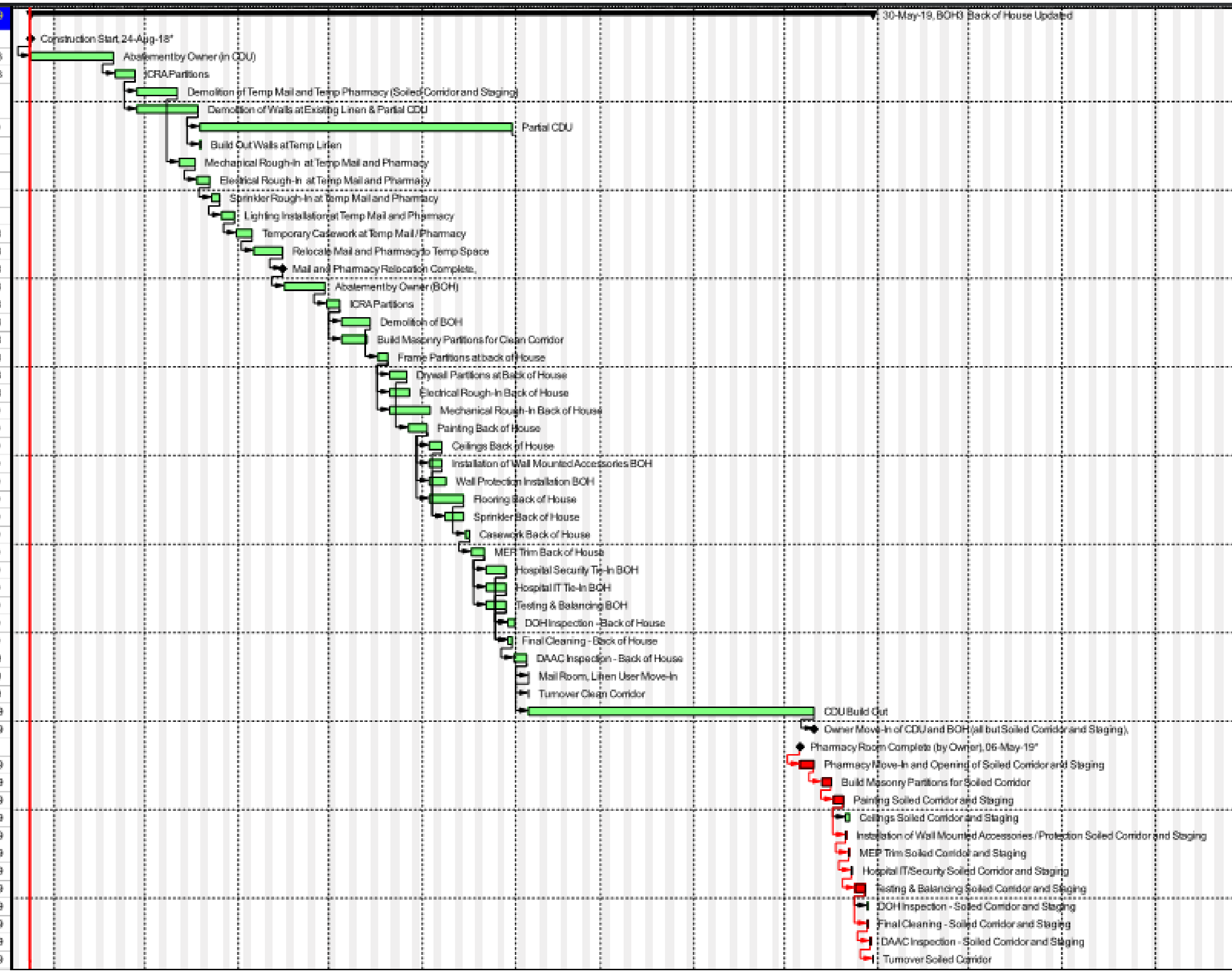
B.3 Simplified Pharmacy Delay Schedule (Not used for construction - CDU Delay)

BOH2	Back of House Original - Pharmacy Delay	297	24-Aug-18	14-Oct-19
A1000	Construction Start	0	24-Aug-18*	
A1010	Abatement by Owner (in CDU)	20	24-Aug-18	20-Sep-18
A1011	ICRA Partitions	5	21-Sep-18	27-Sep-18
A1020	Demolition of Temp Mail Area	2	28-Sep-18	01-Oct-18
A1030	Demolition of Walls at Existing Linen & Partial CDU	15	28-Sep-18	18-Oct-18
A1033	Partial CDU	74	19-Oct-18	30-Jan-19
A1035	Partition Framing for Temp Mail Room	2	19-Oct-18	22-Oct-18
A1040	Build Out Walls at Temp Linen	1	19-Oct-18	19-Oct-18
A1050	Temp Mail Room Electrical Rough In	1	22-Oct-18	22-Oct-18
A1060	Drywall at Temp Mail Room	3	23-Oct-18	25-Oct-18
A1070	Paint at Temp Mail Room	1	26-Oct-18	26-Oct-18
A1080	Ceiling at Temp Mail Room	2	29-Oct-18	30-Oct-18
A1090	Flooring at Temp Mail Room	1	31-Oct-18	31-Oct-18
A1100	Temporary Casework at Temp Mail Room	1	01-Nov-18	01-Nov-18
A1110	Relocate Mail Room to Temp Space	2	02-Nov-18	05-Nov-18
A1115	Mail Room Relocation Complete	0		05-Nov-18
A1120	Pharmacy Room Complete (by Owner)	0	06-May-19*	
A1130	Abatement by Owner (BOH)	10	06-May-19	17-May-19
A1131	ICRA Partitions	3	20-May-19	22-May-19
A1140	Demolition of BOH	8	23-May-19	03-Jun-19
A1150	Build Masonry Partitions for Clean Corridor	7	23-May-19	31-May-19
A1160	Build Masonry Partitions for Soiled Corridor	4	23-May-19	28-May-19
A1170	Frame Partitions at back of House	4	04-Jun-19	07-Jun-19
A1175	Drywall Partitions at Back of House	4	10-Jun-19	13-Jun-19
A1180	Electrical Rough-In Back of House	5	10-Jun-19	14-Jun-19
A1190	Mechanical Rough-In Back of House	10	10-Jun-19	21-Jun-19
A1200	Painting Back of House	5	14-Jun-19	20-Jun-19
A1210	Ceilings Back of House	3	21-Jun-19	25-Jun-19
A1220	Installation of Wall Mounted Accessories BOH	3	21-Jun-19	25-Jun-19
A1230	Wall Protection Installation BOH	4	21-Jun-19	26-Jun-19
A1240	Flooring Back of House	8	21-Jun-19	02-Jul-19
A1250	Sprinkler Back of House	5	26-Jun-19	02-Jul-19
A1260	Casework Back of House	2	03-Jul-19	04-Jul-19
A1270	MEP Trim Back of House	3	05-Jul-19	09-Jul-19
A1280	Hospital Security Tie-In BOH	5	10-Jul-19	16-Jul-19
A1290	Hospital IT Tie-In BOH	5	10-Jul-19	16-Jul-19
A1300	Testing & Balancing BOH	5	10-Jul-19	16-Jul-19
A1310	DOH Inspection - Back of House	3	17-Jul-19	19-Jul-19
A1320	Final Cleaning - Back of House	2	17-Jul-19	18-Jul-19
A1330	DAAC Inspection - Back of House	3	19-Jul-19	23-Jul-19
A1340	Mail Room, Linen User Move-In	0	24-Jul-19	24-Jul-19
A1350	Turnover Soiled & Clean Corridors	0	24-Jul-19	24-Jul-19
A1360	CDU Build Out	59	24-Jul-19	14-Oct-19
A1370	Owner Move-In	0		14-Oct-19



B.4 Proposed Schedule for Pharmacy Relocation

BOH3	Back of House Updated	199	24-Aug-18	30-May-19
A1000	Construction Start	0	24-Aug-18*	
A1010	Abatement by Owner (in CDU)	20	24-Aug-18	20-Sep-18
A1011	ICRA Partitions	5	21-Sep-18	27-Sep-18
A1020	Demolition of Temp Mail and Temp Pharmacy (Soiled Corridor and Staging)	10	28-Sep-18	11-Oct-18
A1030	Demolition of Walls at Existing Linen & Partial CDU	15	28-Sep-18	18-Oct-18
A1035	Partial CDU	74	19-Oct-18	30-Jan-19
A1040	Build Out Walls at Temp Linen	1	19-Oct-18	19-Oct-18
A1050	Mechanical Rough-In at Temp Mail and Pharmacy	4	12-Oct-18	17-Oct-18
A1060	Electrical Rough-In at Temp Mail and Pharmacy	3	18-Oct-18	22-Oct-18
A1070	Sprinkler Rough-In at Temp Mail and Pharmacy	3	23-Oct-18	25-Oct-18
A1080	Lighting Installation at Temp Mail and Pharmacy	3	26-Oct-18	30-Oct-18
A1100	Temporary Casework at Temp Mail / Pharmacy	4	31-Oct-18	05-Nov-18
A1110	Relocate Mail and Pharmacy to Temp Space	8	06-Nov-18	15-Nov-18
A1115	Mail and Pharmacy Relocation Complete	0		15-Nov-18
A1130	Abatement by Owner (BOH)	10	16-Nov-18	29-Nov-18
A1131	ICRA Partitions	3	30-Nov-18	04-Dec-18
A1140	Demolition of BOH	8	05-Dec-18	14-Dec-18
A1150	Build Masonry Partitions for Clean Corridor	7	05-Dec-18	13-Dec-18
A1170	Frame Partitions at back of House	4	17-Dec-18	20-Dec-18
A1175	Drywall Partitions at Back of House	4	21-Dec-18	26-Dec-18
A1180	Electrical Rough-In Back of House	5	21-Dec-18	27-Dec-18
A1190	Mechanical Rough-In Back of House	10	21-Dec-18	03-Jan-19
A1200	Painting Back of House	5	27-Dec-18	02-Jan-19
A1210	Ceilings Back of House	3	03-Jan-19	07-Jan-19
A1220	Installation of Wall Mounted Accessories BOH	3	03-Jan-19	07-Jan-19
A1230	Wall Protection Installation BOH	4	03-Jan-19	08-Jan-19
A1240	Flooring Back of House	8	03-Jan-19	14-Jan-19
A1250	Sprinkler Back of House	5	08-Jan-19	14-Jan-19
A1260	Casework Back of House	2	15-Jan-19	16-Jan-19
A1270	MEP Trim Back of House	3	17-Jan-19	21-Jan-19
A1280	Hospital Security Tie-In BOH	5	22-Jan-19	28-Jan-19
A1290	Hospital IT Tie-In BOH	5	22-Jan-19	28-Jan-19
A1300	Testing & Balancing BOH	5	22-Jan-19	28-Jan-19
A1310	DOH Inspection - Back of House	3	29-Jan-19	31-Jan-19
A1320	Final Cleaning - Back of House	2	29-Jan-19	30-Jan-19
A1330	DAAC Inspection - Back of House	3	31-Jan-19	04-Feb-19
A1340	Mail Room, Linen User Move-In	0	05-Feb-19	05-Feb-19
A1350	Turnover Clean Corridor	0	05-Feb-19	05-Feb-19
A1360	CDU Build Out	69	05-Feb-19	10-May-19
A1370	Owner Move-In of CDU and BOH (all but Soiled Corridor and Staging)	0		10-May-19
A1380	Pharmacy Room Complete (by Owner)	0	06-May-19*	
A1390	Pharmacy Move-In and Opening of Soiled Corridor and Staging	5	06-May-19	10-May-19
A1400	Build Masonry Partitions for Soiled Corridor	4	13-May-19	16-May-19
A1430	Painting Soiled Corridor and Staging	2	17-May-19	20-May-19
A1440	Ceilings Soiled Corridor and Staging	2	21-May-19	22-May-19
A1450	Installation of Wall Mounted Accessories / Protection Soiled Corridor and Stag	1	21-May-19	21-May-19
A1460	MEP Trim Soiled Corridor and Staging	1	22-May-19	22-May-19
A1480	Hospital IT/Security Soiled Corridor and Staging	1	23-May-19	23-May-19
A1510	Testing & Balancing Soiled Corridor and Staging	2	24-May-19	27-May-19
A1520	DOH Inspection - Soiled Corridor and Staging	1	28-May-19	28-May-19
A1530	Final Cleaning - Soiled Corridor and Staging	1	28-May-19	28-May-19
A1540	DAAC Inspection - Soiled Corridor and Staging	1	29-May-19	29-May-19
A1550	Turnover Soiled Corridor	0	30-May-19	30-May-19

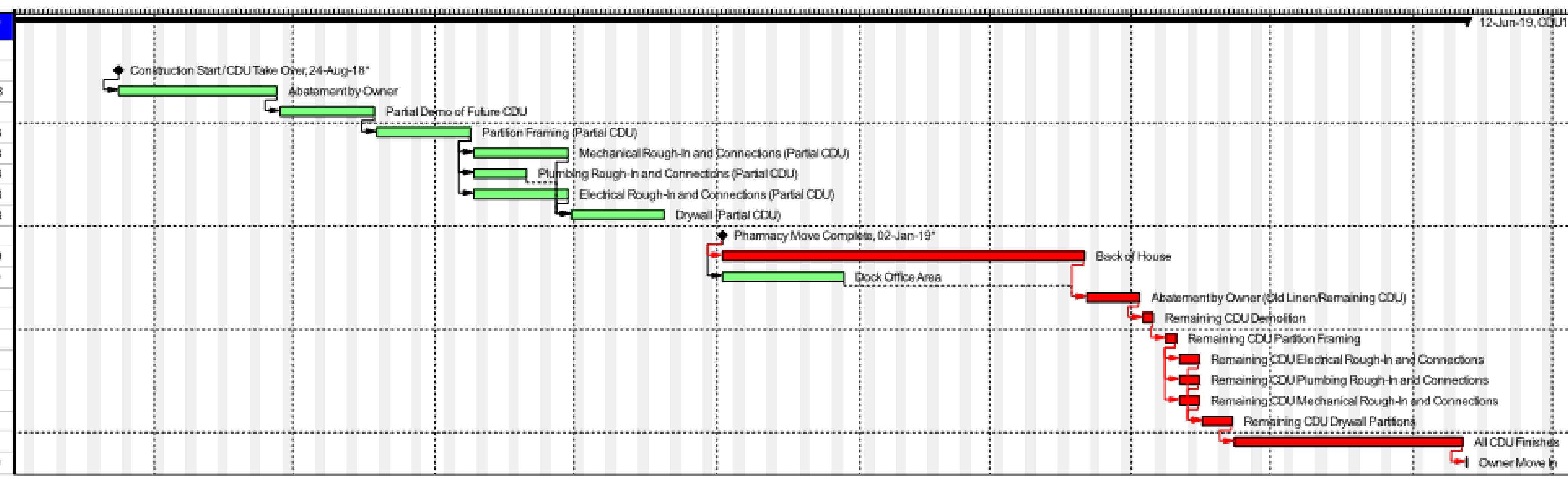


Appendix C

Prefabrication Schedules

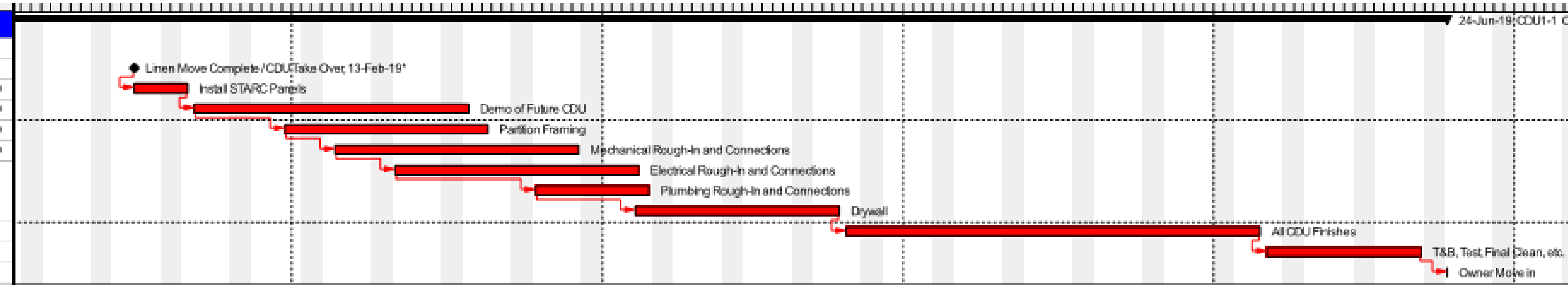
C.1 Original Schedule Simplified for CDU

CDU1	Original CDU	266	06-Jun-18	12-Jun-19
A1000	Recieve DD Drawings	0	06-Jun-18	
A1010	Construction Start / CDU Take Over	0	24-Aug-18*	
A1020	Abatement by Owner	25	24-Aug-18	27-Sep-18
A1030	Partial Demo of Future CDU	15	28-Sep-18	18-Oct-18
A1040	Partition Framing (Partial CDU)	15	19-Oct-18	08-Nov-18
A1050	Mechanical Rough-In and Connections (Partial CDU)	15	09-Nov-18	29-Nov-18
A1055	Plumbing Rough-In and Connections (Partial CDU)	8	09-Nov-18	20-Nov-18
A1060	Electrical Rough-In and Connections (Partial CDU)	15	09-Nov-18	29-Nov-18
A1070	Drywall (Partial CDU)	15	30-Nov-18	20-Dec-18
A1075	Pharmacy Move Complete	0	02-Jan-19*	
A1080	Back of House	57	02-Jan-19	21-Mar-19
A1090	Dock Office Area	19	02-Jan-19	28-Jan-19
A1100	Abatement by Owner (Old Linen/Remaining CDU)	8	22-Mar-19	02-Apr-19
A1110	Remaining CDU Demolition	3	03-Apr-19	05-Apr-19
A1120	Remaining CDU Partition Framing	3	08-Apr-19	10-Apr-19
A1130	Remaining CDU Electrical Rough-In and Connections	3	11-Apr-19	15-Apr-19
A1140	Remaining CDU Plumbing Rough-In and Connections	3	11-Apr-19	15-Apr-19
A1150	Remaining CDU Mechanical Rough-In and Connections	3	11-Apr-19	15-Apr-19
A1160	Remaining CDU Drywall Partitions	5	16-Apr-19	22-Apr-19
A1170	All CDU Finishes	36	23-Apr-19	11-Jun-19
A1180	Owner Move In	1	12-Jun-19	12-Jun-19



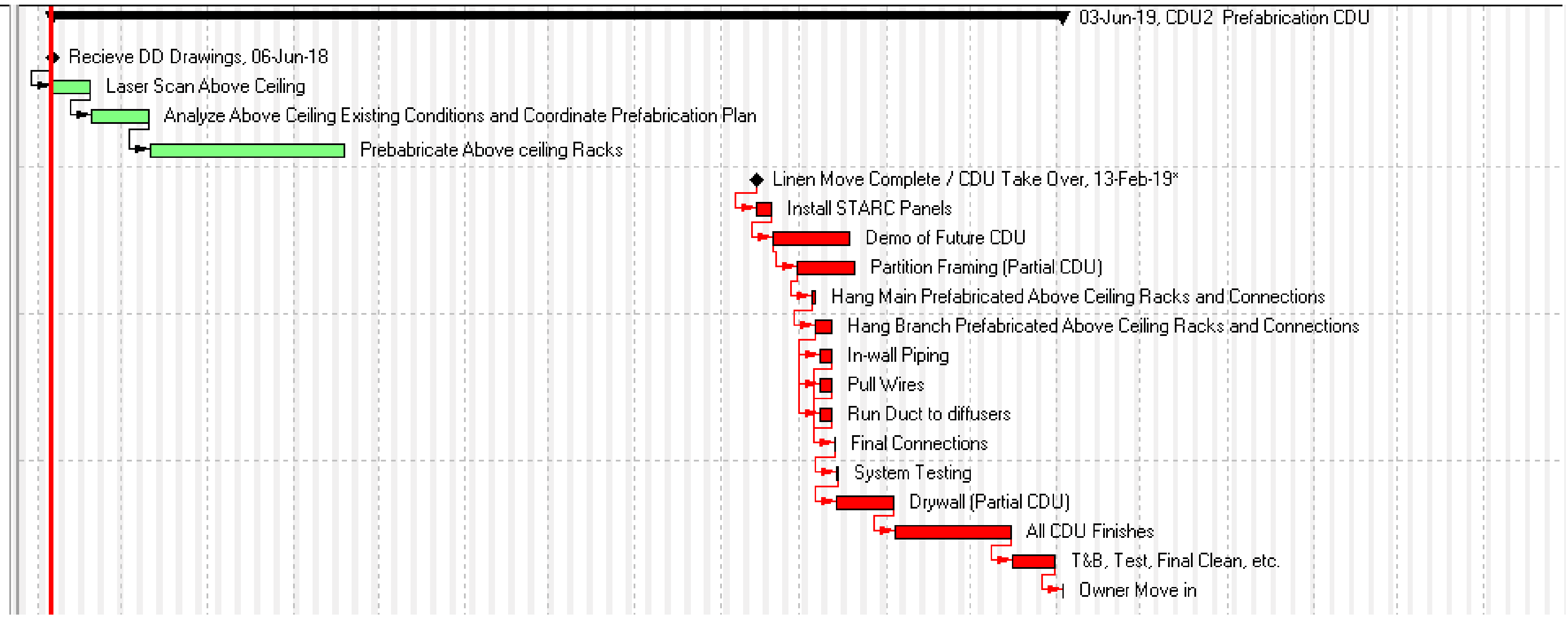
C.2 Current Schedule Simplified for CDU

CDU1-1	Original CDU NEW	273	06-Jun-18	24-Jun-19
A1000	Recieve DD Drawings	0	06-Jun-18	
A1010	Linen Move Complete / CDU Take Over	0	13-Feb-19*	
A1020	Install STARC Panels	4	13-Feb-19	18-Feb-19
A1030	Demo of Future CDU	20	19-Feb-19	18-Mar-19
A1040	Partition Framing	15	28-Feb-19	20-Mar-19
A1050	Mechanical Rough-In and Connections	19	05-Mar-19	29-Mar-19
A1054	Electrical Rough-In and Connections	19	11-Mar-19	04-Apr-19
A1055	Plumbing Rough-In and Connections	10	25-Mar-19	05-Apr-19
A1070	Drywall	15	04-Apr-19	24-Apr-19
A1170	All CDU Finishes	30	25-Apr-19	05-Jun-19
A1180	T&B, Test, Final Clean, etc.	12	06-Jun-19	21-Jun-19
A1190	Owner Move in	0	24-Jun-19	24-Jun-19



C.3 Current Schedule Modified for Prefabricated Rack Proposal

CDU2	Prefabrication CDU	258	06-Jun-18	03-Jun-19
A1000	Recieve DD Drawings	0	06-Jun-18	
A1001	Laser Scan Above Ceiling	10	06-Jun-18	19-Jun-18
A1002	Analyze Above Ceiling Existing Conditions and Coordinat	15	20-Jun-18	10-Jul-18
A1003	Prebabricate Above ceiling Racks	50	11-Jul-18	18-Sep-18
A1010	Linen Move Complete / CDU Take Over	0	13-Feb-19*	
A1020	Install STARC Panels	4	13-Feb-19	18-Feb-19
A1030	Demo of Future CDU	20	19-Feb-19	18-Mar-19
A1040	Partition Framing (Partial CDU)	15	28-Feb-19	20-Mar-19
A1050	Hang Main Prefabricated Above Ceiling Racks and Conr	2	05-Mar-19	06-Mar-19
A1060	Hang Branch Prefabricated Above Ceiling Racks and Cc	5	06-Mar-19	12-Mar-19
A1080	In-wall Piping	3	08-Mar-19	12-Mar-19
A1090	Pull Wires	3	08-Mar-19	12-Mar-19
A1100	Run Duct to diffusers	3	08-Mar-19	12-Mar-19
A1110	Final Connections	1	13-Mar-19	13-Mar-19
A1120	System Testing	1	14-Mar-19	14-Mar-19
A1130	Drywall (Partial CDU)	15	14-Mar-19	03-Apr-19
A1170	All CDU Finishes	30	04-Apr-19	15-May-19
A1180	T&B, Test, Final Clean, etc.	12	16-May-19	31-May-19
A1190	Owner Move in	0	03-Jun-19	03-Jun-19



C.4 Prefabrication Labor Cost Savings Breakdown

Mechanical	Take Off		Labor Cost per unit		Total Labor Cost	
Ductwork	2194	lb	$	5.05	$	11,079.70
Piping to VAV (Copper Type L)(3/4")	396	lf	$	6.55	$	2,593.80
Electrical						
Cable Tray						
18"	200	lf	$	10.85	$	2,170.00
12"	336	lf	$	11.35	$	3,813.60
Plumbing						
CW (Copper Type L)						
2.5"	200	lf	$	14.45	$	2,890.00
3/4"	336	lf	$	6.55	$	2,200.80
HW (Copper Type K)						
1.5"	200	lf	$	9.60	$	1,920.00
3/4"	336	lf	$	6.60	$	2,217.60
HWR (Copper Type K) (3/4")	536	lf	$	6.60	$	3,537.60
Medical Gas 1 (Copper Type K) (2")	900	lf	$	12.45	$	11,205.00
Medical Gas 2 (Copper Type K) (1")	900	lf	$	7.55	$	6,795.00
Vent Piping (PVC) (3")	536	lf	$	16.90	$	9,058.40
TOTAL INITIAL LABOR COST					$	59,481.50
20% Deduction					$	47,585.20

Appendix D

Mechanical Breadth TRACE700 Outputs

D.1 AHU and VAV Outputs

System Checksums

By ACADEMIC

System - 001 — **Variable Volume Reheat (30% Min Flow Default)**

COOLING COIL PEAK — Peaked at Time: Mo/Hr: 7 / 15; Outside Air: OADB/WB/HR: 86 / 71 / 95

CLG SPACE PEAK — Mo/Hr: 7 / 15; OADB: 86

	Cooling Coil Peak: Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Clg Space Peak: Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	0	0	0	0	0
Glass Solar	0	0	0	0	0	0
Glass/Door Cond	0	0	0	0	0	0
Wall Cond	0	0	0	0	0	0
Partition/Door	0		0	0	0	0
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	0		0	0	0	0
Sub Total ==>	0	0	0	0	0	0
Internal Loads						
Lights	65,890	16,473	82,363	54	65,890	78
People	12,055	0	12,055	8	6,697	8
Misc	0	0	0	0	0	0
Sub Total ==>	77,945	16,473	94,418	62	72,587	85
Ceiling Load	10,507	-10,507	0	0	12,328	15
Ventilation Load	0	0	59,517	39	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	0		0	0	0	0
Exhaust Heat		-2,570	-2,570	-2		
Sup. Fan Heat			0	0		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	88,453	3,395	151,365	100.00	84,916	100.00

HEATING COIL PEAK — Mo/Hr: Heating Design; OADB: 5

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	0	0	0.00
Glass Solar	0	0	0.00
Glass/Door Cond	0	0	0.00
Wall Cond	0	0	0.00
Partition/Door	0	0	0.00
Floor	0	0	0.00
Adjacent Floor	0	0	0
Infiltration	0	0	0.00
Sub Total ==>	0	0	0.00
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	0	0	0.00
Sub Total ==>	0	0	0.00
Ceiling Load	0	0	0.00
Ventilation Load	0	-90,316	69.97
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	4	4	0.00
Exhaust Heat		0	0.00
OA Preheat Diff.		-38,329	29.70
RA Preheat Diff.		0	0.00
Additional Reheat		-429	0.33
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	4	-129,070	100.00

TEMPERATURES

	Cooling	Heating
SADB	56.8	70.0
Ra Plenum	76.4	70.0
Return	76.4	70.0
Ret/OA	80.8	6.5
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	4,375	1,332
Terminal	4,375	1,332
Main Fan	4,375	1,332
Sec Fan	0	0
Nom Vent	1,967	1,302
AHU Vent	1,967	1,302
Infil	0	0
MinStop/Rh	1,332	1,332
Return	4,161	1,156
Exhaust	1,752	1,126
Rm Exh	215	176
Auxiliary	0	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	45.0	97.7
cfm/ft²	0.18	0.06
cfm/ton	346.86	
ft²/ton	1,913.15	
Btu/hr·ft²	6.27	-5.29
No. People	27	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB/WB/HR °F	Enter °F	Enter gr/lb	Leave DB/WB/HR °F	Leave °F	Leave gr/lb
Main Clg	12.6	151.4	109.6	4,281	80.8	66.7	80.3	56.8	55.3	66.0
Aux Clg	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	12.6	151.4								

AREAS

	Gross Total	Glass ft²	(%)
Floor	24,132		
Part	0		
Int Door	0		
ExFlr	0		
Roof	0	0	0
Wall	0	0	0
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-18.8	1,332	56.8	70.0
Aux Htg	0.0	0	0.0	0.0
Preheat	-108.8	1,967	5.0	56.8
Reheat	-18.8	1,332	56.8	70.0
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-127.5			

D.2 Chilled Beam Outputs

System Checksums

By ACADEMIC

System - 001 | **Active Chilled Beams**

COOLING COIL PEAK / CLG SPACE PEAK

Cooling Coil Peak — Peaked at Time: Mo/Hr: 7 / 15; Outside Air: OADB/WB/HR: 86 / 71 / 95

CLG Space Peak — Mo/Hr: 7 / 15; OADB: 86

	Space Sens. + Lat. Btu/h	Plenum Sens. + Lat Btu/h	Net Total Btu/h	Percent Of Total (%)	Space Sensible Btu/h	Percent Of Total (%)
Envelope Loads						
Skylite Solar	0	0	0	0	0	0
Skylite Cond	0	0	0	0	0	0
Roof Cond	0	0	0	0	0	0
Glass Solar	0	0	0	0	0	0
Glass/Door Cond	0	0	0	0	0	0
Wall Cond	0	0	0	0	0	0
Partition/Door	0		0	0	0	0
Floor	0		0	0	0	0
Adjacent Floor	0	0	0	0	0	0
Infiltration	0		0	0	0	0
Sub Total ==>	0	0	0	0	0	0
Internal Loads						
Lights	65,890	16,473	82,363	57	65,890	64
People	12,055	0	12,055	8	6,697	7
Misc	0	0	0	0	0	0
Sub Total ==>	77,945	16,473	94,418	66	72,587	71
Ceiling Load	16,333	-16,333	0	0	16,333	16
Ventilation Load	0	0	39,718	28	0	0
Adj Air Trans Heat	0		0	0	0	0
Dehumid. Ov Sizing			0	0		
Ov/Undr Sizing	13,952		13,952	10	13,952	14
Exhaust Heat		-3,995	-3,995	-3		
Sup. Fan Heat			0	0		
Ret. Fan Heat		0	0	0		
Duct Heat Pkup		0	0	0		
Underflr Sup Ht Pkup			0	0		
Supply Air Leakage		0	0	0		
Grand Total ==>	108,230	-3,856	144,093	100.00	102,872	100.00

HEATING COIL PEAK

Mo/Hr: Heating Design; OADB: 5

	Space Peak Space Sens Btu/h	Coil Peak Tot Sens Btu/h	Percent Of Total (%)
Envelope Loads			
Skylite Solar	0	0	0.00
Skylite Cond	0	0	0.00
Roof Cond	0	0	0.00
Glass Solar	0	0	0.00
Glass/Door Cond	0	0	0.00
Wall Cond	0	0	0.00
Partition/Door	0	0	0.00
Floor	0	0	0.00
Adjacent Floor	0	0	0
Infiltration	0	0	0.00
Sub Total ==>	0	0	0.00
Internal Loads			
Lights	0	0	0.00
People	0	0	0.00
Misc	0	0	0.00
Sub Total ==>	0	0	0.00
Ceiling Load	0	0	0.00
Ventilation Load	0	-138,508	86.83
Adj Air Trans Heat	0	0	0
Ov/Undr Sizing	0	0	0.00
Exhaust Heat		0	0.00
OA Preheat Diff.		0	0.00
RA Preheat Diff.		0	0.00
Additional Reheat		-21,011	13.17
Underflr Sup Ht Pkup		0	0.00
Supply Air Leakage		0	0.00
Grand Total ==>	0	-159,519	100.00

TEMPERATURES

	Cooling	Heating
SADB	65.3	75.0
Ra Plenum	77.1	70.0
Return	77.1	70.0
Ret/OA	85.7	6.0
Fn MtrTD	0.0	0.0
Fn BldTD	0.0	0.0
Fn Frict	0.0	0.0

AIRFLOWS

	Cooling	Heating
Diffuser	2,028	2,028
Terminal	2,028	2,028
Main Fan	2,028	2,028
Sec Fan	0	0
Nom Vent	1,967	1,996
AHU Vent	1,967	1,996
Infil	0	0
MinStop/Rh	2,028	2,028
Return	1,814	1,814
Exhaust	1,752	1,782
Rm Exh	215	215
Auxiliary	15,843	0
Leakage Dwn	0	0
Leakage Ups	0	0

ENGINEERING CKS

	Cooling	Heating
% OA	97.0	98.4
cfm/ft²	0.08	0.08
cfm/ton	307.19	
ft²/ton	3,654.72	
Btu/hr-ft²	3.28	-6.53
No. People	27	

COOLING COIL SELECTION

	Total Capacity ton	Total Capacity MBh	Sens Cap. MBh	Coil Airflow cfm	Enter DB °F	Enter WB °F	Enter HR gr/lb	Leave DB °F	Leave WB °F	Leave HR gr/lb
Main Clg	6.6	79.2	49.1	2,028	85.7	70.6	93.6	65.3	59.1	68.4
Aux Clg	6.8	81.7	81.7	15,843	75.0	60.8	60.5	70.2	59.1	60.5
Opt Vent	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0
Total	13.4	160.9								

AREAS

	Gross Total	Glass ft²	Glass (%)
Floor	24,132		
Part	0		
Int Door	0		
ExFlr	0		
Roof	0	0	0
Wall	0	0	0
Ext Door	0	0	0

HEATING COIL SELECTION

	Capacity MBh	Coil Airflow cfm	Ent °F	Lvg °F
Main Htg	-29.2	2,028	61.5	75.0
Aux Htg	0.0	0	0.0	0.0
Preheat	-128.3	2,028	6.0	65.3
Reheat	-29.2	2,028	61.5	75.0
Humidif	0.0	0	0.0	0.0
Opt Vent	0.0	0	0.0	0.0
Total	-157.5			

D.3 Ductwork Cost Calculations

MAIN	wt (lb/ft)	length (ft)	total wt (lb)	cost per lb	Cost of Main
AHU	8.7	610	5307	5.26	27914.82
Chilled Beam	6	610	3660	5.26	19251.6
BRANCH					
AHU	4.35	1095	4763.25	5.26	25054.695
Chilled Beam	3	1095	3285	5.26	17279.1
TOTAL COST					
AHU	$ 52,969.52				
Chilled Beam	$ 36,530.70				

Appendix E

Acoustics Breadth Calculations

	STC	Receiving Sound Level	Additional Cost Incurred (per square foot)
Current Wall	49	44.11	$0
Additional insulation and GWB	55	38.11	$5.75
Temporary Sound Attenuation Fire Blanket	60	33.11	$1.28

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EDUCATION:

Masters of Architectural Engineering | Minor in Business
Construction Management Option
Five year professional degree – ABET Accredited
The Pennsylvania State University, University Park - **Schreyer Honors College**
Graduation: May 2019 | Dean's List: All Semesters

Teaching Assistant - Penn State Department of Architectural Engineering
AE 476: Building Construction & Engineering:
Introduction to Mechanical, Electrical, & Plumbing Systems

ENGINEERING EXPERIENCE:

Engineering Assistant, Turner Construction, Pittsburgh, PA
Shell Ethane Cracker Plant, Monaca, PA, valued at $61M (Summer 2018)

- Gained experience working on nine different buildings that spanned across three contracts
- Compared contract documents to detect changes in revisions and scopes of work
- Gained lean construction experience and participated in pull-planning sessions
- Updated "required on job" (ROJ) log reflecting lead times and submittal review timelines
- Exposed to quality control procedures, including the processing of non-compliance reports
- Participated in safety review sessions and training
- Created white sheets to level bids by comparing scopes of work and budget reports for each bid package; updated buyout schedule to reflect bid status and awarded subcontracts
- Observed how security, transportation, deliveries, and weather challenges are managed on large project sites
- Reviewed submittals pertaining to early stages of the construction project, including, but not limited to structural steel, foundations, MEP equipment, and wall panel assemblies

Engineering Intern, PJ Dick, Pittsburgh, PA
Central Catholic District High School STEM Building, valued at $10.8M (Summer 2016)
UPMC Lemieux Sports Complex, valued at $45.2M (Summer 2015)

- Managed punch list and work to complete items; presented weekly duties to subcontractors
- Reviewed and approved operation and maintenance manuals and other closeout documents
- Interpreted architectural drawings; updated submittal documents for approval by architect
- Coordinated with project manager and owner to create cost events, approval requests, request for change orders, contract change orders, and owner change orders
- Reviewed and submitted requests for information to architect
- Directed installation and assured quality of work
- Developed and updated meeting minutes for coordination meetings between trades

GLOBAL ENGAGEMENT:

Construction Manager, Penn State Bridges to Prosperity Travel Team: Rwanda (Summer 2017)
- Delegated daily tasks to team members; addressed all on-site construction challenges
- Performed materials estimates and tracked materials usage during construction
- Created and modified the construction schedule, noting worst and best case scenarios
- Managed and inventoried all tools and recorded site and labor information daily

Department of Architectural Engineering: China Summer Program (Summer 2017)
Schreyer Honors College World Media Studies in the Czech Republic (Spring 2016)
Schreyer Honors College South America Study Tour: Colombia (Spring 2015)

LEADERSHIP & SERVICE:

Career Envoy, Penn State College of Engineering (2017-2019)
President, S:PACE Partnership for Achieving Construction Excellence (2016-2019)
Inventory Captain, Supply Logistics Committee, Penn State Dance Marathon (2014-2019)
Coach, Penn State WEP Advisory Council (2017-2018)
Envoy Captain, Penn State WEP Sophomore Women Ambassador Team (SWAT) (2015-2017)

HONORS:

WEP Joelle Women in Engineering Leadership Award, First Runner Up - 2018
PACE Leadership in Construction Management Award - 2018
Outstanding Performance in Penn State AE Construction Management Award - 2018
Clark Construction Architectural Engineering Scholarship - 2017 & 2018
CBG Building Company Construction Scholarship - 2016 & 2017