Thesis Report *Spring 2009*

THE DETROIT INTEGRATED TRANSPORTATION CAMPUS

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Detroit Integrated Transportation Campus - Detroit, MI

Shane Goodman

Sponsored By
Barton Malow Company

Construction Management

www.arche.psu.edu/thesis/eportfolio/2008/portfolios/smg5003

Project Team

Owner	- The State of Michigan
Architect	- Barton Malow Design
Structural Engineer	- Desai Nasr Consulting
Mechanical Engineer	- Sellinger Associates
Electrical Engineer	- Berbiglia Associates
General Contractor	- Not Selected

MEP System

HVAC - Two 6,505 CFM Rooftop AHUs to supply operations zone, and two 16,430 CFM Rooftop AHUs to supply non-operations zone. VAV boxes with reheat to control room temperature and save energy.

Plumbing - Two 44 GPM boilers to heat hot water supply and chilled water supplied from city utilities. Sloped sanitary and storm drainage lines.

Power - 1000 kVA 480Y/277V primary feeder
480Y/277V Diesel Generator backup
Series of 3-phase transformers
Three 3-phase 277/480V panel boards
Eleven 3-phase 120/208V panel boards

Lighting - Outdoor surface mounted metal halide lamps. Compact fluorescent lighting of office space

Project Features

Construction Date - October 2008 to October 2009
Overall Project Cost - $12,000,000
Project Size - 2 Floors, 45,097 Total Square Feet
Delivery Method - Design-Bid-Build (Lump Sum Contract)

Architecture

Design Executive - Algis Bublys

Designed to have an urban feel, the DITC is pushed up against the street, and lengthened to run the whole block. Extruding sun shades and a yellow reveal on the facade accentuate the building's length. The building's facade consists of Metal Panels, Glass Curtain Wall and Brick Veneer, and the Roof of Single Ply PVC Roofing Membrane on Rigid Insulation.

Structural System

A Cast in Place Conrete footing and grade beam foundation support a Structural Fame constisting of Wide Flange Structural Steel Columns and Beams with Open Web Joists integrated into the roof support. The First Floor is Concrete Slab on Grade, and the Second Floor and Roof are both Composite Slab on Deck.

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Executive Summary

This report contains a comprehensive analysis of critical industry issues and the design and construction of the Detroit Integrated Transportation Campus (DITC). A project overview of the DITC is followed by three areas of analysis. A construction management emphasis will be the main focus of analysis for each area.

The depth analysis of this report explores the critical industry issue of inadequate interoperability in the capital facilities industry, and specifically the inadequate interoperability due to a lack of planning for the execution of Building Information Modeling (BIM) on facilities projects. This research falls under an effort by the Computer Integrated Construction Group to develop a BIM Execution Planning Guide, which will aid the creation of a BIM execution plan in the early stages of a project, and is intended for facility owners, designers, contractors, subcontractors and manufacturers. This research looks at the development of a generic process map for 4D modeling, and applies the generic map to develop specific process maps for utilizing 4D modeling on the DITC project. Also, a Model Progression Requirements document was developed to aid project participants in planning the development of a model for different BIM uses throughout a project's lifetime. The Model Progression Requirement was applied to the DITC project, and completed for three different BIM uses. It is recommended that the DITC project uses the model created in design to aid in the construction of the building. Ultimately, it is recommended that the facilities industry should increase the use of 4D modeling, utilize process maps to plan for BIM uses, and document the planned progression of building information models for projects that have multiple BIM uses.

The DITC was originally planned to start construction in October, 2008; however, due to complications with the general contractor bid process, the construction has yet to begin as of March, 2009. In order to increase the speed of construction on the DITC, and help the project finish before the planned one year construction period, prefabrication of building systems was analyzed for the DITC.

One analysis looks into replacing the typical brick on metal stud façade of the DITC with precast brick panels. The assessment of this analysis revealed that precast brick panels would increase the project's cost by $ 10,613, decrease the building's annual operation costs by $453, and decrease the overall project schedule by 3 construction days.

The other prefabrication analysis looks into replacing the typical drywall on metal stud interior walls of the DITC with a modular wall system. The assessment of this analysis reveals that a modular wall system would add to the sustainability and flexibility of the interior spaces, increase the project cost by $48,628.71, and decreases the project schedule by 6 days. Assuming a 10% per year move rate, the upfront increase in cost for the modular wall system could be recovered in a 60 month payback period due to tax and renovation savings.

Acknowledgements

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Penn State BIM Execution Planning Research Team

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Professional Organizations

Barton Malow Company
State of Michigan, Design and Construction Division
National Precast, Inc.
THERMOMASS Building Insulation Systems
Environmental Wall Systems
Exponent Engineering and Scientific Consulting
The Charles Pankow Foundation
The Construction Industry Institute
Penn State OPP
The Partnership for Achieving Construction Excelence
The buildingSMART alliance

Special Thanks To

Fellow AE Students

1 - Project Introduction

The Detroit Integrated Transportation Campus (DITC) is a two-story, 45,000 Square Foot office and operations building for the State of Michigan. Located within the building are offices and a 24 hour operations center for the Michigan Department of Transportation. The building also includes a 24 hour operations center for The Michigan State Police, which includes space for police control, dispatch, warrants, and server storage.

The original design intent of the building was to achieve LEED certification, however, due to budget constraints the building is no longer seeking LEED certification. The DITC was still designed with sustainability in mind, and features such as the sun shades and efficient HVAC system reflect this goal. Building Information Modeling was integrated into the project's design by the Architect, Barton Malow Design, and the Structural Engineer, Desai Nasr Consulting Engineers. Both parties coordinated the design with 3D models of their systems.

The DITC is located within the city limits of Detroit Michigan, south of the city center, on Fort Street. It is conveniently located less than one block from the John C Lodge Freeway, a major highway in Detroit. The city is attempting to rebuild the area where the DITC Is located, as it was once a very industrious part of the city. The location of the DITC can be seen below in Image 1.1.

Image 1.1, DITC Location, Google Maps

Construction of the DITC was originally scheduled to start in early October, 2009; however, complications with the general contractor bid process have held back the start date. As of March, 2009 a subcontractor has yet to be selected, and a start date has yet to be determined. Due to this delay some information about the schedule, cost, and construction methods were not yet obtainable.

2 - Project Overview

2.1 - Building Design

Architectural design of the Detroit Integrated Transportation Campus was based off the program requirements from the State of Michigan. Barton Malow Design knew the building site and requirements, and Algis Bublys, the design executive, created the DITC with both in mind. The building was designed to have an urban feel; therefore the building was pushed up against the street, and lengthened to run the whole block. This also reflects the design of the greyhound bus station in Detroit, a basis for the design of the DITC. Two stories was a product of the length and the program requirements.

The building envelope of the DITC is made up of three different wall systems and a single roof system. The roof system is a flat PVC roofing system comprised of a PVC membrane, rigid insulation, and metal deck. Three different wall systems include a glass curtain wall system, a masonry wall system, and a metal panel wall system.

Structural steel frame is the main support for the 2-story 45,000 square foot building. Structural steel for the building is mostly W-Shapes: ASTM A992, Grade 50. Open web joists, which include K-series steel joists and Long-span steel joists, are also integrated into the roof support. Bracing for the structural steel frame is provided by W-Shape rigid frames, and include no cross bracing members. There are six rigid frames running North and South that span the whole width of the building at grid lines 18, 14, 9, 7, 5, and 1. There are also six rigid frames running East and West that each span one to three bays. The second floor is mostly comprised of 3 inches of regular weight concrete with welded wire fabric, on 3" 20 gauge galvanized composite steel deck. The roof of the DITC is comprised of 3 ½ inches of regular weight concrete with welded wire fabric, on 2" 20 Gauge Epicore steel roof deck.

HVAC for the DITC is regulated by four central rooftop air handling units that are fed from city utilities. Two units weigh 3,500 lb and supply 6,505 CFM to service the operations zone and the other two units weigh 7600 lb and supply 16,430 CFM to service the non-operations zone. Cooling for each unit is controlled by a supply-air refrigerant coil and an outdoor-air refrigerant coil, which each circulate R-407C Refrigerant. Heating for each unit is controlled by factory assembled gas furnaces, which are fueled by natural gas supplied from city utilities. Variable air volume (VAV) boxes with reheat are used to control the temperature throughout the different rooms in the building. These VAV boxes allow for a constant supply of air from the air handling units, while varying the amount of air flow for each room to control specific room temperatures. The boxes have hot water reheat to recycle return air, and save energy the Air Handling units would have to expend to heat 100% outdoor air. Four cabinet unit heaters are used to heat the stairwells and vestibules. These units are supplied with hot water from the boilers.

Electricity to the DITC is fed by a 1000 KVA, 3-Φ 480Y/277 V Primary Feeder with power supplied by DTE Energy. The 15 KV Primary Switchgear is located outside the building, and the Electrical Room, which houses the electrical distribution equipment, is located on the second floor in the North East corner of the building. Emergency backup is provided by an outdoor 3-Φ 480/277 V Diesel Generator. To ensure constant power to the buildings computer systems, an Uninterrupted Power System is located in the buildings Server Room.

Lighting is provided to the DITC site and exterior by Metal Halide Lamps. The south entry ramp is illuminated with metal halide lamps that are recessed in the building's exterior façade. Inside, most of the DITC's office and operations spaces are lit with compact fluorescent lamps recessed in box fixtures in these spaces hung ceilings. Open office area is also illuminated with compact fluorescent lamps housed in low profile continuous row fixtures which are hung at 9 feet above the finished floor. These fixtures are hung from the ceiling above with air craft cable mounting. Hallways and common spaces in the DITC are lit with metal halide lamps in round, wall wash fixtures that are recessed in the ceiling.

Fire suppression for the DITC was designed to be an automatic wet pipe sprinkler system that can provide a flow of 1800 GPM with a density of .2 GPM per square foot. Both floors of the DITC have a full building fire alarm system, with visual and audible alarms placed throughout the building. These alarms are all connected to four fire alarm panels, with two located on each floor.

One hydraulic elevator located in the center on the north side of the building, which services both floors. The elevator is an under-the-car single cylinder hydraulic elevator with a rated load of 3,500 pounds, and the car's interior is 80 inches wide, 51 inches deep, and 94 inches tall. It is incased in a shaft wall and supported by tube steel that runs the whole height of the shaft.

2.2 - Project Schedule

Barton Malow Design finished the design of the Detroit Integrated Transportation Campus for the State of Michigan in August of 2008. Construction was set to start at the beginning of October, however complications with the general contractor bid process have held back the start date, and it is yet to be determined. The detailed schedule is based on 5-day work weeks, was created using Primavera Project Manager, and can be found in *Appendix A*. It is based off the original start of construction, which is October 1st, 2008, and is divided into the categories shown below in Figure 2.1.

	Start	Finish
Design and Preconstruction	9/3/2007	6/5/2009
Site Work	7/28/2008	12/16/2008
Structure	11/12/2008	2/3/2009
Exterior MEP	12/16/2008	2/13/2009
Building Enclosure	1/15/2009	4/7/2009
Site Paving and Landscaping	4/8/2009	1/23/2009
Interiors	1/26/2009	9/1/2009
Completion and Closeout	6/29/2009	10/13/2009

Figure 2.1, Schedule Summary.

In order to finish on time the trades were scheduled to move into an area once the predecessor trade finishes in that area. Lag times were applied at the beginning of certain trade activities to ensure these trades can move throughout the building without interruption. The nature of this scheduling method leads to the fact that the critical path only exists in the first couple of sequences for most activities. Once these activities have moved past the first couple of sequences, the next activity begins in that area and the critical path is passed to that activity. It is therefore imperative for these trades to begin on time and get a good start on their activity. Exceptions to this are the exterior stud framing, brick masonry, interior stud framing, and drywall activities. Due to their sequence duration and critical connections with other activities, these activities are on the critical path for most or all of their duration on site.

As shown in Figure 2.2 below, flow of construction for all trades is from East to West, therefore the trades can closely follow their predecessors, starting on the East side of the building. Seventeen different work areas (noted as sequences in the detailed schedule) were defined to break up the work throughout the building. The structure and building enclosure phases of construction follow a tight schedule, allowing the building to be enclosed early and the interior trades to begin their work.

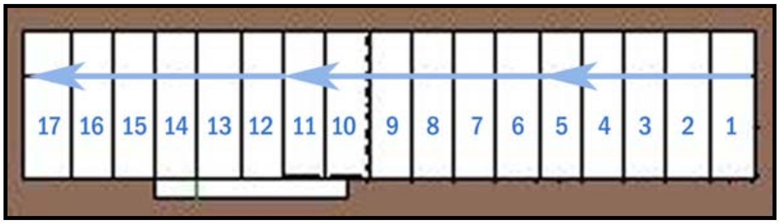


Figure 2.2, Sequence Breakdown

2.3 - Project Cost

All costs below do not represent the actual costs of the building. The estimates were obtained from the very early stages of design and do not represent the actual construction costs or budget for the Detroit Integrated Transportation Campus.

Construction Cost (CC)

Construction Cost is the total cost for construction of the building. It does not include land costs, site work, permitting, or design fees.

Total Construction Cost = $9,480,000

Construction Cost per Square Foot = $9,480,000 / 45,378 SF
= $208.90 per Square Foot

Total Project Cost (TC)

Total Project Cost = $12,000,000

Total Cost per Square Foot = $12,000,000 / 45,378 SF
= $264.44 per Square Foot

Building Systems Cost

Mechanical Systems Cost = $1,811,700

Mechanical Systems Cost / SF = $1,811,700 / 45,378 SF
= $39.92 per Square Foot

Electrical Systems Cost = $1,376,000

Electrical Systems Cost / SF = $1,376,000 / 45,378 SF
= $30.32 per Square Foot

Structural Systems Cost = $2,969,500

Structural Systems Cost / SF = $2,969,500 / 45,378 SF
= $60.44 per Square Foot

2.4 - Site Layout

Located in downtown Detroit, the Detroit Integrated Transportation Campus has both positives and negatives that come with the project's location. The site is less than one block from the John C Lodge Freeway, which makes it a great location for workers to get to site and for site deliveries to be made. However, the site is located in a section of Detroit where crime will be a concern. A site fence and security cameras will be installed early in the construction of the building to help lessen the possibility of crime on site.

Even though the Detroit Integrated Transportation Campus is an urban construction project, site space is not an issue for this project. The on-site future parking lot to the North of the building is large enough to provide space for parking, trailers, dumpsters, and on-site storage. A temporary road through the middle of the site keeps site traffic in one direction, and allows for easy site deliveries from Interstate 75. A temporary site fence surrounds the entire site to keep pedestrians and crime off site.

During the Superstructure phase of construction the major activities taking place will be concrete foundations, slab on grade, steel, metal deck, and slab on deck. Site traffic will consist of concrete deliveries, steel deliveries, and a crane for steel erection. The heaviest lift is 3496 lb at a maximum distance of 75 feet, which requires a 50 ton crawler crane with an 86' boom. A snapshot of site layout during the superstructure phase can be found below in Figure 3.

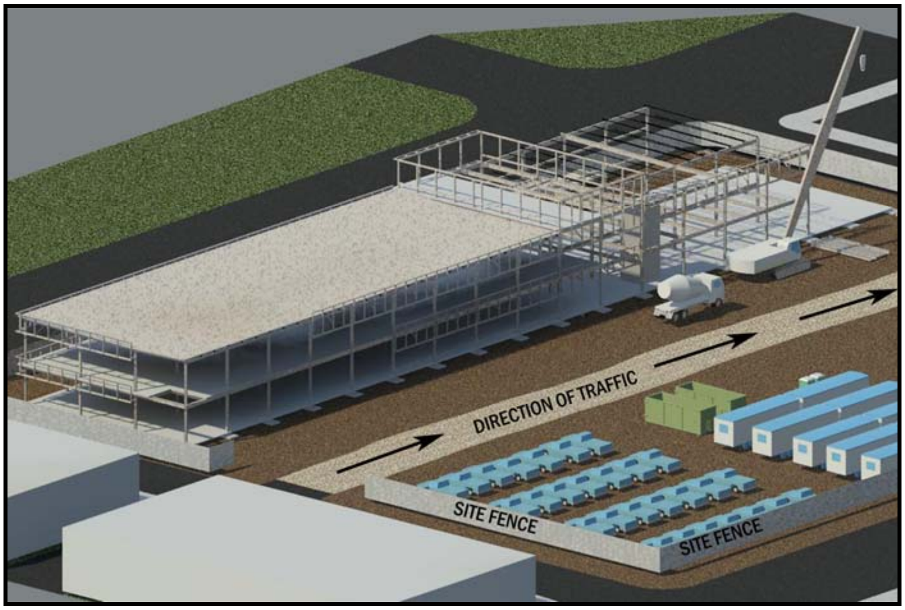


Figure 2.3, Superstructure Site Layout

2.5 - Project Delivery

The Detroit Integrated Transportation Campus is being delivered using a Design-Bid-Build project delivery system. Barton Malow Design was chosen to be the architect for the project, and due to complications with the bid process, a general contractor has yet to be selected. The project contract requirements can be seen below in Figure 2.4.

One special requirement on the DITC project is the contract between BMD and Desai Nasr Consulting, the structural engineer. BMD planned to design the building in 3D using Autodesk Revit Architecture, and wanted to coordinate this effort with the structural engineer. Therefore, Desai Nasr Consulting was contracted to provide a structural model of the design in a 3D format that could be coordinated with the architectural model. No structure has been set so the models can be used by the general contractor or subs for construction BIM uses.

The subcontractors will be selected using a standard bid process in which the lowest bidder will be selected to perform the required work. The contractors selected for the DITC have to be fully bonded with payment and performance bonds. In addition to being fully bonded, the contractors will be required to have workers compensation, employers' liability, commercial general liability, and automotive liability.

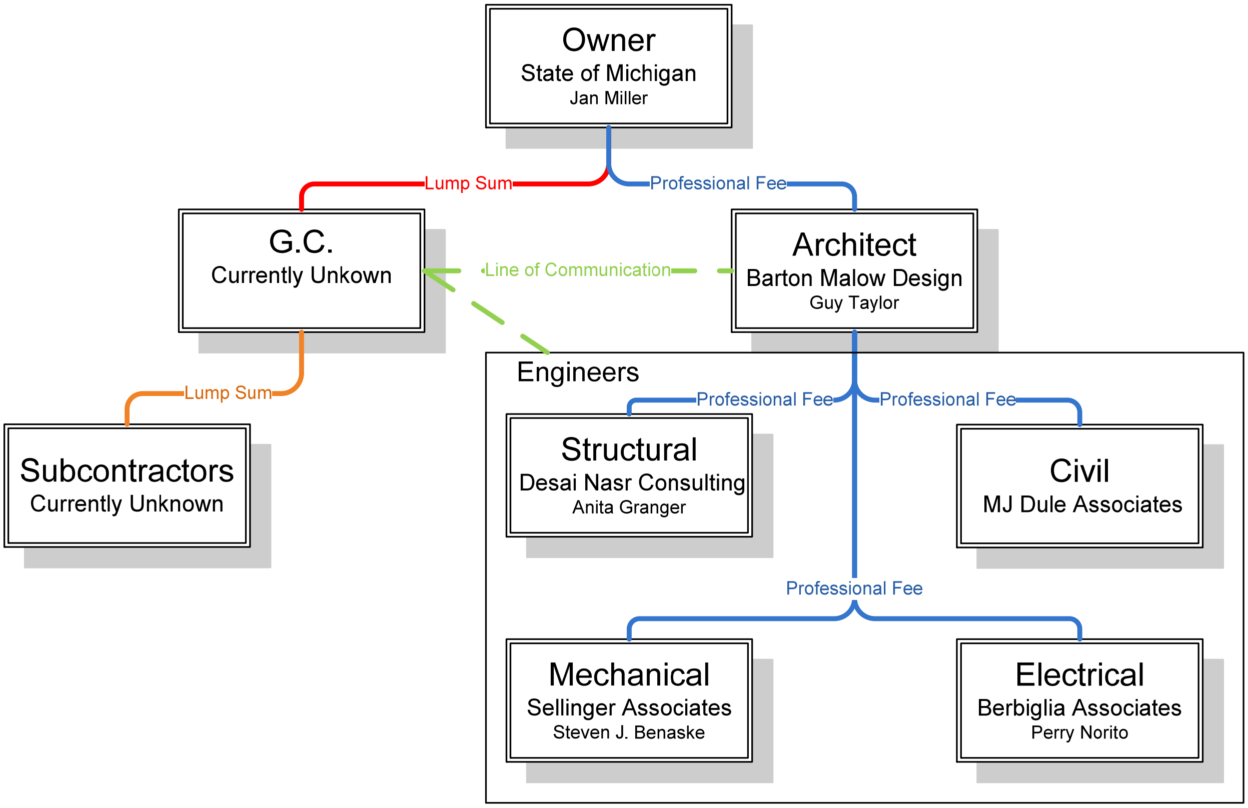


Figure 2.4, Project Contract Requirements

3 - Designing the Design Model (With a Focus on 4D Modeling)

3.1 - Introduction

According to a National Institute of Standards and Technology study, “Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry – 2008”, the estimated cost of inadequate interoperability among computer-aided design, engineering and software systems is $15.8 billion per year in the U.S. Capital Facilities Industry. In order to combat this loss due to inadequate interoperability, many AEC and Facilities organizations have begun efforts to improve the interoperability of software systems and the facility construction process.

One effort by the buildingSMART alliance is focused on the industry wide adoption of Building Information Modeling (BIM). This effort is aimed at open interoperability and full facility lifecycle implementation of building information models in order to obtain lowest overall cost, optimum sustainability, energy conservation and environmental stewardship. As a part of the buildingSMART alliance effort, the Computer Integrated Construction (CIC) Research Group at Penn State is currently working on The BIM Execution Planning (BIMex) research project. The goal of this research is to develop a BIM Execution Planning Guide to aide in the creation a BIM execution plan in the early stages of a project, which is intended for facility owners, designers, contractors, subcontractors and manufacturers. A BIM Execution Plan would help project participants reach decisions on BIM implementation for the different stages of a project.

The research of this thesis analysis falls under the goal of the BIMex research project, and specifically under the task of developing a process for BIM planning on a project. If the goal of a project team is to use multiple BIM uses at multiple stages of a project, it is important for that team to plan a process that is customized for that project. The planned process should include BIM supported tasks with the exchange information needed between the tasks. The BIMex research team selected process mapping as a way to visually create and convey BIM work processes. Process mapping can help to establish a logical sequence of tasks, identify the process inputs, identify the process outputs, and identify the team participants (agents) responsible for the tasks.

One goal of this research is to utilize process mapping in order to distinguish the difference between creating a design stage building information model and a for construction building information model. Designers typically build a model for design intent purposes only; and the content, level of detail and grouping of a design stage model does not typically meet the needs for that model to be used for construction BIM uses. This problem is caused by the fact that the designers typically lack the downstream information from contractors and manufactures required to build a model for construction.

BIM uses in construction include 3D coordination, 3D construction system design, unit price estimating (5D), 4D planning and site utilization planning. This research will focus on the use of 4D planning for construction. 4D planning is defined as a 3D building model linked to a construction schedule in order to visually simulate the progression of construction over time. Process maps were created to convey the process of developing a 4D model. The Model Progression Requirements Document was also developed for this analysis in order to identify the necessary model content, level of detail, and grouping requirements of a model used for different BIM uses at different stages of a project.

The Detroit Integrated Transportation Campus (DITC) project created a building information model for 3D design coordination during the design phase. This model includes the architectural components (exterior walls, roofing, windows, doors, interior walls, ceilings, flooring, etc.) and structural components. The model was only used during design for coordination, and within the design-bid-build delivery, the project has no plan of handing the model to the contractor for use in construction. A "what-if" scenario was taken for this research to analyze the process of using the DITC model during design to create a 4D Milestone Model, and also using the model for construction as a 4D Detailed CPM model. Two process maps for developing a 4D milestone model and a 4D detailed CPM model were compared to highlight the difference in tasks, inputs, outputs and agents for each process. Also, the Model Progression Requirements Document was used to compare the differences of the model content, level of detail and grouping requirements between the 3D Design Coordination Model, 4D milestone model and 4D detailed CPM model.

3.2 - Process Mapping

The BIMex research team selected process mapping as a way for project teams to visually create and convey BIM work processes for a company or a project. Process maps can be used on a company level to establish typical work flows for specific BIM uses that a company utilizes, and set a company-wide standard. Process maps can also be utilized on a project level to establish the work flows for project specific BIM uses.

There is not a standard type of process modeling for the Construction Industry. For precedence the BIMex Research Team looked at different process modeling types that have been created in the Construction Industry. The BIMex team reviewed the Integrated Business Process Model (IBPM) developed by Victor Sanvido et al. (1990) at Penn State, which utilizes IDEF0 modeling methodology, to convey the process required to provide a facility. The team also reviewed the Generic Design and Construction Process Protocol, developed by a research team at the University of Salford, which breaks down the design and construction process using no particular modeling methodology. The BIMex team selected to use Business Process Modeling Notation (BPMN) for the creation of process maps, specifically utilizing TIBCO, a process modeling software. The goal of the BIMex Research Project is to create generic process maps for multiple BIM uses, which will be utilized by project teams as templates to create project specific process maps.

Chitwan Saluja, a member of the Computer Integrated Construction (CIC) Research Group and BIMex Team at Penn State, created a procedure to develop process maps for BIM task execution. The procedure along with a format that divides the process maps into four swim-lanes (External Info, Enterprise Info, Process, and BIM Info Ex.), will allow teams to map project specific BIM tasks. The six step procedure is as follows:

- Step 1: Hierarchically decompose the task into a set of activities.
- Step 2: Define the dependency with other activities.
- Step 3: Break up every activity within the task (repeat a-c)
  - a: RESOURCE: Identify the resource to be used
  - b: RESULT: Define intermediate and final results in the form of BIM models, and information exchange required for the activity.
  - c: AGENT: the agent performing the activity.
- Step 4: Check if the results have been met – e.g.: decision making criteria, entry – exit criteria.
- Step 5: The feedback to be provided to other agents concerned (e.g.: the client for his approval of the estimation, the designer, etc.)
- Step 6: Document, review and redesign this process for further use.

As part of the BIMex Research Project and for this research, a process map for developing a 4D model was created utilizing the process and format developed by Chitwan Saluja. This process map, titled “Develop 4D Model”, is available in Appendix B and was created as a generic process map for an ideal project delivery such as Integrated Project Delivery. The process map is based on ideal project delivery to promote such delivery; however, it can easily be edited to represent other deliveries such as Design-Bid-Build. The process map was created as a generic map so that it can be used at any stage of a project, and for different levels of 4D modeling. In order to create a generic process map no specific agents were identified, tasks were kept generic, and specific outputs were not identified.

The DITC model was only used during design for coordination, and within the design-bid-build delivery, the project has no plan of handing the model to the contractor for use in construction. A “what-if” scenario was taken for this research to analyze the process of using the DITC model during design to create a 4D Milestone Model, and also using the model for construction as a 4D Detailed CPM Model. In order to visually represent the process of creating each 4D model, process maps were created for developing a 4D Milestone Model during design, and developing a 4D Detailed CPM Model for construction. These process maps are titled “Develop 4D Milestone Model” and “Develop 4D Detailed CPM Model”, and are available in Appendix B. In order to create each of these project specific process maps; specific agents were identified for tasks, tasks were changed to represent each model’s development, and specific outputs were identified. Editing the generic map to represent these specific processes was a simple task, which helps to validate the process of using generic process maps to create project specific maps.

3.3 - Model Progression Requirements

This research also focuses developing a tool to define the progression requirements of a model. If a project intends to utilize multiple BIM uses on a project; either multiple models must be created for those uses, or ideally, one project model must be capable of being utilized for all project BIM uses. Because models for different uses and different stages of a project require different information, level of detail and grouping requirements, the model must be edited for each BIM use. Defining the different requirements for the progression of a BIM model was identified as an industry wide problem by the BIMex Team and the BIMex advisory board, comprised of industry BIM experts.

In order to help define the progression requirements of a model for different BIM uses on a project, the American Institute of Architects (AIA) published the AIA Document E202-2008: BIM Protocol Exhibit. AIA Document E202-2008 utilizes a spreadsheet to define the Level of Detail (LOD) and Model Element Author (MEA) for the different model elements of a project Building Information Model, and is available in Appendix C. The table prompts the user to identify each project phase; and the LOD and MEA required for each model element at the end of each phase. Document E202-2008 organizes the different model elements in the table by CSI UniFormat™. The document also indentifies different levels of detail (increasing in detail at 100, 200, 300, 400 and 500) for multiple BIM uses. These uses include Design and Coordination, 4D Scheduling, Cost Estimating, Program Compliance, Sustainable Materials and Environmental. Table 3.1 below represents the defined levels of detail for 4D Scheduling.

	Level 100	Level 200	Level 300	Level 400	Level 500
4D Scheduling	Total project construction duration Phasing of major elements	Time-scaled, ordered appearance of major activities	Time-scaled, ordered appearance of detailed assemblies	Fabrication and assembly detail including construction means and methods	

Table 3.1, Level of Detail for 4D Scheduling, AIA E202-208: BIM Protocol Exhibit

After review of AIA Document E202-2008 with John Messner Ph.D., BIMex Project Advisor, it was determined that the document was missing some key features for a model progression document. The problems with AIA Document E202-2008 are as follows:

- Although the CSI UniFormat™ is effective at dividing the work packages of a construction project, it is not as effective at defining the model elements required for many different BIM uses.

- Project phases do not successfully divide the requirements of a BIM model for different uses. Different uses during the same project stage may require different model requirements.

- The generic levels of detail (100-500) can not entirely define the detail requirements of model elements for different BIM uses, and there is no space for element grouping requirements.

In order to cover the deficiencies of AIA Document E202-2008, the Model Progression Requirements (MPR) Document was developed for this research. The document is a spreadsheet, similar to AIA Document E202-2008, which project participants complete to define the progression requirements for a Building Information Model throughout a project's lifecycle. A blank MPR document is available in Appendix C. The differences from the AIA Document are as follows:

- The Model Elements are organized using CSI UniFormat™, along with added categories that include elements missed by AIA Document E202-2008 and CSI UniFormat™. These added categories include Construction Systems and Equipment, Temporary Safety and Security, Temporary Facilities and Weather Protection, Construction Activity Space, Facility Space, and Project Information. Also, all categories are not sub-divided beyond the first level of CSI UniFormat™ as they are in AIA Document E202-2008; therefore the user can define sub categories as needed.

- The model progression stages are not divided by project stage; however, they are divided by BIM use.

- Grouping was added as a definition field for model elements of a particular BIM use. Level of Detail is important to define; however, it is also important to define grouping requirements as they will be different for different BIM uses.

- Model Element Author is not included in the MPR, as a Model Element Author would be defined by work package and is not necessary for a model progression document.

- The Level of Detail and Grouping for each element and BIM use is defined with the users own terms. This allows the user to define these characteristics in detail, and with their own project specific terms.

In order to complete the Model Progression Requirements a user would follow the steps outlined below:

1. Define the intended BIM uses for a project across the top of the BIM Use columns of the spreadsheet. These uses should be listed in chronological order so the progression of the model uses run from left to right.

2. Identify the necessary Model Content down the left side of the spread sheet.

3. Work through each BIM Use defining the Level of Detail and Grouping requirements for each Model element.

The activity "Establish Model Progression Requirements" within the process map for "Develop 4D Model" is a reference to using the MPR Document. A sub-process map was created for this activity, and walks a user through the steps of completing the document. This process map, “Establish Model Progression Requirements”, is available in Appendix C.

In order to substantiate the usability of the MPR, the document was applied to the DITC project’s use of Design Coordination, and the “what-if” scenario of utilizing the model for a 4D Milestone Model and a 4D Detailed CPM Schedule. The three uses Identified for the DITC in the MPR Document were Design Coordination, 4D Milestone Model, and 4D Detailed CPM Model. The requirements for Design Coordination were filled out in retrospect, referencing the model that had been produced for the design of the project, and the requirements for both 4D models were completed also. The completed Model Progression Requirements for the DITC project is available in Appendix C, titled “Model Progression Requirements – Detroit Integrated Transportation Campus”.

When reviewing the completed MPR for the DITC the differences between Model Content for each BIM use is obvious. The Level of Detail remained the same across all BIM uses, as neither 4D model required more LOD than was defined in the design model. However, the Grouping of Model Content changed drastically for each BIM use. The reason behind this is that the design model was not created in mind of utilizing it for a 4D model, and the grouping requirements for a 4D Milestone Model and a 4D Detailed CPM Model differ due to differences in the breakdown of construction activities. When a Grouping requirement stated to group elements, it inferred the elements were too small, and needed to be grouped with other elements. Conversely, when a Grouping requirement stated to divide elements, the elements were too large, and needed to be divided into different groups. The added Model Content categories became very valuable for the use of the MPR. Especially the Construction Activity Space category, as not all model content included in the schedule activities were modeled in design; therefore, allowing those activities to be modeled as simple construction spaces rather than detailed model elements. The Project Information category also became valuable in order to define the level of schedule needed for each 4D model. This category is not only valuable to the 4D modeling BIM use; for example, it could be used to define material properties for Engineering Analysis, estimate levels for Cost Analysis (5D), O&M manuals for a Record Model, etc.

3.4 - 4D Modeling

Currently in the AEC industry, the use of 4D modeling on projects is still sparse. However, as the industry is adopting the use of Building Information Modeling, 4D Modeling is becoming more prevalent on projects. Unfortunately, many industry members do not realize the potential of 4D modeling to be used throughout both the design and construction of a project. Most projects that utilize 4D modeling, have one project 4D model for visualizing the entire construction of project. This 4D model is also typically created at one level of schedule, whether it is a milestone schedule or a CPM schedule. This lack of “whole project” 4D modeling can be related to the slow acceptance of BIM and the lack of defined levels of scheduling within the construction industry.

It is very difficult to find defined levels of scheduling within the construction industry. After speaking with construction industry professionals and reviewing different literature on construction, only one source was able to produce a substantial definition for different levels of scheduling. Kevin Coyne, of Exponent, directed me towards the book "Construction Scheduling: Preparation, Liability, and Claims – Second Edition". The book defined five different levels of scheduling as follows:

Level No. 1: Executive level Master Summary Control Schedule – Consists of a bar chart of a time-scaled network of 15 to 50 activities. This level of detail and be useful for periodic management briefings and reporting.

Level No. 2: Detailed Integrated Schedule – Detailed master integrated schedule covering all phases of the project and in network format. This is the schedule that is used to plan implement and control the overall project.

Level No. 3: Contract Schedules – Schedules prepared by contracted parties for each contract involved in the overall project. Major contracts are usually in networking format. Some exceptions may be made for small contracts, which may use bar charts.

Level No. 4: Two- or Three-Week Look-Ahead Schedules – Schedules that are prepared each week and in advance of the next two or three weeks of planned efforts. These may be prepared for each of the major construction trades and may be in bar cart form or in simple network abstracts. These schedules should include the identification of all required resources (equipment and manpower by craft/trade) on a daily basis.

Level No.5: Daily Work Schedules – These schedules should be prepared at least one day in advance and with the participation of field superintendants, area supervisors, craft supervisors, foreman, and so on. The objective is to plan, schedule, and coordinate on a daily basis the required labor, construction equipment, and materials needed for each work task. In addition, they need to communicate work task versus cost accounting information essential for capturing and documenting actual field costs. This includes not only base contract work, but also changes, problems, and areas of potential disputes. Such schedules can also aid in capturing manpower data and measuring labor productivity. Because of the extent of construction brokering being used today, these schedules are not common on construction projects.

These different levels define the different types of schedules that can be used to communicate different levels of scheduling on a project; however, they do not define the level of schedule detail for a project. According to the book, level of schedule detail should be determined by including as many activities as seem necessary to effectively plan, schedule, and control the overall project. These different levels of schedule can also be applied to 4D modeling to illustrate the many different 4D models that could be utilized on a project. The effort to have different levels of schedules and 4D models on a project would not only help plan, schedule, and control the overall project, but could visually communicate the schedules to project participants. In order to tie the defined levels of schedule to the DITC Model Progression Requirements, the level of schedule was noted in the Project Information category under Model Content. The 4D Milestone Model was associated with an Executive Level no. 1 Master Summary Control Schedule, and the 4D Detailed CPM Model was associated with a Level no. 2 Detailed Integrated Schedule.

3.5 - Summary & Conclusions

A generic process map was created for developing a 4D Model for this research and the BIMex Research Project, just as other BIM use process maps will be created for the BIMex Research Project. These generic process maps will accompany the BIM Execution Planning Guide, utilized as template process maps for project teams to create project specific processes. Editing the generic “Develop 4D Model” process map to represent the specific processes, “Develop 4D Milestone Model” and “Develop 4D Detailed CPM Model”, was a simple procedure, which helps to validate the idea of using generic process maps to create project specific maps.

The AIA Document E202-2008: BIM Protocol Exhibit is a good tool for defining the progression of a model throughout a project; however, it is missing key elements in order to cover a wide-range of BIM uses and model content; and the document doesn’t allow for the necessary description to properly define Level of Detail for model content. In order to cover the deficiencies of AIA Document E202-2008, the Model Progression Requirements Document was developed. To substantiate the usability of the MPR, the document was applied to the Design Coordination of DITC model, and the “what-if” scenario of utilizing the model for a 4D Milestone Model and a 4D Detailed CPM Schedule. The MPR for the DITC conveyed the progression of the model throughout the three uses, and defined the model content requirements with a detailed, project specific method.

The DITC has yet to begin construction, and the project has no plan of passing the model to contractor to be utilized for construction. This process would fall under the inadequate interoperability in the U.S. capital facilities industry, as defined by the National Institute of Standards and Technology study. Therefore, the model should be passed on, with a “no-liability” clause, for the contractor to use as they please. As it is a Design-Bid-Build delivery, the contractor selected may have no BIM experience; however, no matter the experience level, the contractor should attempt to use the model in construction.

As an effort to implement the industry wide adoption of Building Information Modeling (BIM), through open interoperability and full facility project lifecycle, the AEC industry should utilize process mapping and model progression documentation to develop BIM Execution Plans on both a company and project level. Process maps and model progression documents could be created on a company level to better define company specific BIM processes, while also created on a project level to define project specific BIM processes. Ideally, BIM participants on a project would combine their company process maps and model progression documents to create project specific documents.

The lack of “whole project” 4D modeling can be related to the slow acceptance of BIM and the lack of defined levels of scheduling within the construction industry. By defining levels of scheduling and relating those levels to the creation of multiple 4D models, the construction industry would not only benefit from improved planning, scheduling and project control; but could also benefit from improved communication on projects.

4 - Prefab with Precast Brick Panels

4.1 - Introduction

The Detroit Integrated Transportation Campus (DITC) was to begin construction in October of 2008. However, due to complications with the General Contractor bid submissions, as of March, 2009 the project has yet to begin construction. Due to this delay, the State of Michigan will not only expect the construction to be completed within the expected one year construction period, but would find it beneficial to accelerate the construction and complete the job as soon as possible.

One of the current trends within the architecture and construction industry is leaning project delivery through the prefabrication of building systems. Prefabrication involves fabricating a system off site, bringing it to site in pieces, and installing those pieces on site. This process ensures quality because the systems are fabricated in shops; it also saves cost of on-site construction, and increases the rate of construction. The design of the Detroit Integrated Transportation Campus currently has typical brick on metal studs, which makes up one-third of the building's façade, with the rest of the building comprised of metal panels and strips of curtain wall windows. The brick on metal stud is currently on the critical path, and if the construction of this activity is expedited, the overall project schedule can be reduced.

Precast brick panels are fabricated in shops, and shipped to site to be erected, quicker than typical brick on metal stud is constructed on site. Because they are fabricated indoors, the quality and durability of precast brick panels is very high. Not only do precast brick panels increase the speed of construction when compared to typical brick, but they reduce the site congestion that is associated with typical masonry construction. Also, insulated precast panels can offer high R-Values, decreasing the heating and cooling loads of a building.

National Precast, Inc., located near Detroit, MI, is a company which manufactures many types of precast concrete products, including precast brick panels. The THERMOMASS insulated precast panel system, manufactured by National Precast, was selected to replace the typical brick on metal stud on the DITC for this analysis. National Precast was selected because of its close vicinity to the DITC, and their experience with construction in Detroit. In order to fully evaluate the substitution of National Precast's precast brick panel system its application to the DITC, structural impacts, mechanical impacts, cost and schedule impacts will have to be analyzed.

4.2 - Methods

1. Research the design of the precast brick panel system.
2. Analyze the application of National Precast's precast panels to the DITC.
3. Perform a structural breadth analysis of the new precast panel system.
4. Perform a mechanical breadth analysis of the new precast system.
5. Compare the cost of precast brick panels versus typical brick on metal stud.
6. Determine the schedule impacts of the precast panels on the DITC.

4.3 - References

1. Detroit Integrated Transportation Campus, 100% Construction Documents
2. National Precast, Inc.
3. ACI Concrete Design Handbook (SP-17) 1997
4. PCI Design Handbook: Precast and Prestressed Concrete 6th Edition, 2004
5. THERMOMASS Building Insulation Systems
6. Engineering Weather Data, Mcgraw Hill
7. 2005 ASHRAE Handbook - Fundamentals
8. R.S. Means Assemblies Cost Data, 2009 Edition

4.4 - System Overview

Precast brick panels selected for the DITC are insulated precast panels, and are comprised of three layers. The exterior layer has standard size half brick, 2 ¼ inches thick, with a mortar in between and behind the brick, giving this layer a total thickness of 3 inches. The next layer is the "sandwich" insulation, which is 2 inches of blue DOW insulation. The final, interior layer is a structural concrete mix that is 5" thick. This panel composition is referred to as a 3"-2"-5" configuration, and is held together using THERMOMASS connectors. THERMOMASS connectors, are high-strength, fiber-composite connectors that penetrate the insulation layer on both sides, allowing the concrete of both faces to form to the connectors. The connectors are not only high-strength, but because they are fiber-composite, they reduce the thermal bridging that is typically associated with metal connectors. A picture of the system can be seen below in Image 4.1.

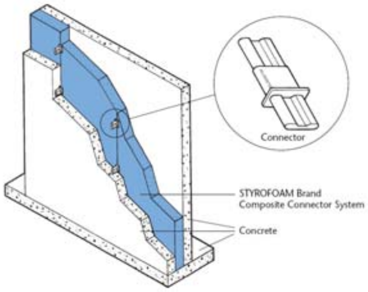


Image 4.1, THERMOMASS Precast Panel, The DOW Chemical Company

The precast brick panels are constructed in National Precast's fabrication shop, and shipped to site to be erected. In the shop, the forms are laid out so that the exterior face is down. An image of a precast shop with forms laid out for pouring can be seen below in Image 4.2. The half brick with dovetails are set in place first, and the mortar layer is poured over top. Next, the panel, with the THERMOMASS connectors, is placed on top of the mortar layer. Last, the structural concrete is poured on top of the insulation. Once the panels have cured, and the formwork is removed they are ready to be shipped to site. The panels are shipped, and erected on site with a crane. Grab points for the crane are precast into the panels initially, and after they are used to set the pieces, they are removed.

Image 4.2, Precast Concrete Forms

There are many different possibilities when it comes to the layout and sizing of precast concrete panels. For transportation purposes it is important to limit either the height or the width of the panels to 8'-6". Therefore, the panels for the DITC could either be placed vertically, the whole height of the DITC with a width of 8'-6"; or horizontally spanning column to column, and stacked, each with a height of 8' – 6". For the DITC it was chosen to stack the panels horizontally, spanning from column to column. This layout required less connections, and therefore would cost less.

One option with precast panel walls is to make them structural, and allow them to carry the load of floors and roof located at the precast walls. National Precast found a similar job to the DITC, the Penta Career Center that they had constructed, and the precast wall system selected for the DITC was based off the precast system for the Penta Career Center. The system selected for the DITC will not carry the load of the floors and roof, which will remain supported by the exterior steel columns and beams in those areas. Even though this option is possible, a large amount of stress on the panels can cause the joint caulking to strip, and possible problems with the brick it-self. The precast wall panel system for the DITC will be stacked so that the bearing of the panels is transferred to the foundation below. The panels are laterally connected to the steel, but apply no vertical loading to the steel. This was important so that the size of the steel did not need to increase. All connections for the panels are inserts that are precast into the panels, connected to the steel on-site, and allow for movement because they are slotted connections. The panels are connected to each other at the vertical joints, at the bottom and top of each panel; and laterally connected back to the structural steel at these joints. The panels are stacked directly on-top of each other, and shimmed at each horizontal joint. The bottom of the panels rest directly on the foundations below, and are grouted to the foundation. The connections, illustrated below in images 4.3 – 4.6, were selected from the Penta Career Center, and will be the typical connections used on the DITC for the panels.

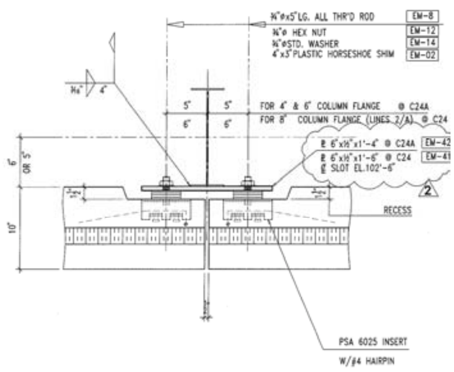


Image 4.3, Vertical Joint Connection at Column, National Precast

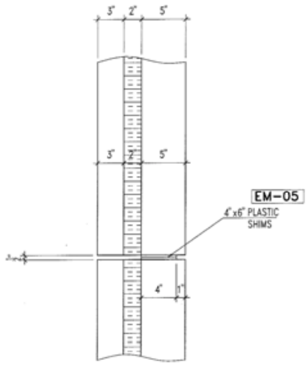


Image 4.4, Horizontal Joint Connection, National Precast

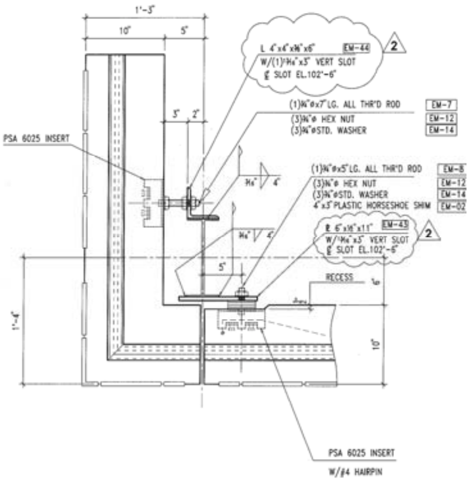


Image 4.5, Corner Joint Connection at Column, National Precast

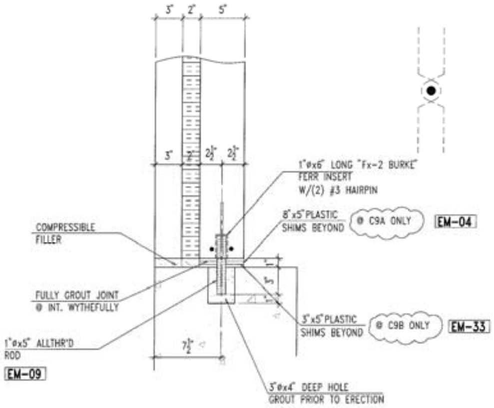


Image 4.6, Connection to Foundation at Panel Base, National Precast

The location of the brick exterior on the DITC is where the Michigan State Police control, dispatch, warrants, and server rooms are located. These interior spaces have an industrious feel with exposed ceilings, exposed structural steel, and a two-story control room. The space is currently designed with gypsum board on metal stud, to back up the exterior brick on metal stud. The precast brick panels have a finished concrete interior face, and therefore will not need gypsum board for the interior finish. The natural concrete feel will not only save money, without having gypsum board, but will add to the industrious feel of the spaces.

4.5 - Structural Impacts (Structural Breadth)

In order to assure the panel design and layout for the DITC would work, a structural analysis had to be performed. This analysis involves calculating the wind load and bearing load of the panels, and checking the panels for flexure and compression. Also, the current foundation wall supporting the original brick on metal stud had to be redesigned and checked for compression. All calculations for this structural analysis can be found in Appendix D.

Wind data for the DITC was gathered from the 100% CDs of the building. The CDs had the following data:

Basic Wind Speed (3-second gust): 90 mph
Wind Importance Factor: 1.15
Exposure Category: B
Internal Pressure Coefficient: +/- .18
Interior Zone Wind Pressure: 16 PSF
Exterior Zone & Corner Zone: 18 PSF

Wind pressure was calculated using a 90 mph wind speed, and it was found the Ps30 for the interior zone was 8.5 PSF, and the Ps30 for the exterior zone was 12.8. These numbers were well under the pressures on the CDs, therefore those numbers were used for the wind pressure.

The panels were then checked in the vertical direction for flexure and compression. In order to assure every panels design was satisfactory, a bottom corner panel, with the greatest wind load and bearing load, was checked. The panel was checked using the strip method, and a one foot vertical section of the wall was used. It was found that the ΦMn = 2.14 foot-kip and the ΦPn = 173 kips, with an As = .20 in (#4 bars every foot). After applying the wind and dead load on the panels, it was found that Mu = .305 foot-kip and Pu = 2.56 kips. An interaction curve was developed for the panel based on these figures, and is below in Figure 4.7. The graph did not have to be readjusted to represent an actual interaction curve because the design proved to be very conservative.

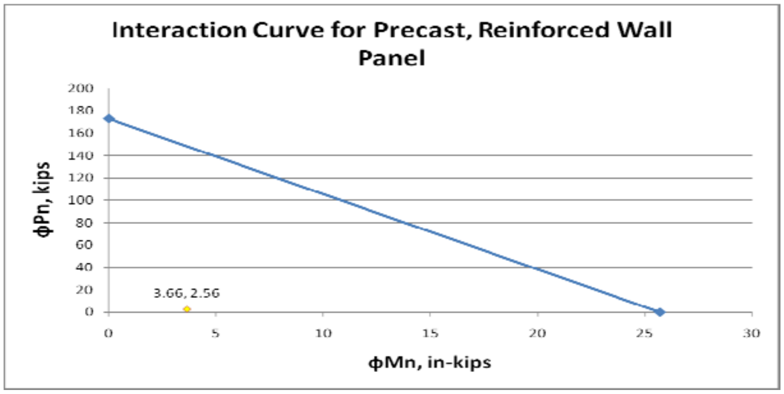


Figure 4.7, Interaction Curve for Precast, Reinforced Wall Panel

A second-order analysis of an un-braced member using the PCI Design Handbook was also used to check the design of the panels. This analysis proved to be valid with Mu = .375 foot-kips and Pu = 2.05 kips.

The panels were checked in the horizontal direction for flexure due to wind loading. This span is 22 feet, and the same ΦMn = 2.14 foot-kip could be used due to the same parameters of the vertical direction. The wind load was applied and it was found that Mu = 1.05 foot-kips, which was acceptable as it is less than ΦMn.

Foundations had to be redesigned because there was no longer a need for a brick shelf. The size of the foundation could be reduced with the panel bearing directly on the footing. Checking for compression of the footing, Vu was calculated to be .853 kips, which was less than 1/2ΦVc = 5.92 kips; therefore, the design was acceptable. The new and original footing designs are below in Figures 4.8 and 4.9.

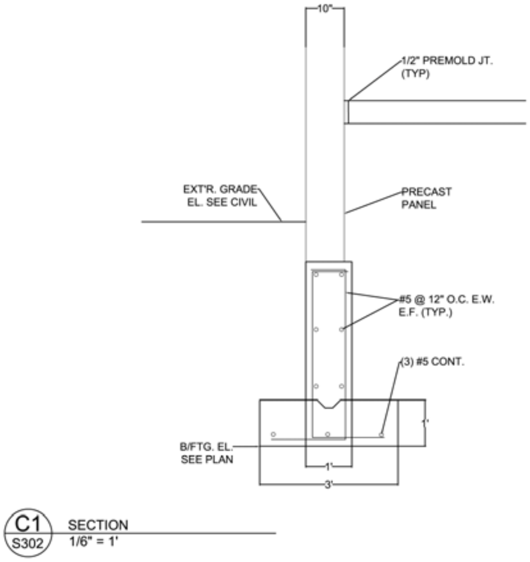


Figure 4.8, New Foundation Design for Precast Panels

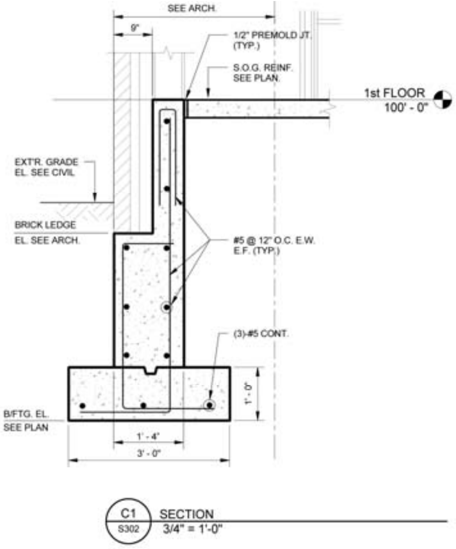


Figure 4.9, Original Foundation Design for Brick

4.6 - Mechanical Load Impacts (Mechanical Breadth)

The composition of the THERMOMASS precast panel system provides a good R-Value, which can reduce the heating and cooling loads of a building. The system offers a good R-Value because of the high R-Value of the 2" Insulation, the reduction of thermal bridging due to the fiber-composite connectors, and the increase in thermal mass due to the 5" layer structural concrete. Image 4.10 below is a thermal image of the THERMOMASS precast panel system, and it illustrates the constant R-Value of the panels as a product of the reduced thermal bridging.

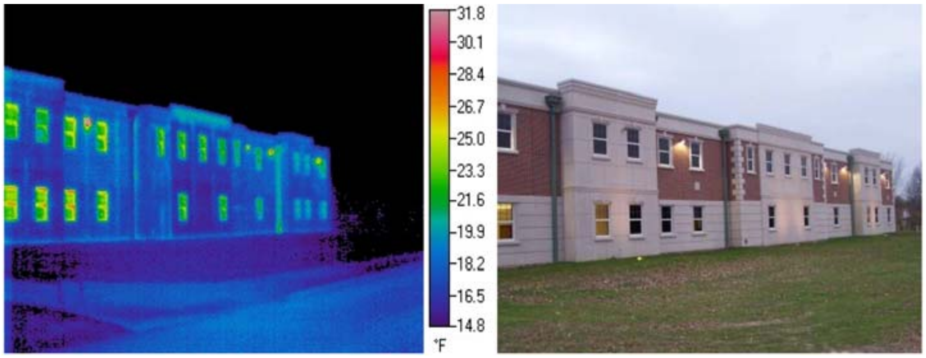
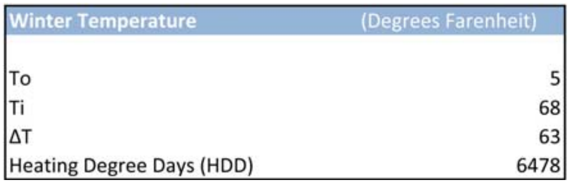


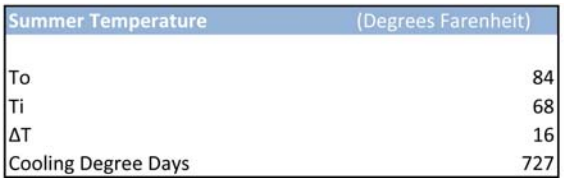
Image 4.10, Thermal Image, THERMOMASS Building Insulation Systems

In order to effectively compare the heating and cooling load difference between the typical brick on metal stud and the precast brick panels, the weather data for Detroit was obtained from the book “Engineering Weather Data”. The data below in Figures 4.11 and 4.12 represent the outdoor summer and winter temperatures, the indoor design temperature, and the heating and cooling degree days for the DITC.



Winter Temperature	(Degrees Farenheit)
To	5
Ti	68
ΔT	63
Heating Degree Days (HDD)	6478

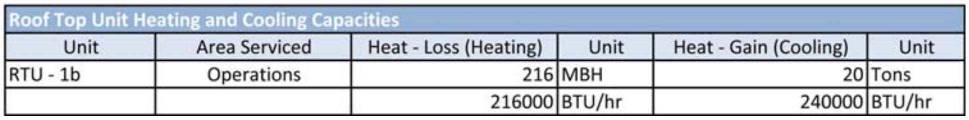
Figure 4.11, Detroit Winter Data, Engineering Weather Data



Summer Temperature	(Degrees Farenheit)
To	84
Ti	68
ΔT	16
Cooling Degree Days	727

Figure 4.12, Detroit Summer Data, Engineering Weather Data

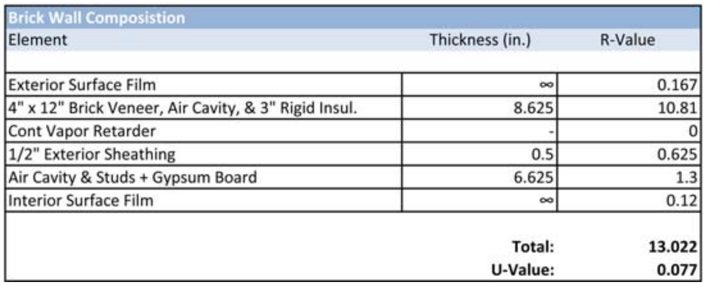
Also, to effectively compare any changes to the heating and cooling loads for the DITC, the heating and cooling capacity of the Rooftop AHU supplying the affected operations zone was gathered from the 100% Construction Documents for the DITC. These capacities are represented below in Figure 4.13.



Roof Top Unit Heating and Cooling Capacities					
Unit	Area Serviced	Heat - Loss (Heating)	Unit	Heat - Gain (Cooling)	Unit
RTU - 1b	Operations	216	MBH	20	Tons
		216000	BTU/hr	240000	BTU/hr

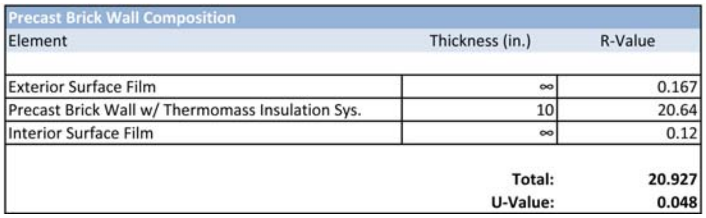
Figure 4.13, RTU Heating and Cooling Capacities, DITC 100% CDs

R-values for both wall systems had to be gathered in order to find the heating gains and losses of each assembly. A report generated by THERMOMASS compared the R-value’s of the THERMOMASS system to a typical panel assembly, including the loss due to thermal bridging. The assumed R-value in the study for a typical, non-THERMOMASS, panel assembly with 3” of insulation was similar to the brick, air cavity and insulation of a typical brick on metal stud façade of the DITC; therefore, the R-Value of this assembly was taken from the report including the loss due to thermal bridging. The effective R-Value of the brick on metal stud, air cavity and insulation was 10.81, reduced from 16.66 due to thermal bridging effects. The report used the Series-Parallel Path Analysis from the ASHRAE Handbook – 2001 Fundamentals, and it can be viewed in Appendix E. The precast brick panel system also benefits from the thermal mass of the concrete in the assembly. The system maximizes the thermal mass effect, thereby reducing heating and cooling loads, effectively providing an R-Value greater than expected. THERMOMASS performed an analysis to find the effective R-Value of the system, accounting for thermal mass, using ASHRAE/IESNA Standard 90.1: System Performance Criteria. This report is available in Appendix E, showed the R-Value of the system increased from 11.49 to 20.64 due to the effects of thermal mass. The remaining R-Values of the layers not included in these studies were found in the 2005 ASHRAE Handbook – Fundamentals. The R-Value of each assembly was calculated using all values, and each assembly’s R-Value calculation is shown below in Figures 4.14 and 4.15.



Brick Wall Composistion		
Element	Thickness (in.)	R-Value
Exterior Surface Film	∞	0.167
4" x 12" Brick Veneer, Air Cavity, & 3" Rigid Insul.	8.625	10.81
Cont Vapor Retarder	-	0
1/2" Exterior Sheathing	0.5	0.625
Air Cavity & Studs + Gypsum Board	6.625	1.3
Interior Surface Film	∞	0.12
	Total:	**13.022**
	U-Value:	**0.077**

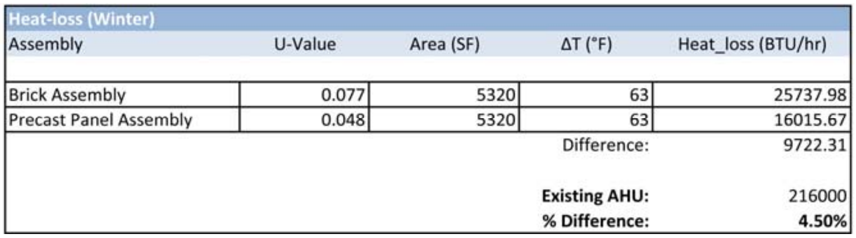
Figure 4.14, DITC Brick on Metal Stud R-Value Calculation



Precast Brick Wall Composition		
Element	Thickness (in.)	R-Value
Exterior Surface Film	∞	0.167
Precast Brick Wall w/ Thermomass Insulation Sys.	10	20.64
Interior Surface Film	∞	0.12
	Total:	**20.927**
	U-Value:	**0.048**

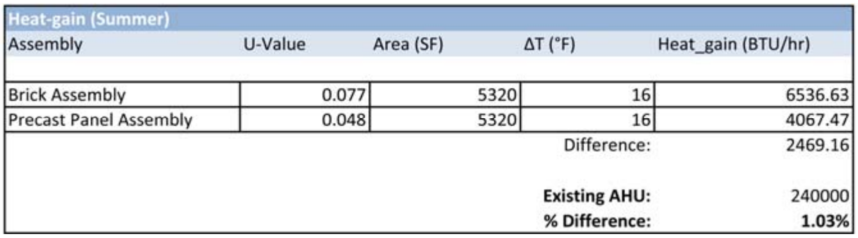
Figure 4.15, National Precast Brick Panel R-Value Calculation

After calculating the effective R-value of each assembly, the R-Values were applied to the DITC in order to calculate the Heat-loss in the winter and Heat-gain in the summer of each assembly. Because the precast panel system offers a higher R-Value, the heating and cooling loads for the DITC can be reduced. If large enough, the savings in heat-loss and heat-gain could reduce the size of the AHU supplying the operations zone of the DITC. The savings were compared to the existing AHU heating and cooling capacities in order to determine if they were large enough to reduce the size of the AHU. With the precast panel system the reduction of heat-loss was 4.5% of the heating capacity, and the reduction of heat-gain was 1.03% of the cooling capacity. These percentages were not large enough to decrease the size of the AHU supplying the operations zone. The calculations for heat-loss and heat-gain, and the comparison to the existing AHU capacities can be seen below in Figures 4.16 and 4.17. The heat-loss and heat-gain (Q) in BTU/hr was calculated using the equation: Q = U-value * Area * ΔT.



Heat-loss (Winter)				
Assembly	U-Value	Area (SF)	ΔT (°F)	Heat_loss (BTU/hr)
Brick Assembly	0.077	5320	63	25737.98
Precast Panel Assembly	0.048	5320	63	16015.67
			Difference:	9722.31
			Existing AHU:	216000
			% Difference:	**4.50%**

Figure 4.16, Heat-loss Calculation and AHU Heating Capacity Comparison



Heat-gain (Summer)				
Assembly	U-Value	Area (SF)	ΔT (°F)	Heat_gain (BTU/hr)
Brick Assembly	0.077	5320	16	6536.63
Precast Panel Assembly	0.048	5320	16	4067.47
			Difference:	2469.16
			Existing AHU:	240000
			% Difference:	**1.03%**

Figure 4.17, Heat-gain Calculation and AHU Cooling Capacity Comparison

Even though the heat-gain and heat-loss savings from the precast brick panels were not enough to reduce the size of the AHU, these savings still contribute to savings in the operations costs of the building. Because the annual heating and cooling loads can be reduced with the precast panel system, savings occur with the energy costs required to heat and cool the building. The annual heating fuel consumption was calculated using the equation:

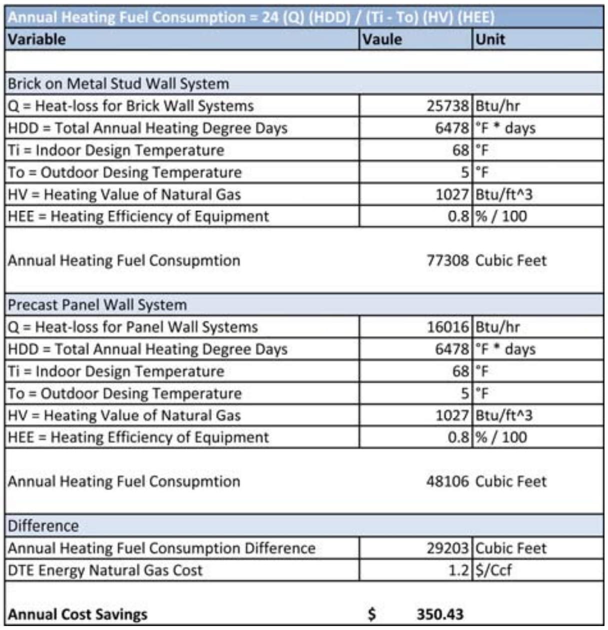
$$\text{Annual Heating Fuel Consumption} = [24*Q*HDD] / [(Ti - To)*HV*HEE]$$

The equation was obtained from the book “Engineering Weather Data” and uses the heat-loss (Q), the heating degree days (HDD), the temperature difference (Ti – To), the heating value of natural gas (HV) and the heating efficiency of the AHU. The fuel consumption required for each wall system was calculated, along with the difference between the two fuel consumptions. The fuel consumption savings (difference between the annual heating fuel consumptions) was multiplied by DTE Energy’s (DITC energy supplier) cost for Natural gas to calculate the annual cost savings for heating load. The calculations for annual heating of the DITC can be seen below in figure 4.18. The total annual cost savings for heating of the DITC was $350.43.

The annual cooling energy consumption was calculated using the same equation; however, it was changed to find cooling energy. The equation used was:

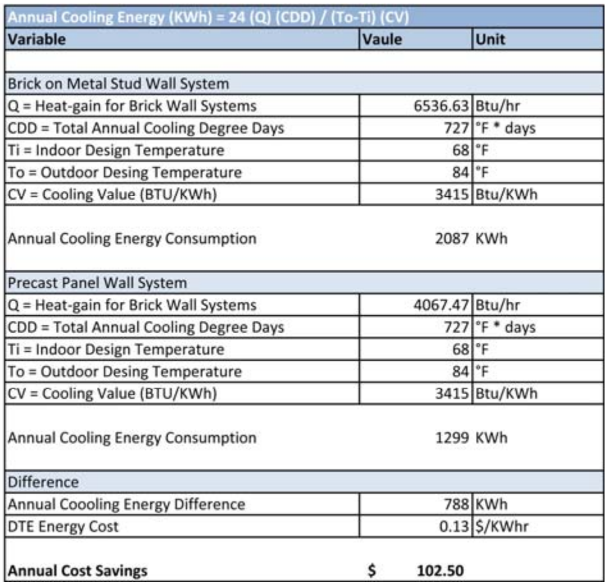
$$\text{Annual Cooling Energy Consumption} = [24*Q*CDD] / [(To - Ti)*CV]$$

The equation uses the heat-gain (Q), the cooling degree days (CDD), the temperature difference (To – Ti) and the cooling value (CV) of the AHU. The cooling energy required for each wall system was calculated, along with the difference between the two cooling energies. The energy savings (difference between the annual energy consumptions) was multiplied by DTE Energy’s (DITC energy supplier) cost in $/KWh to calculate the annual cost savings for cooling load. The calculations for annual cooling of the DITC can be seen below in figure 4.19. The total annual cost savings for cooling of the DITC was $102.50.



Annual Heating Fuel Consumption = 24 (Q) (HDD) / (Ti - To) (HV) (HEE)		
Variable	**Vaule**	**Unit**
Brick on Metal Stud Wall System		
Q = Heat-loss for Brick Wall Systems	25738	Btu/hr
HDD = Total Annual Heating Degree Days	6478	°F * days
Ti = Indoor Design Temperature	68	°F
To = Outdoor Desing Temperature	5	°F
HV = Heating Value of Natural Gas	1027	Btu/ft^3
HEE = Heating Efficiency of Equipment	0.8	% / 100
Annual Heating Fuel Consupmtion	77308	Cubic Feet
Precast Panel Wall System		
Q = Heat-loss for Panel Wall Systems	16016	Btu/hr
HDD = Total Annual Heating Degree Days	6478	°F * days
Ti = Indoor Design Temperature	68	°F
To = Outdoor Desing Temperature	5	°F
HV = Heating Value of Natural Gas	1027	Btu/ft^3
HEE = Heating Efficiency of Equipment	0.8	% / 100
Annual Heating Fuel Consupmtion	48106	Cubic Feet
Difference		
Annual Heating Fuel Consumption Difference	29203	Cubic Feet
DTE Energy Natural Gas Cost	1.2	$/Ccf
Annual Cost Savings	**$ 350.43**	

Figure 4.18, Annual Heating Savings

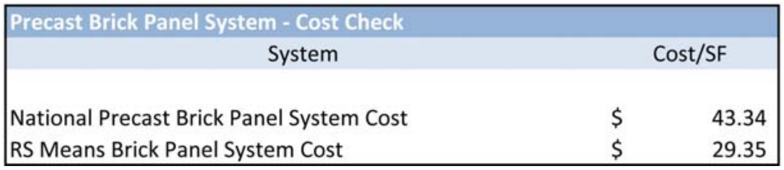


Annual Cooling Energy (KWh) = 24 (Q) (CDD) / (To-Ti) (CV)		
Variable	**Vaule**	**Unit**
Brick on Metal Stud Wall System		
Q = Heat-gain for Brick Wall Systems	6536.63	Btu/hr
CDD = Total Annual Cooling Degree Days	727	°F * days
Ti = Indoor Design Temperature	68	°F
To = Outdoor Desing Temperature	84	°F
CV = Cooling Value (BTU/KWh)	3415	Btu/KWh
Annual Cooling Energy Consumption	2087	KWh
Precast Panel Wall System		
Q = Heat-gain for Brick Wall Systems	4067.47	Btu/hr
CDD = Total Annual Cooling Degree Days	727	°F * days
Ti = Indoor Design Temperature	68	°F
To = Outdoor Desing Temperature	84	°F
CV = Cooling Value (BTU/KWh)	3415	Btu/KWh
Annual Cooling Energy Consumption	1299	KWh
Difference		
Annual Coooling Energy Difference	788	KWh
DTE Energy Cost	0.13	$/KWhr
Annual Cost Savings	**$ 102.50**	

Figure 4.19, Annual Cooling Savings

4.7 - Cost Impacts

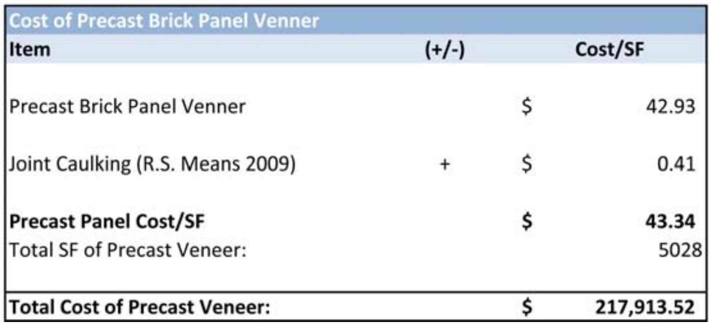
To obtain an accurate estimate of the precast brick panel system for the DITC, a takeoff of the panels was performed and sent to National Precast. The estimate received from National Precast used the number of panels, panel sizes and types of connection; and included fabrication, forms, detailing and engineering, field labor, transportation, erection, overhead and profit. The total price for the system received from National Precast was $215,850 or $42.93 / SF. To validate the estimate from National Precast R.S. Means Assemblies Cost Data, 2009 Edition was used to find the SF cost of a precast brick panel assembly. This assembly was not found in the book; therefore, the cost for an insulated precast panel was combined with the cost of masonry. This cost, available below in Figure 4.20, was much lower than the estimate received from National Precast; which is most likely due to the fact the combination of the precast panel and masonry did not accurately account for the design of National Precast's system.



Precast Brick Panel System - Cost Check	
System	Cost/SF
National Precast Brick Panel System Cost	$ 43.34
RS Means Brick Panel System Cost	$ 29.35

Figure 4.20, R.S. Means Precast Brick Panel Cost Check

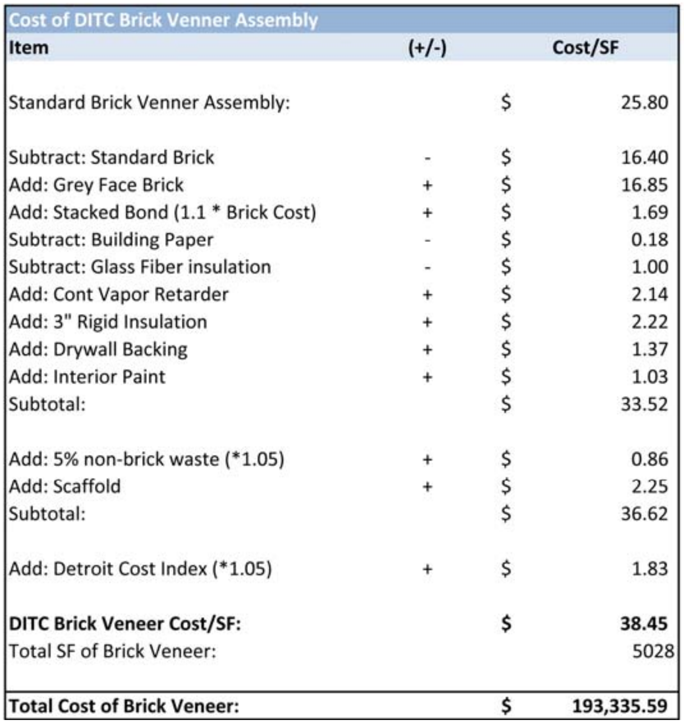
The estimate received from National Precast did not include the Joint Caulking required between the panels. To account for this cost data was gathered from R.S. Means 2009, and the cost was added to the estimate for the precast brick panel system. The overall cost for the precast brick panels is represented below in Figure 4.21.



Cost of Precast Brick Panel Venner			
Item	**(+/-)**		**Cost/SF**
Precast Brick Panel Venner		$	42.93
Joint Caulking (R.S. Means 2009)	+	$	0.41
Precast Panel Cost/SF		**$**	**43.34**
Total SF of Precast Veneer:			5028
Total Cost of Precast Veneer:		**$**	**217,913.52**

Figure 4.21, Total Cost of Precast Brick Panels

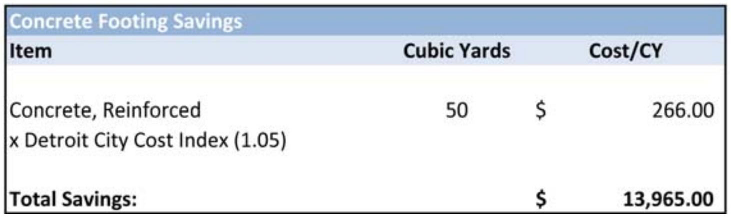
In order to compare the cost for the precast panels to the brick on metal stud an estimate of the brick on metal stud was performed using R.S. Means Assemblies Cost Data, 2009 Edition. The assembly was adjusted in order to obtain an accurate cost for the brick on metal stud assembly of the DITC. The cost of the system was calculated to be $38.45 / SF, with a total cost of $ 193,335.59. The calculation of this estimate is below in Figure 4.20.



Cost of DITC Brick Venner Assembly			
Item	**(+/-)**		**Cost/SF**
Standard Brick Venner Assembly:		$	25.80
Subtract: Standard Brick	-	$	16.40
Add: Grey Face Brick	+	$	16.85
Add: Stacked Bond (1.1 * Brick Cost)	+	$	1.69
Subtract: Building Paper	-	$	0.18
Subtract: Glass Fiber insulation	-	$	1.00
Add: Cont Vapor Retarder	+	$	2.14
Add: 3" Rigid Insulation	+	$	2.22
Add: Drywall Backing	+	$	1.37
Add: Interior Paint	+	$	1.03
Subtotal:		$	33.52
Add: 5% non-brick waste (*1.05)	+	$	0.86
Add: Scaffold	+	$	2.25
Subtotal:		$	36.62
Add: Detroit Cost Index (*1.05)	+	$	1.83
DITC Brick Veneer Cost/SF:		**$**	**38.45**
Total SF of Brick Veneer:			5028
Total Cost of Brick Veneer:		**$**	**193,335.59**

Figure 4.20, DITC Brick on Metal Stud Cost, R.S. Means 2009

Savings were incurred for the precast brick panels with the redesign of the footing supporting the panels. Because the brick shelf could be eliminated, the concrete, rebar and formwork associated with the brick shelf could be eliminated. It was calculated that 50 Cubic Yards of concrete could be saved. A Cost per Cubic Yard was obtained from R.S. Means 2009, including the concrete, rebar and formwork. The estimated savings for the new foundation is below in Figure 4.21.

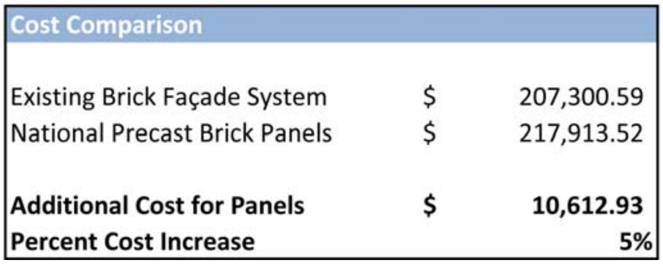


Concrete Footing Savings

Item	Cubic Yards		Cost/CY
Concrete, Reinforced	50	$	266.00
x Detroit City Cost Index (1.05)			
Total Savings:		**$**	**13,965.00**

Figure 4.21, Concrete Footing Savings

Once the total cost for each system was calculated the costs were compared. The cost of the brick on metal stud system includes the cost savings for the foundation. It was found that the precast brick panels cost $10,612.93 more than the original brick on metal stud system, 5% more than the cost of the brick on metal stud system. This cost comparison is available below in Figure 4.22.



Cost Comparison

Existing Brick Façade System	$	207,300.59
National Precast Brick Panels	$	217,913.52
Additional Cost for Panels	**$**	**10,612.93**
Percent Cost Increase		**5%**

Figure 4.22, Precast Brick Panel vs. Brick on Metal Stud Cost

Cost savings were also incurred for the operations of the DITC. The increased R-Value of the precast brick panels saved $ 452.90 annually in heating and cooling costs. The Return on Investment for the extra cost for the precast panel system was calculated by dividing the extra $10,612.93 upfront, by the annual energy savings of the precast panel system. Assuming that inflation stays constant with energy costs, the payback period for the precast brick panels was calculated to be 23 years and 5 months. There is a possibility that energy rates will actually increase at a greater rate than inflation, and in this case the payback period of the precast brick panels will be less than estimated.

4.8 - Schedule Impacts

Precast brick panels are fabricated in shops, and shipped to site to be erected, quicker than typical brick on metal stud is constructed on site. Although the on-site construction is expedited, a precast brick panel system requires more lead time than a typical brick on metal stud construction. Durations for the activities that precede the on-site erection of the panels for the DITC were received from National Precast, and are as follows:

Drafting and Engineering:	4 weeks
Fabrication:	4 weeks

Therefore, the overall lead time for the panels is eight weeks. The General Contractor of the DITC would have to be well aware of this lead time, and schedule these activities to occur before the erection of the panels. The construction durations for the panels to be used on the DITC were also received from National Precast, and are as follows:

Erection: 1 week
Clean-up and Detailing: 1 week

Because the precast panels will replace all the typical brick on metal stud for the DITC, the activity of constructing the masonry could be eliminated from the schedule. Also the precast panels do not require exterior metal studs as a back-up. Therefore the exterior framing activities where the brick was located can be reduced in duration. The durations for the exterior framing were reduced according to the amount of exterior framing that was eliminated in each sequence. Figure 4.16 below shows the duration decreases applied to the brick masonry and the exterior stud framing, and the new durations of those activities.

Current Schedule Duratinos with Duration Decrease

Activity	Duration (days)	Duration Decrease (days)	New Duration (days)
Exterior Framing, Seq 10-12	5	1	4
Exterior Framing, Seq 13-15	5	2	3
Exterior Framing, Seq 16-17	6	3	3
Brick Masonry, Seq 10-12	4	4	0
Brick Masonry, Seq 13-15	10	10	0
Brick Masonry, Seq 16-17	16	16	0
Total:	**46**	**36**	**10**

Figure 4.16, Brick on Metal Stud Duration Decreases

The decrease in duration for the brick on metal stud activities was 36 days. After subtracting the week for erection of the precast panels, the overall schedule duration decrease for the precast concrete panels is 31 days.

The brick masonry activities were removed from the DITC schedule, the precast panel erection activity was added, and the durations of the exterior framing activities were decreased. The erection of the precast panels could begin after the installation of the west stairwell structure. After adjusting the schedule for the activity changes, the overall project schedule was only decreased by 3 days (based on a 5-day work week). This decrease was minimal compared to the duration decrease of 31 days due to the precast panels. Even though the brick on metal stud construction was on the critical path, the schedule only decreased by 3 days because the construction of the metal panels originally finished 3 days ahead of the brick on metal stud construction. Therefore, after the addition of the precast panels, the critical path was pushed to the metal panel construction. Interior construction activities can’t begin until the building is enclosed, which was dependant on both the brick on metal stud construction and the metal panel construction. The updated schedule including the precast brick panels is available in Appendix F.

It is not only important to look at the critical path activities of a schedule for acceleration scenarios, but it is important to also look at the activities with little total float. Accelerating a critical path activity may not help decrease a schedule if successor activities are also dependant on another activity with little float. This was the case when substituting precast panels for the brick on metal stud for the DITC. However, typical brick on metal stud construction is very dependent on weather conditions, and therefore prone to possible delays. Removing this activity from the DITC by using precast panels helps to reduce the possibility of delays due to unfavorable weather conditions.

4.9 - Conclusion

Due to delay of the construction of the DITC, the project's completion date is continuously being pushed back. In order to increase the speed of construction, and decrease the overall project schedule, the project participants should look into replacing the typical brick on metal stud façade of the DITC with precast brick panels. After a comprehensive analysis it was determined that National Precast's brick panel system would increase the project's cost by $ 10,613, decrease the building's annual operation costs by $ 453, and decrease the overall project schedule by 3 construction days.

The precast brick panels for the DITC would not be vertically supported by the structural steel of the DITC; however, the panels are stacked and the bearing of the panels is transferred to the foundation below. The panels are laterally supported by the structural steel, with slotted connections that allow for movement. It was determined through structural analysis that the design of the panels was conservative and adequate to resist self and wind loading. The size of the foundation wall at the precast panels could also be reduced because the brick shelf is no longer needed. The new foundations were analyzed and it was determined the design was adequate to support the loading of the precast panels.

Although the substitution of the precast brick panels, utilizing the THERMOMASS system, does not reduce the size of the AHU supplying the affected areas, it does decrease the annual heating and cooling loads. This decrease in heating and cooling load is credited to the high R-Value of the precast panel assembly. The R-Value of the assembly is barely affected by thermal bridging due to the fiber-composite connectors, and increased due to the thermal mass of the concrete in the assembly. The R-Value of the precast brick assembly was calculated to be 20.927, compared to the brick on metal stud assembly's R-Value of 13.022.

From a construction management viewpoint it is recommended that the DITC change the original design intent of the building, and substitute the precast brick panels for the brick on metal stud. The upfront cost increase of the precast panels could be returned in 23 years due to the annual heating and cooling cost savings. This payback period could be even shorter if energy costs increase at a greater rate of inflation. Even though the overall construction schedule is only decreased by 3 days, eliminating the brick on metal stud removes any delays that are possible with masonry construction. Eliminating the masonry construction also gives way to a less congested site, as the scaffolding required for masonry would congest the southwest corner of the building, which is already tight to the street.

5 - Modularization of Interior Walls

5.1 - Introduction

The Detroit Integrated Transportation Campus (DITC) was to begin construction in October of 2008. However, due to complications with the General Contractor bid submissions, as of March, 2009 the project has yet to begin construction. Due to this delay, the State of Michigan will not only expect the construction to be completed within the expected one year construction period, but would find it beneficial to accelerate the construction to complete the job as soon as possible.

One of the current trends within the architecture and construction industry is leaning project delivery through the prefabrication of building systems. Prefabrication involves fabricating a system off site, bringing it to site in pieces, and installing those pieces on site. This process ensures quality because the systems are fabricated in shops; it also saves cost of on-site construction, and increases the rate of construction. The design of the Detroit Integrated Transportation Campus design currently has interior walls of gypsum board on metal stud, constructed on site. This interior wall system is currently on the critical path and if accelerated could decrease the overall schedule of construction.

Modular interior wall systems are prefabricated, and if substituted for the current interior wall system of the DITC could increase the speed of construction and add to the sustainability of the building. Interior building renovation is more sustainable and efficient with modular walls, because they can be easily deconstructed and reconstructed to suit new building spaces.

Environmental Wall Systems (EWS), located near Cleveland, Ohio, is a company which produces the IrisWall modular wall system. The IrisWall system was selected as the replacement for the typical gypsum board on metal stud on the DITC for this analysis. EWS was selected because of its close vicinity to the DITC, and their easy-to-install design of the IrisWall system. In order to fully evaluate the substitution of the IrisWall system its application to the DITC, cost, and schedule impacts were analyzed.

5.2 - Methods

1. Research the design of the IrisWall System.
2. Analyze the application of the IrisWall System to the DITC.
3. Compare the cost of IrisWall versus typical gypsum board on metal stud.
4. Determine the schedule impacts of the IrisWall System on the DITC.

5.3 - References

1. Detroit Integrated Transportation Campus, 100% Construction Documents
2. Environmental Wall Systems
3. R.S. Means Interiors Cost Data, 2009 Edition

5.4 - System Overview

The IrisWall system is not only sustainable because it reduces renovation waste and allows for flexible floor design, but it is also utilizes sustainable materials. The IrisWall face consists of 95% recycled material, the aluminum is between 65-85% recycled content, and the standard finishes are water-based. Panel options for the IrisWall system include wall panels, window panels, and door panels. The panels can be made up to 10 feet high, and between 6-48 inches wide. IrisWall doors are full height and can match any existing specifications for width and finish. IrisWall doors come with finished locks, hinges, and doorstops. An example of the IrisWall system is shown below in Image 5.1.

Image 5.1, IrisWall System, Environmental Wall Systems

The IrisWall system utilizes continuous aluminum ceiling and floor tracks that allow for easy construction and renovation. IrisWall ceiling track connects to a typical ceiling grid system, and the floor track connects to carpet with carpet gripers. Each panel is connected to one another by an aluminum panel to panel connection. The system also connects to foreign walls and allows for variance by utilizing a spring loaded wall channel. An elevation of a typical office layout and typical IrisWall connections are shown below in Images 5.2 – 5.6.

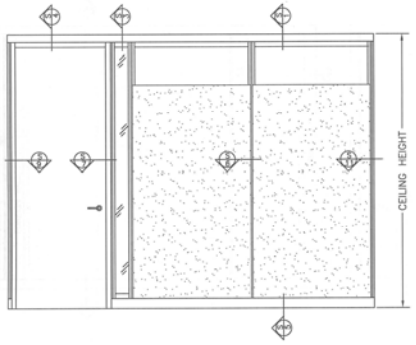


Image 5.2, IrisWall Elevation, EWS

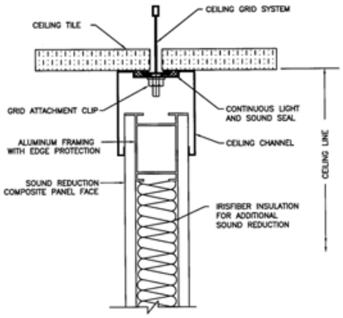


Image 5.3, IrisWall Ceiling Connection, EWS

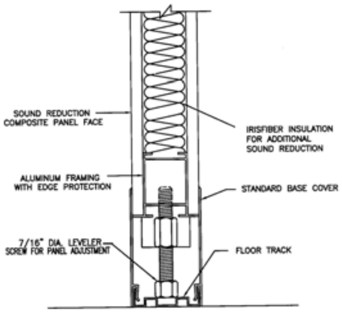


Image 5.4, IrisWall Floor Connection, EWS

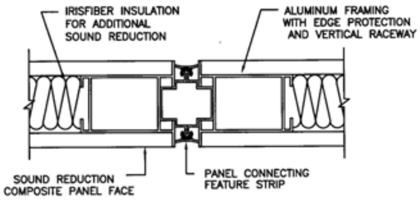


Image 5.5, Panel to Panel Connection, EWS

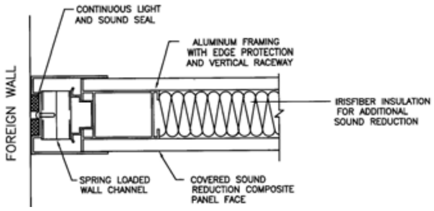


Image 5.6 IrisWall to Foreign Wall Connection, EWS

IrisWall system design allows for the inclusion of in-wall electrical and data connections. Switches, outlets, and data connections can be prefabricated in the panels, along with the conduit needed to run the wiring to these connections. Panels that require electrical and data connections must be noted so they can be prefabricated to meet the specifications. Conduit can be run down to the floor track from the electrical and data boxes. Wiring is pulled from above the ceiling into the vertical raceway, down to the floor track, and then up to the electrical and data boxes through the conduit. An elevation of conduit layout within a panel is shown below in Image 5.7.

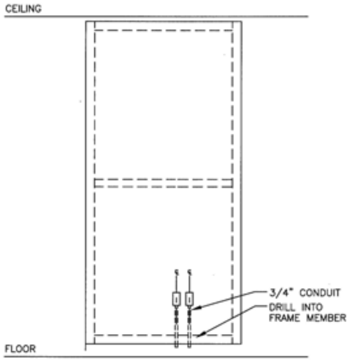


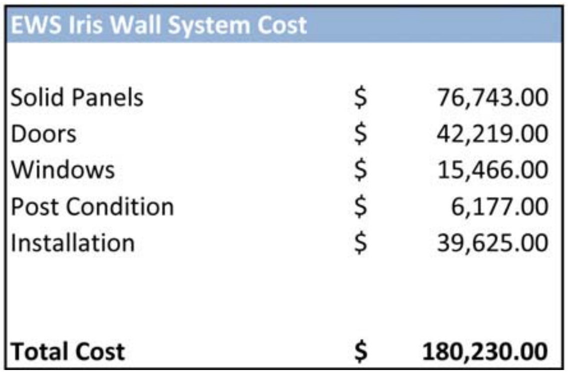
Image 5.7, IrisWall Conduit Layout, EWS

Because the design of the IrisWall system is flexible, the design of room systems with IrisWall should also be flexible. In order to obtain the ability to change room spaces the above ceiling systems should be designed so they also can be changed also. Ceiling diffusers should be connected with flex duct, in-grid lighting fixtures should be run with longer wiring, and sprinkler heads should be connected with adjustable piping to allow these systems to move.

The Iris-Wall system works well for the Detroit Integrated Transportation Campus because it is office building with an open floor plan. IrisWall could not be applied all interior walls of the DITC for multiple reasons. Some areas of the DITC were designed to have exposed ceiling and IrisWall could not be applied in such areas as it needs a ceiling grid to attach to. Walls in kitchen, lavatory, and toilet rooms have to remain typical gypsum board on metal stud due to the in-wall mechanical systems required. IrisWall also could not be applied to walls in permanent locations such as entries, stairwells, elevators, and mechanical chases. For the purpose of this analysis IrisWall was applied in all acceptable locations.

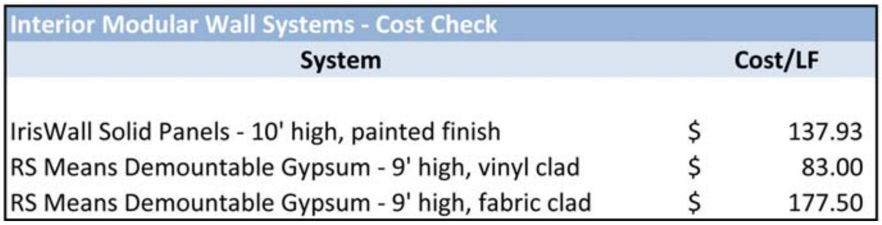
5.5 - Cost Impacts

An IrisWall system includes many different panels and connections, and in order to achieve an accurate estimate, a quote was obtained from EWS for the DITC IrisWall system. Floor plans, including IrisWall panels, windows, doors, connections, and in-wall electrical components, were created. An excel sheet quantifying these different elements was also created. The excel sheet, available in Appendix G, was then sent to EWS for an accurate estimate. A breakdown of the estimate received from EWS can be seen below in Figure 5.1. In order to check the costs received from EWS, similar modular wall cost were compiled from R.S. Means 2009. The cost comparison can be seen below in Figure 5.2, and confirms the accuracy of the estimate received from EWS.



EWS Iris Wall System Cost		
Solid Panels	$	76,743.00
Doors	$	42,219.00
Windows	$	15,466.00
Post Condition	$	6,177.00
Installation	$	39,625.00
Total Cost	**$**	**180,230.00**

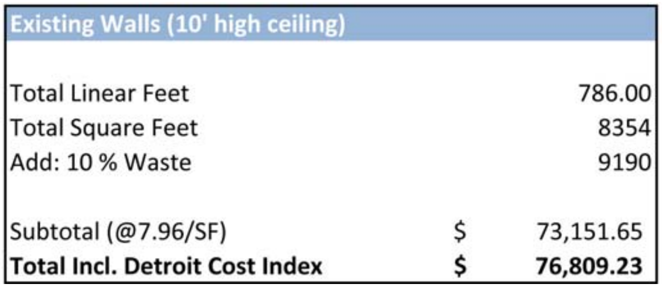
Figure 5.1, Iris Wall Cost Estimate, Estimate Received From EWS



Interior Modular Wall Systems - Cost Check		
System		**Cost/LF**
IrisWall Solid Panels - 10' high, painted finish	$	137.93
RS Means Demountable Gypsum - 9' high, vinyl clad	$	83.00
RS Means Demountable Gypsum - 9' high, fabric clad	$	177.50

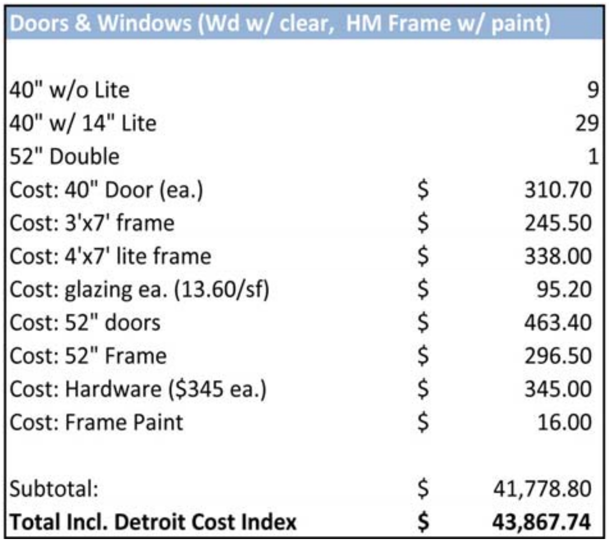
Figure 5.2, Modular Wall Cost Check, EWS & R.S. Means 2009

In order to effectively compare the existing drywall on metal stud to the proposed IrisWall system, a detailed estimate of the replaced drywall on metal stud system was generated. First, a detailed estimate of the drywall on metal studs, doors, and windows was compiled using cost data from R.S. Means Interiors Cost Data 2009. These estimate breakdowns include material, construction, and finishing costs; and can be viewed below in Figures 5.3 and 5.4.



Existing Walls (10' high ceiling)		
Total Linear Feet		786.00
Total Square Feet		8354
Add: 10 % Waste		9190
Subtotal (@7.96/SF)	$	73,151.65
Total Incl. Detroit Cost Index	**$**	**76,809.23**

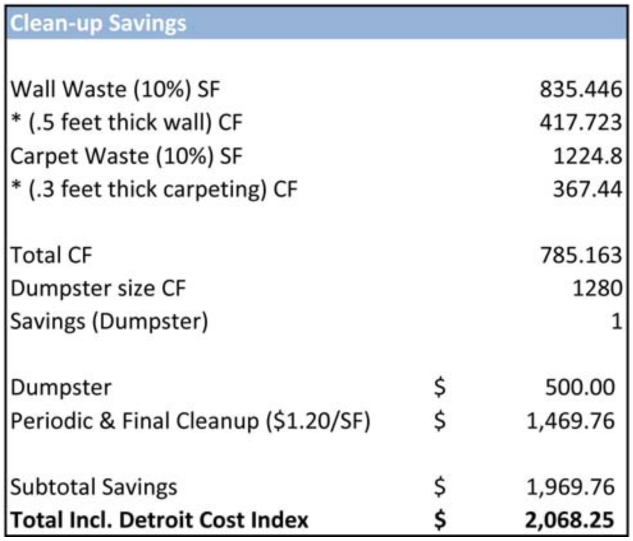
Figure 5.3, Drywall on Metal Stud Estimate, R.S. Means 2009



Doors & Windows (Wd w/ clear, HM Frame w/ paint)		
40" w/o Lite		9
40" w/ 14" Lite		29
52" Double		1
Cost: 40" Door (ea.)	$	310.70
Cost: 3'x7' frame	$	245.50
Cost: 4'x7' lite frame	$	338.00
Cost: glazing ea. (13.60/sf)	$	95.20
Cost: 52" doors	$	463.40
Cost: 52" Frame	$	296.50
Cost: Hardware ($345 ea.)	$	345.00
Cost: Frame Paint	$	16.00
Subtotal:	$	41,778.80
Total Incl. Detroit Cost Index	**$**	**43,867.74**

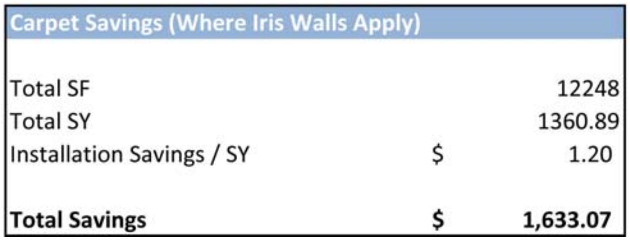
Figure 5.4, Existing Doors and Windows Estimate, R.S. Means 2009

Because the IrisWall system is prefabricated and designed to fit into finished spaces, there are some extra cost savings that come with using IrisWall. These savings were added into the cost of the existing drywall on metals stud estimate, as they would be subtracted from construction costs if the IrisWall system was used. Savings include clean-up costs for using a drywall on metal stud construction; carpet installation cost; and electrical switch and outlet costs. Clean-up savings include the dumpster costs for the drywall, metal stud, and carpet waste in areas of typical drywall construction; and include the periodic clean-up associated with these constructions. In areas where the IrisWall system is used, carpet installation savings incur, because the carpet can be installed continuously instead of on a room-by-room basis. Electrical savings are incorporated with the IrisWall system because the in-wall electrical boxes are installed as part of the prefabrication, and therefore can be installed more efficiently than on-site. The savings were generated from cost data received from Environmental Wall Systems, and can be seen below in Figures 5.5 – 5.7.



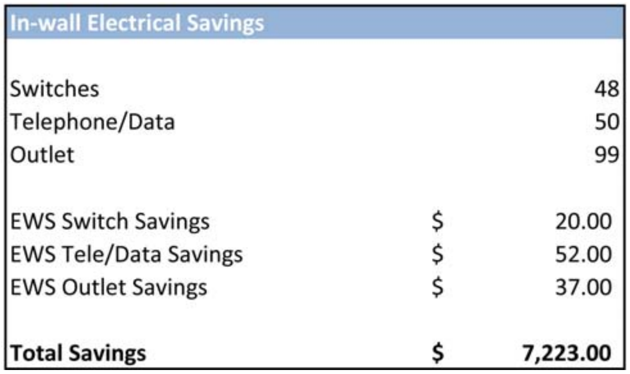
Clean-up Savings		
Wall Waste (10%) SF		835.446
* (.5 feet thick wall) CF		417.723
Carpet Waste (10%) SF		1224.8
* (.3 feet thick carpeting) CF		367.44
Total CF		785.163
Dumpster size CF		1280
Savings (Dumpster)		1
Dumpster	$	500.00
Periodic & Final Cleanup ($1.20/SF)	$	1,469.76
Subtotal Savings	$	1,969.76
Total Incl. Detroit Cost Index	**$**	**2,068.25**

Figure 5.5, Clean-up Savings, EWS



Carpet Savings (Where Iris Walls Apply)		
Total SF		12248
Total SY		1360.89
Installation Savings / SY	$	1.20
Total Savings	**$**	**1,633.07**

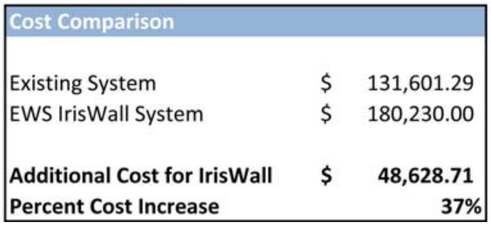
Figure 5.6, Carpet Savings, EWS



In-wall Electrical Savings		
Switches		48
Telephone/Data		50
Outlet		99
EWS Switch Savings	$	20.00
EWS Tele/Data Savings	$	52.00
EWS Outlet Savings	$	37.00
Total Savings	**$**	**7,223.00**

Figure 5.7, In-Wall Electrical Savings, EWS

After performing both estimates the cost of the existing drywall on metal stud system came to a total cost of $131,601.29, and the IrisWall system came to a total cost of $180,230.00. The difference showed that the IrisWall system would cost $48,628.71 more, a cost increase of 37%.



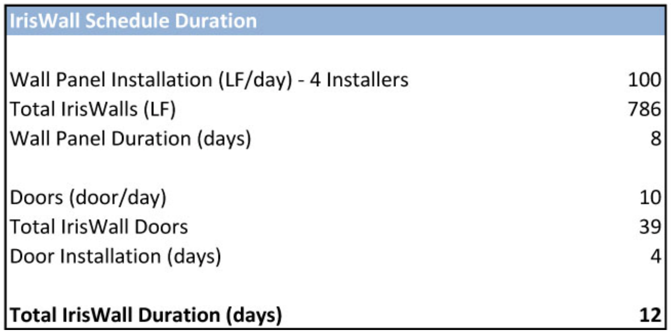
Cost Comparison		
Existing System	$	131,601.29
EWS IrisWall System	$	180,230.00
Additional Cost for IrisWall	**$**	**48,628.71**
Percent Cost Increase		**37%**

Figure 5.8, Cost Comparison

The IrisWall system also offers a good Return on Investment because of tax and renovation savings. Tax savings are incurred because IrisWall is classified as furniture by the Internal Revenue Service, and this allows for a depreciation period of 7 years, compared to 39 years of depreciation for conventional drywall construction. Factoring in renovation savings, the Return on Investment can cover the up-front costs of using the IrisWall system. A Return on Investment spreadsheet was acquired from EWS, and applied to the DITC. With an assumed move rate of 10% per year, and an inflation rate of 5%, it was calculated that the payback period for using IrisWall on the DITC would be 60 months. This spreadsheet is available in Appendix G of this report.

5.6 - Schedule Impacts

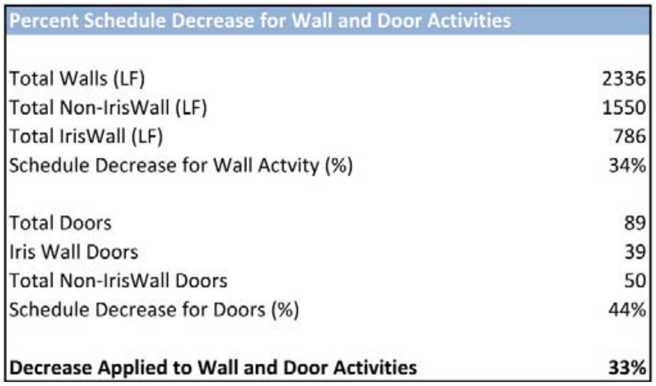
IrisWall can be installed on-site more efficiently than typical drywall construction. Productivity info was received from EWS and applied to the IrisWall quantities in order to obtain the duration for the IrisWall installation. It was assumed that four IrisWall installers would be utilized for the construction. The duration calculations can be seen below in Figure 5.9. It was calculated that the IrisWall installation would take a total of 12 construction days.



IrisWall Schedule Duration	
Wall Panel Installation (LF/day) - 4 Installers	100
Total IrisWalls (LF)	786
Wall Panel Duration (days)	8
Doors (door/day)	10
Total IrisWall Doors	39
Door Installation (days)	4
Total IrisWall Duration (days)	**12**

Figure 5.9, IrisWall Durations, EWS

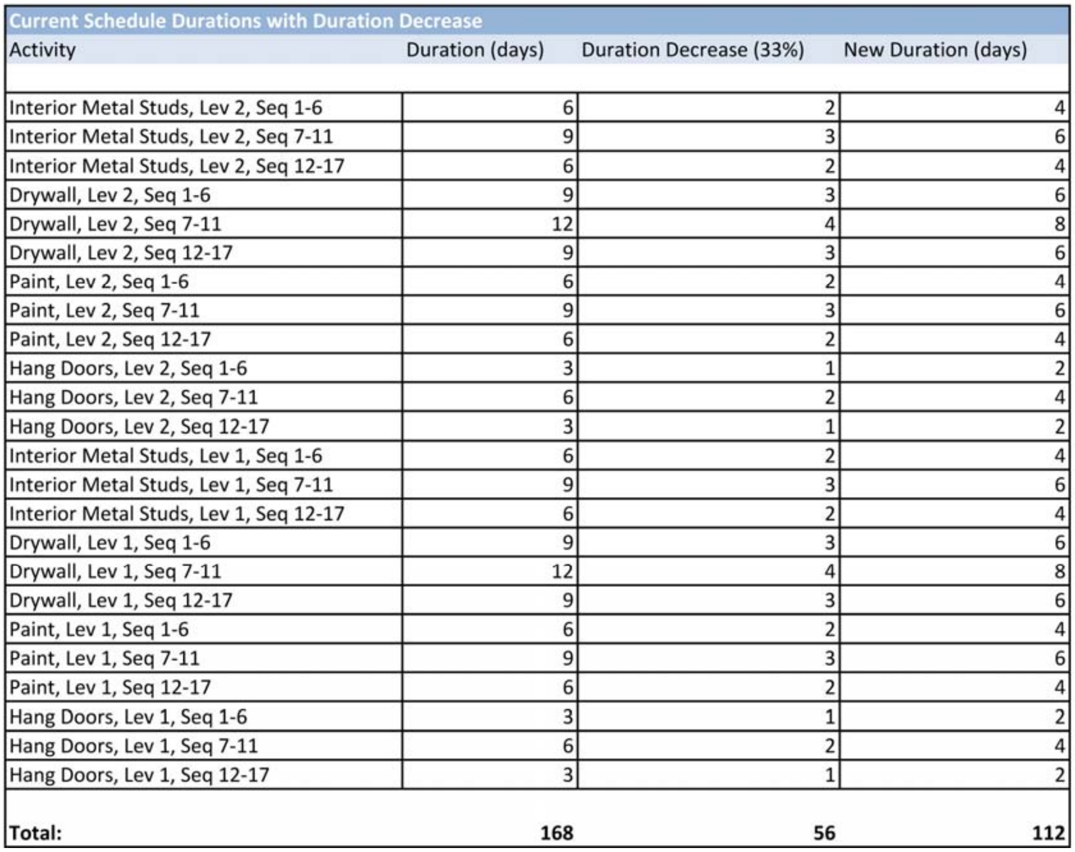
After the IrisWall durations were calculated, the decrease in duration of the typical drywall construction had to be calculated. Not all of the typical drywall construction was replaced by IrisWall, therefore instead of removing these activities, their original durations had to be decreased. Percent of the total drywall construction that was replaced by IrisWall was calculated, and these calculations can be seen below in Figure 5.10.



Percent Schedule Decrease for Wall and Door Activities	
Total Walls (LF)	2336
Total Non-IrisWall (LF)	1550
Total IrisWall (LF)	786
Schedule Decrease for Wall Actvity (%)	34%
Total Doors	89
Iris Wall Doors	39
Total Non-IrisWall Doors	50
Schedule Decrease for Doors (%)	44%
Decrease Applied to Wall and Door Activities	**33%**

Figure 5.10, Duration Decreases for Typical Drywall Construction Activites

A duration decrease of 33% for all typical drywall construction activities was calculated and applied. The activities affected include Interior metal studs, drywall, paint, and doors. The duration decreases in these activities and the new durations can be found below in Figure 5.11.



Current Schedule Durations with Duration Decrease

Activity	Duration (days)	Duration Decrease (33%)	New Duration (days)
Interior Metal Studs, Lev 2, Seq 1-6	6	2	4
Interior Metal Studs, Lev 2, Seq 7-11	9	3	6
Interior Metal Studs, Lev 2, Seq 12-17	6	2	4
Drywall, Lev 2, Seq 1-6	9	3	6
Drywall, Lev 2, Seq 7-11	12	4	8
Drywall, Lev 2, Seq 12-17	9	3	6
Paint, Lev 2, Seq 1-6	6	2	4
Paint, Lev 2, Seq 7-11	9	3	6
Paint, Lev 2, Seq 12-17	6	2	4
Hang Doors, Lev 2, Seq 1-6	3	1	2
Hang Doors, Lev 2, Seq 7-11	6	2	4
Hang Doors, Lev 2, Seq 12-17	3	1	2
Interior Metal Studs, Lev 1, Seq 1-6	6	2	4
Interior Metal Studs, Lev 1, Seq 7-11	9	3	6
Interior Metal Studs, Lev 1, Seq 12-17	6	2	4
Drywall, Lev 1, Seq 1-6	9	3	6
Drywall, Lev 1, Seq 7-11	12	4	8
Drywall, Lev 1, Seq 12-17	9	3	6
Paint, Lev 1, Seq 1-6	6	2	4
Paint, Lev 1, Seq 7-11	9	3	6
Paint, Lev 1, Seq 12-17	6	2	4
Hang Doors, Lev 1, Seq 1-6	3	1	2
Hang Doors, Lev 1, Seq 7-11	6	2	4
Hang Doors, Lev 1, Seq 12-17	3	1	2
Total:	**168**	**56**	**112**

Figure 5.11, Activity Duration Decreases

It is shown in Figure 5.10 that a total of 56 days were saved on the typical drywall construction durations. Subtracting the 12 day duration of the IrisWall construction, gives a total decrease of 44 days. In order to incorporate IrisWall into the schedule, the typical drywall activities had to be adjusted, and IrisWall construction activities added. Carpet installation had to be moved to follow drywall in the schedule, and IrisWall installation was added after carpet installation. After making the necessary changes and adding IrisWall to the CPM schedule, it was determined that the overall construction schedule of one year would be decreased by 6 construction days (based on a 5 day work week). The schedule was only decreased by 6 days, as compared to the 44 day duration decrease, because not all activities were on the critical path. However, more float was added to the schedule, which will allow for more leeway during construction. The project schedule that includes the IrisWall construction can be viewed in Appendix H.

5.7 - Conclusion

Substituting IrisWall for the typical drywall construction on the Detroit Integrated Transportation Campus adds to the buildings sustainability and flexibility, increases the project cost by $48,628.71, and decreases the project schedule by 6 days. Assuming a 10% per year move rate, the upfront increase in cost for the IrisWall could be recovered in a 60 month payback period due to the tax and renovation savings.

The above ceiling MEP systems where the IrisWall system would be installed are already designed to be flexible for renovation. After speaking with Jan Miller, the State of Michigan's Project Manager on the DITC, about incorporating the IrisWall system, she noted that some of the furniture systems in the building were designed to be permanent. Therefore, the furniture systems would also have to be redesigned to allow the office spaces to be truly flexible, and achieve the full benefits of the IrisWall system.

It is recommended that the IrisWall system be substituted on the DITC in the areas identified, and the furniture system be redesigned to be more flexible. Jan Miller also said the State of Michigan would stay with the original design for the DITC; however, they are implementing a modular wall system on a current construction project, and will look into the idea for future projects.

6 - Summary & Conclusions

Designing the Design Model (With a Focus on 4D Modeling)

As an effort to implement the industry wide adoption of Building Information Modeling (BIM), through open interoperability and full facility project lifecycle, the AEC industry should utilize process mapping and model progression documentation to develop BIM Execution Plans on both a company and project level. Process maps and model progression documents could be created on a company level to better define company specific BIM processes, while also created on a project level to define project specific BIM processes. Ideally, BIM participants on a project would combine their company process maps and model progression documents to create project specific documents.

The lack of "whole project" 4D modeling can be related to the slow acceptance of BIM and the lack of defined levels of scheduling within the construction industry. By defining levels of scheduling and relating those levels to the creation of multiple 4D models, the construction industry would not only benefit from improved planning, scheduling and project control, but could also benefit from improved communication on projects.

The Detroit Integrated Transportation Campus (DITC) has yet to begin construction, and the project has no plan of passing the model to contractor to be utilized for construction. This process would fall under the inadequate interoperability in the U.S. capital facilities industry, as defined by the National Institute of Standards and Technology study. Therefore, the model should be passed on, with a "no-liability" clause, for the contractor to use as they please. As it is a Design-Bid-Build delivery, the contractor selected may have no BIM experience; however, no matter the experience level, the contractor should attempt to use the model in construction.

Prefab with Precast Brick Panels

Due to delay of the construction of the DITC, the project's completion date is continuously being pushed back. In order to increase the speed of construction, and decrease the overall project schedule, the project participants should look into the prefabrication of building systems. One prefabrication possibility is replacing the typical brick on metal stud façade of the DITC with precast brick panels. After a comprehensive analysis it was determined that National Precast's brick panels would increase the project's cost by $ 10,613, decrease the building's annual operation costs by $453, and decrease the overall project schedule by 3 construction days. From a construction management viewpoint it is recommended that the DITC substitute the precast brick panels for the brick on metal stud. The upfront cost increase of the precast panels could be recovered in 23 years due to the annual heating and cooling cost savings. Even though the overall construction schedule is only decreased by 3 days, eliminating the brick on metal stud removes any delays that are possible with masonry construction. Eliminating the masonry construction also gives way to a less congested site, as the scaffolding required for masonry would congest the southwest corner of the building, which is already tight to the street.

Modularization of Interior Walls

Another prefabrication possibility is replacing the typical drywall on metal stud interior walls of the DITC with a modular wall system. After a comprehensive analysis it was determined that a modular wall system would add to the sustainability and flexibility of the interior spaces, increase the project cost by $48,628.71, and decreases the project schedule by 6 days. Assuming a 10% per year move rate, the upfront increase in cost for the modular wall system could be recovered in a 60 month payback period due to the tax and renovation savings. Therefore, it is recommended that the IrisWall system be substituted on the DITC, and the furniture system redesigned to be more flexible. The State of Michigan stated it would stay with the original design for the DITC; however, they are implementing a modular wall system on a current construction project, and will look into the idea for future projects.

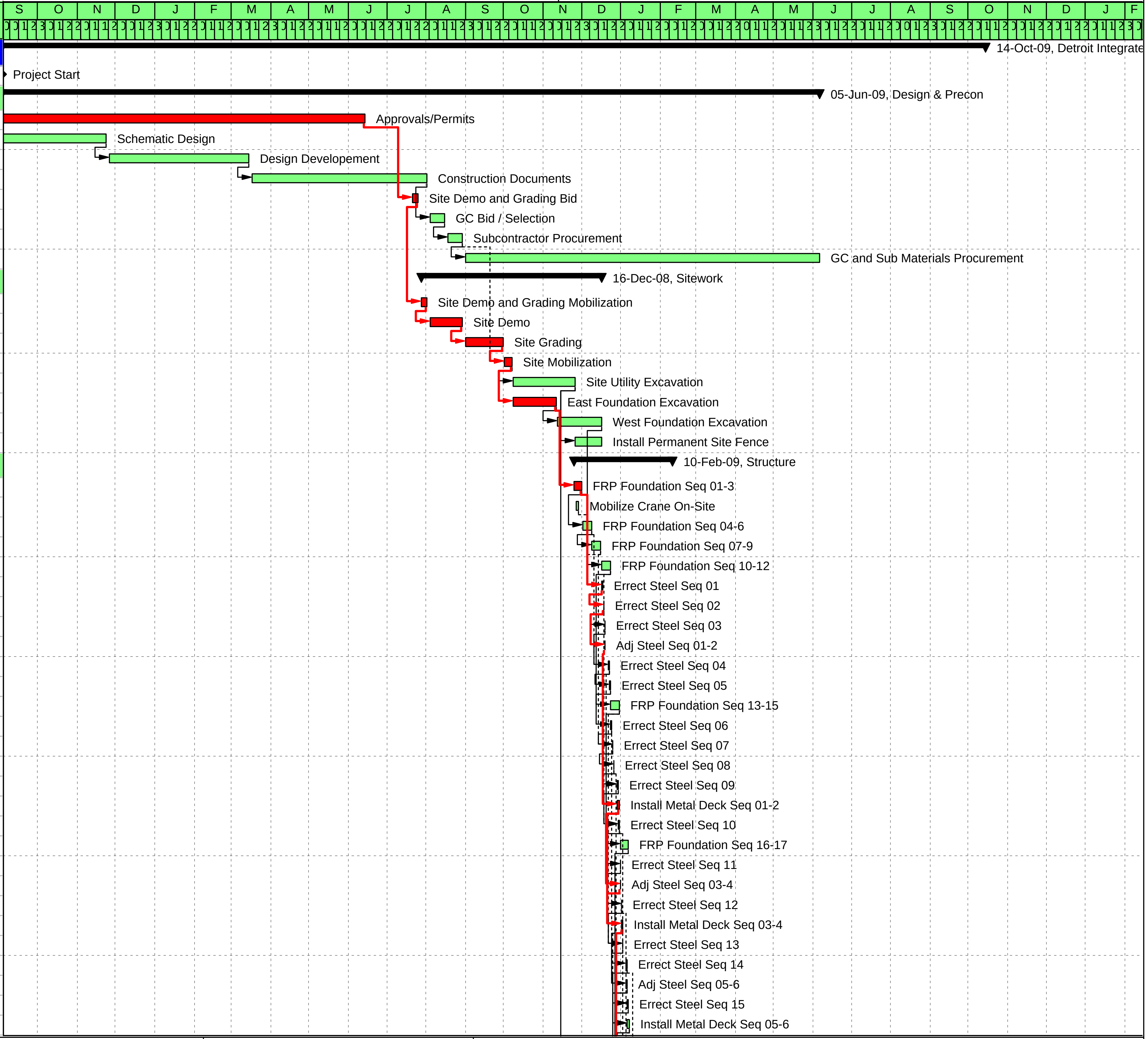
Appendix A: Initial Project Schedule

DITC

Classic WBS Layout

09-Mar-09 20:23

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
Detroit Integrated Transportation ...		553	03-Sep-07	14-Oct-09	0
A100	Project Start	0	03-Sep-07		0
Design & Precon		460	03-Sep-07	05-Jun-09	93
A101	Approvals/Permits	205	03-Sep-07	13-Jun-08	0
A102	Schematic Design	60	03-Sep-07	23-Nov-07	22
A103	Design Developement	80	26-Nov-07	14-Mar-08	22
A104	Construction Documents	100	17-Mar-08	01-Aug-08	22
A105	Site Demo and Grading Bid	5	21-Jul-08	25-Jul-08	0
A106	GC Bid / Selection	10	04-Aug-08	15-Aug-08	22
A107	Subcontractor Procurement	10	18-Aug-08	29-Aug-08	22
A108	GC and Sub Materials Procurement	200	01-Sep-08	05-Jun-09	93
Sitework		102	28-Jul-08	16-Dec-08	216
C100	Site Demo and Grading Mobilization	5	28-Jul-08	01-Aug-08	0
C101	Site Demo	20	04-Aug-08	29-Aug-08	0
C102	Site Grading	22	01-Sep-08	30-Sep-08	0
C103	Site Mobilization	5	01-Oct-08	07-Oct-08	0
C104	Site Utility Excavation	35	08-Oct-08	25-Nov-08	211
C105	East Foundation Excavation	25	08-Oct-08	11-Nov-08	0
C106	West Foundation Excavation	25	12-Nov-08	16-Dec-08	19
C107	Install Permanent Site Fence	15	26-Nov-08	16-Dec-08	216
Structure		56	25-Nov-08	10-Feb-09	176
S100	FRP Foundation Seq 01-3	5	25-Nov-08	01-Dec-08	0
S103	Mobilize Crane On-Site	2	27-Nov-08*	28-Nov-08	12
S101	FRP Foundation Seq 04-6	5	02-Dec-08	08-Dec-08	15
S102	FRP Foundation Seq 07-9	5	09-Dec-08	15-Dec-08	20
S104	FRP Foundation Seq 10-12	5	17-Dec-08	23-Dec-08	19
S105	Errect Steel Seq 01	1	17-Dec-08	17-Dec-08	0
S106	Errect Steel Seq 02	1	18-Dec-08	18-Dec-08	0
S107	Errect Steel Seq 03	1	19-Dec-08	19-Dec-08	6
S108	Adj Steel Seq 01-2	1	19-Dec-08	19-Dec-08	0
S109	Errect Steel Seq 04	1	22-Dec-08	22-Dec-08	6
S111	Errect Steel Seq 05	1	23-Dec-08	23-Dec-08	13
S112	FRP Foundation Seq 13-15	5	24-Dec-08	30-Dec-08	33
S113	Errect Steel Seq 06	1	24-Dec-08	24-Dec-08	13
S115	Errect Steel Seq 07	1	25-Dec-08	25-Dec-08	14
S117	Errect Steel Seq 08	1	26-Dec-08	26-Dec-08	14
S118	Errect Steel Seq 09	1	29-Dec-08	29-Dec-08	15
S110	Install Metal Deck Seq 01-2	2	29-Dec-08	30-Dec-08	0
S120	Errect Steel Seq 10	1	30-Dec-08	30-Dec-08	15
S122	FRP Foundation Seq 16-17	5	31-Dec-08	06-Jan-09	33
S123	Errect Steel Seq 11	1	31-Dec-08	31-Dec-08	17
S114	Adj Steel Seq 03-4	1	31-Dec-08	31-Dec-08	0
S124	Errect Steel Seq 12	1	01-Jan-09	01-Jan-09	17
S116	Install Metal Deck Seq 03-4	2	01-Jan-09	02-Jan-09	0
S126	Errect Steel Seq 13	1	02-Jan-09	02-Jan-09	32
S128	Errect Steel Seq 14	1	05-Jan-09	05-Jan-09	32
S119	Adj Steel Seq 05-6	1	05-Jan-09	05-Jan-09	6
S129	Errect Steel Seq 15	1	06-Jan-09	06-Jan-09	33
S121	Install Metal Deck Seq 05-6	2	06-Jan-09	07-Jan-09	6



🟦 Actual Work 🟥 Critical Remaining Work ▼ Summary

🟩 Remaining Work ◆ ◆ Milestone

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TASK filter: All Activities

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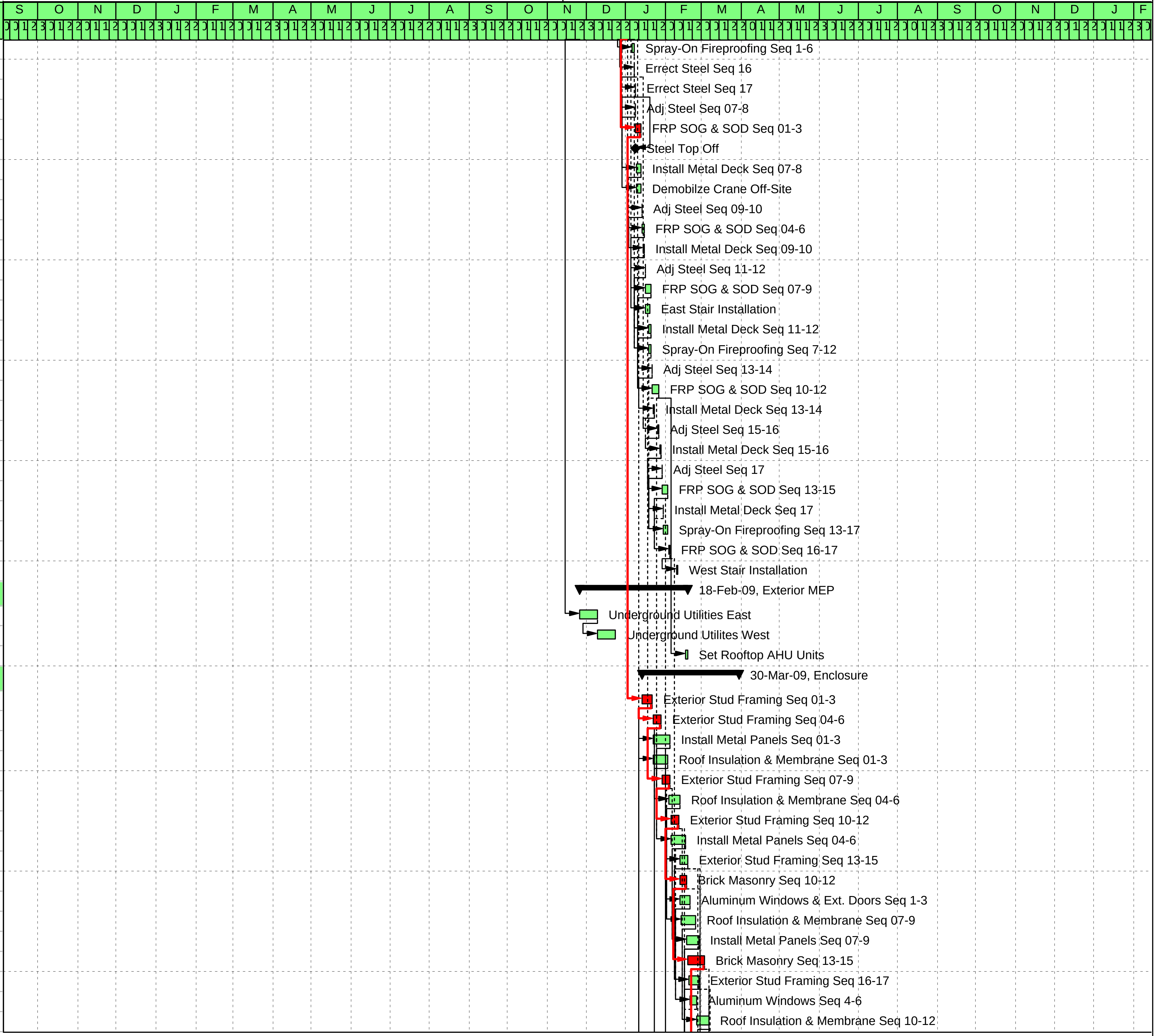
DITC

Classic WBS Layout

09-Mar-09 20:23

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
S150	Spray-On Fireproofing Seq 1-6	2	06-Jan-09	07-Jan-09	196
S131	Errect Steel Seq 16	1	07-Jan-09	07-Jan-09	33
S133	Errect Steel Seq 17	1	08-Jan-09	08-Jan-09	197
S125	Adj Steel Seq 07-8	1	08-Jan-09	08-Jan-09	6
S141	FRP SOG & SOD Seq 01-3	3	08-Jan-09	12-Jan-09	0
S134	Steel Top Off	0		08-Jan-09	199
S127	Install Metal Deck Seq 07-8	2	09-Jan-09	12-Jan-09	6
S136	Demobilze Crane Off-Site	2	09-Jan-09	12-Jan-09	197
S130	Adj Steel Seq 09-10	1	13-Jan-09	13-Jan-09	6
S144	FRP SOG & SOD Seq 04-6	3	13-Jan-09	15-Jan-09	4
S132	Install Metal Deck Seq 09-10	2	14-Jan-09	15-Jan-09	6
S135	Adj Steel Seq 11-12	1	16-Jan-09	16-Jan-09	7
S146	FRP SOG & SOD Seq 07-9	3	16-Jan-09	20-Jan-09	6
S147	East Stair Installation	2	16-Jan-09	19-Jan-09	192
S137	Install Metal Deck Seq 11-12	2	19-Jan-09	20-Jan-09	7
S152	Spray-On Fireproofing Seq 7-12	2	19-Jan-09	20-Jan-09	189
S138	Adj Steel Seq 13-14	1	21-Jan-09	21-Jan-09	21
S148	FRP SOG & SOD Seq 10-12	4	21-Jan-09	26-Jan-09	7
S139	Install Metal Deck Seq 13-14	2	22-Jan-09	23-Jan-09	21
S140	Adj Steel Seq 15-16	1	26-Jan-09	26-Jan-09	21
S142	Install Metal Deck Seq 15-16	2	27-Jan-09	28-Jan-09	21
S143	Adj Steel Seq 17	1	29-Jan-09	29-Jan-09	25
S149	FRP SOG & SOD Seq 13-15	3	29-Jan-09	02-Feb-09	21
S145	Install Metal Deck Seq 17	1	30-Jan-09	30-Jan-09	25
S153	Spray-On Fireproofing Seq 13-17	2	30-Jan-09	02-Feb-09	182
S151	FRP SOG & SOD Seq 16-17	2	03-Feb-09	04-Feb-09	24
S154	West Stair Installation	2	09-Feb-09	10-Feb-09	176
Exterior MEP		61	26-Nov-08	18-Feb-09	170
M100	Underground Utilities East	10	26-Nov-08	09-Dec-08	211
M101	Underground Utilites West	10	10-Dec-08	23-Dec-08	211
M102	Set Rooftop AHU Units	3	16-Feb-09	18-Feb-09	170
Enclosure		55	13-Jan-09	30-Mar-09	142
F100	Exterior Stud Framing Seq 01-3	7	13-Jan-09	21-Jan-09	0
F101	Exterior Stud Framing Seq 04-6	5	22-Jan-09	28-Jan-09	0
F104	Install Metal Panels Seq 01-3	10	22-Jan-09	04-Feb-09	1
F102	Roof Insulation & Membrane Seq 01-3	8	22-Jan-09	02-Feb-09	142
F103	Exterior Stud Framing Seq 07-9	5	29-Jan-09	04-Feb-09	0
F105	Roof Insulation & Membrane Seq 04-6	8	03-Feb-09	12-Feb-09	142
F106	Exterior Stud Framing Seq 10-12	5	05-Feb-09	11-Feb-09	0
F108	Install Metal Panels Seq 04-6	8	05-Feb-09	16-Feb-09	1
F107	Exterior Stud Framing Seq 13-15	5	12-Feb-09	18-Feb-09	14
F109	Brick Masonry Seq 10-12	4	12-Feb-09	17-Feb-09	0
F117	Aluminum Windows & Ext. Doors Seq 1-3	6	12-Feb-09	19-Feb-09	11
F110	Roof Insulation & Membrane Seq 07-9	8	13-Feb-09	24-Feb-09	142
F113	Install Metal Panels Seq 07-9	8	17-Feb-09	26-Feb-09	1
F111	Brick Masonry Seq 13-15	10	18-Feb-09	03-Mar-09	0
F112	Exterior Stud Framing Seq 16-17	6	19-Feb-09	26-Feb-09	14
F119	Aluminum Windows Seq 4-6	4	20-Feb-09	25-Feb-09	11
F114	Roof Insulation & Membrane Seq 10-12	8	25-Feb-09	06-Mar-09	142



🟦 Actual Work	🟥 Critical Remaining Work
🟩 Remaining Work	◆ Milestone
▬ Summary	

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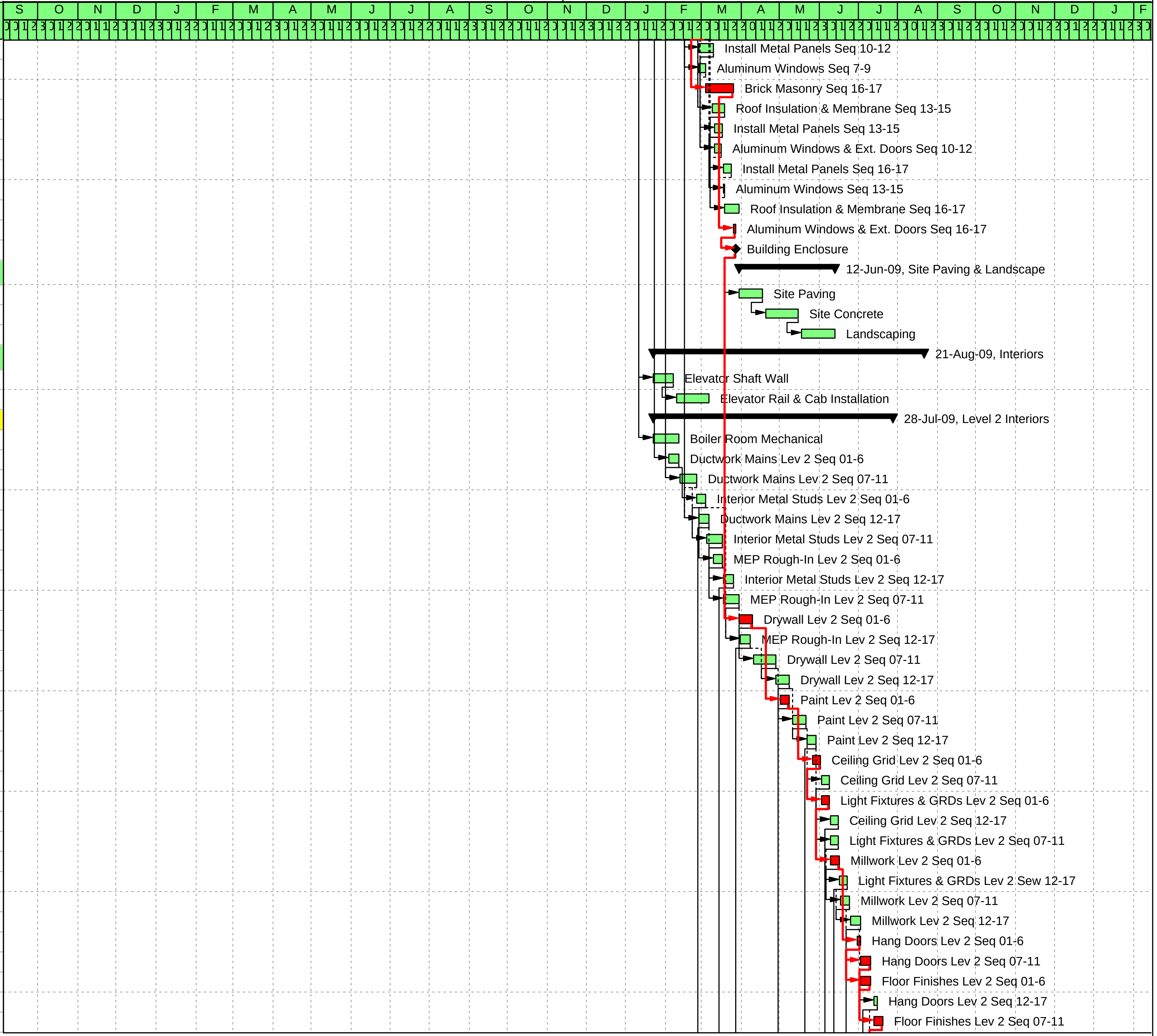
TASK filter: All Activities

DITC Classic WBS Layout 09-Mar-09 20:23

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
F116	Install Metal Panels Seq 10-12	8	27-Feb-09	10-Mar-09	1
F122	Aluminum Windows Seq 7-9	4	27-Feb-09	04-Mar-09	10
F115	Brick Masonry Seq 16-17	16	04-Mar-09	25-Mar-09	0
F118	Roof Insulation & Membrane Seq 13-15	8	09-Mar-09	18-Mar-09	142
F120	Install Metal Panels Seq 13-15	5	11-Mar-09	17-Mar-09	1
F124	Aluminum Windows & Ext. Doors Seq 1...	4	11-Mar-09	16-Mar-09	6
F123	Install Metal Panels Seq 16-17	5	18-Mar-09	24-Mar-09	1
F125	Aluminum Windows Seq 13-15	1	18-Mar-09	18-Mar-09	5
F121	Roof Insulation & Membrane Seq 16-17	8	19-Mar-09	30-Mar-09	142
F126	Aluminum Windows & Ext. Doors Seq 1...	2	26-Mar-09	27-Mar-09	0
F127	Building Enclosure	0		27-Mar-09	0
Site Paving & Landscape		55	30-Mar-09	12-Jun-09	88
C108	Site Paving	15	30-Mar-09	17-Apr-09	88
C109	Site Concrete	20	20-Apr-09	15-May-09	88
C110	Landscaping	20	18-May-09	12-Jun-09	88
Interiors		152	22-Jan-09	21-Aug-09	38
I100	Elevator Shaft Wall	12	22-Jan-09	06-Feb-09	158
I101	Elevator Rail & Cab Installation	20	09-Feb-09	06-Mar-09	158
Level 2 Interiors		134	22-Jan-09	28-Jul-09	56
I102	Boiler Room Mechanical	15	22-Jan-09	11-Feb-09	175
I103	Ductwork Mains Lev 2 Seq 01-6	7	03-Feb-09	11-Feb-09	8
I104	Ductwork Mains Lev 2 Seq 07-11	10	12-Feb-09	25-Feb-09	24
I106	Interior Metal Studs Lev 2 Seq 01-6	6	25-Feb-09	04-Mar-09	8
I105	Ductwork Mains Lev 2 Seq 12-17	6	27-Feb-09	06-Mar-09	30
I107	Interior Metal Studs Lev 2 Seq 07-11	9	05-Mar-09	17-Mar-09	19
I108	MEP Rough-In Lev 2 Seq 01-6	6	10-Mar-09	17-Mar-09	8
I109	Interior Metal Studs Lev 2 Seq 12-17	6	18-Mar-09	25-Mar-09	28
I110	MEP Rough-In Lev 2 Seq 07-11	9	18-Mar-09	30-Mar-09	19
I112	Drywall Lev 2 Seq 01-6	9	30-Mar-09	09-Apr-09	0
I111	MEP Rough-In Lev 2 Seq 12-17	6	31-Mar-09	07-Apr-09	25
I113	Drywall Lev 2 Seq 07-11	12	10-Apr-09	27-Apr-09	11
I115	Drywall Lev 2 Seq 12-17	9	28-Apr-09	08-May-09	11
I114	Paint Lev 2 Seq 01-6	6	01-May-09	08-May-09	0
I116	Paint Lev 2 Seq 07-11	9	11-May-09	21-May-09	11
I118	Paint Lev 2 Seq 12-17	6	22-May-09	29-May-09	11
I117	Ceiling Grid Lev 2 Seq 01-6	5	26-May-09	01-Jun-09	0
I119	Ceiling Grid Lev 2 Seq 07-11	5	02-Jun-09	08-Jun-09	7
I120	Light Fixtures & GRDs Lev 2 Seq 01-6	5	02-Jun-09	08-Jun-09	0
I121	Ceiling Grid Lev 2 Seq 12-17	5	09-Jun-09	15-Jun-09	8
I122	Light Fixtures & GRDs Lev 2 Seq 07-11	5	09-Jun-09	15-Jun-09	7
I123	Millwork Lev 2 Seq 01-6	6	09-Jun-09	16-Jun-09	0
I124	Light Fixtures & GRDs Lev 2 Sew 12-17	5	16-Jun-09	22-Jun-09	8
I125	Millwork Lev 2 Seq 07-11	6	17-Jun-09	24-Jun-09	6
I126	Millwork Lev 2 Seq 12-17	6	25-Jun-09	02-Jul-09	6
I127	Hang Doors Lev 2 Seq 01-6	3	30-Jun-09	02-Jul-09	0
I128	Hang Doors Lev 2 Seq 07-11	6	03-Jul-09	10-Jul-09	0
I129	Floor Finishes Lev 2 Seq 01-6	6	03-Jul-09	10-Jul-09	0
I130	Hang Doors Lev 2 Seq 12-17	3	13-Jul-09	15-Jul-09	3
I131	Floor Finishes Lev 2 Seq 07-11	6	13-Jul-09	20-Jul-09	0



🟦 Actual Work 🟥 Critical Remaining Work ▼ Summary
🟩 Remaining Work ◆ ◆ Milestone

Shane Goodman - Thesis Report

TASK filter: All Activities

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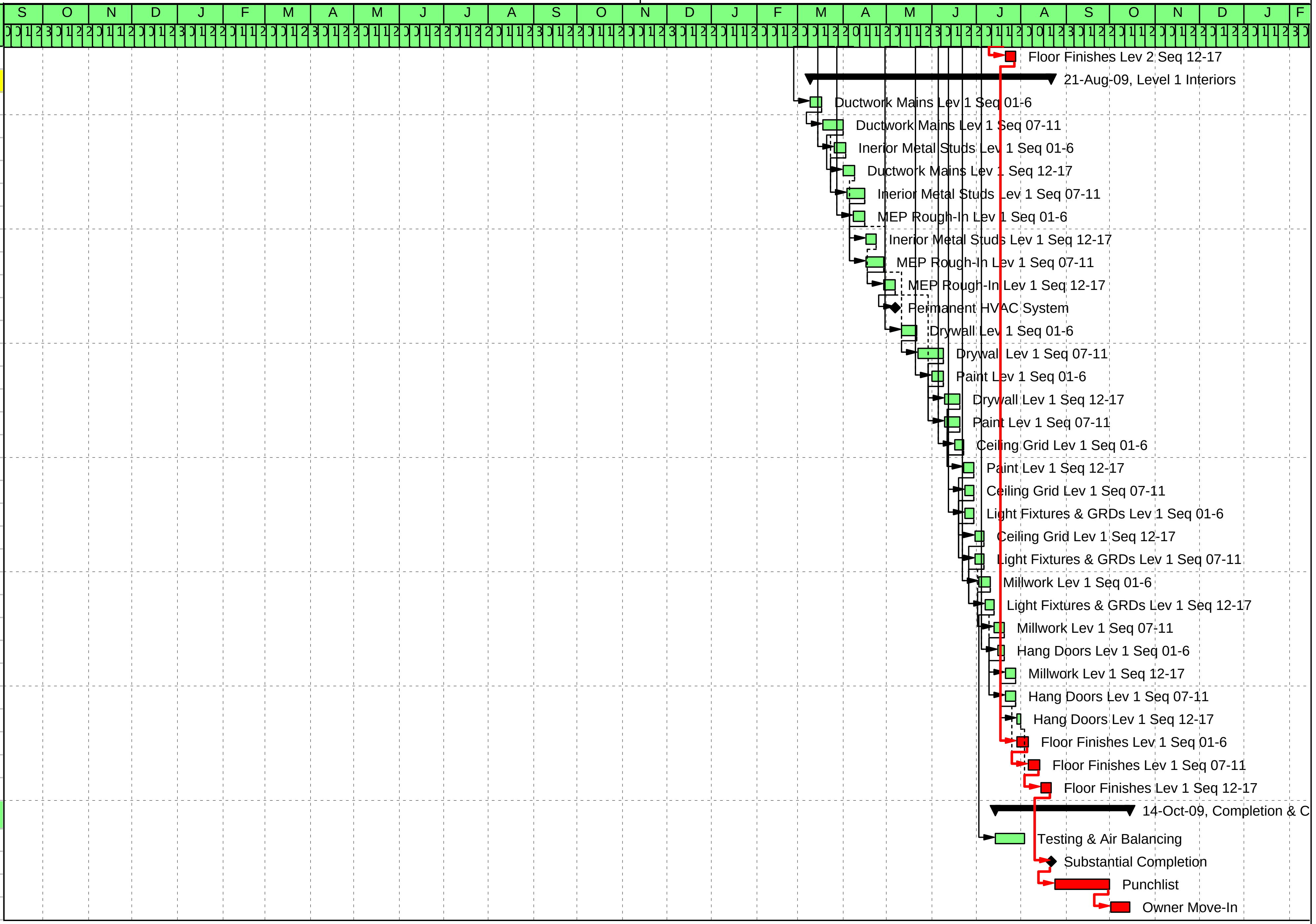
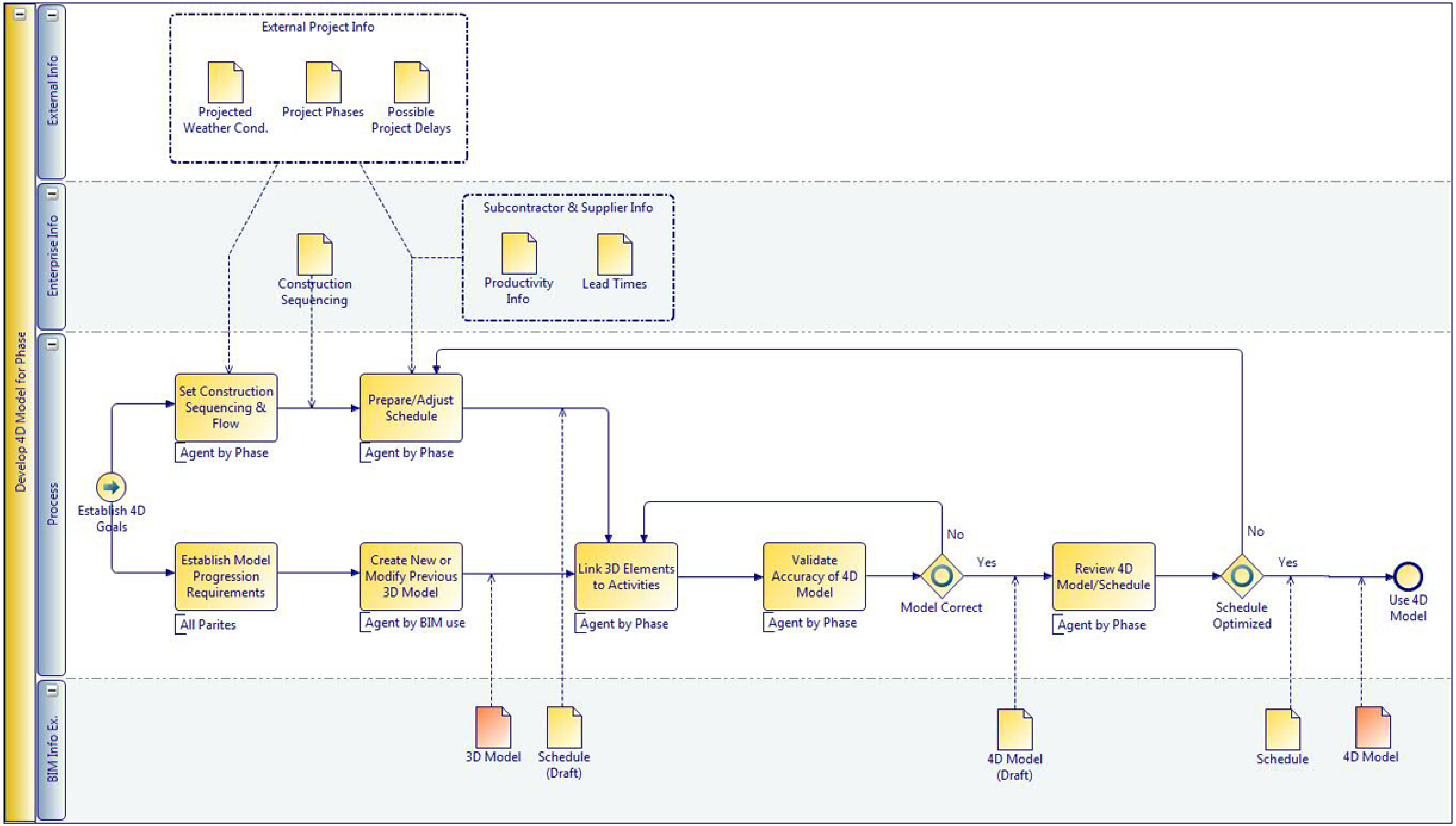
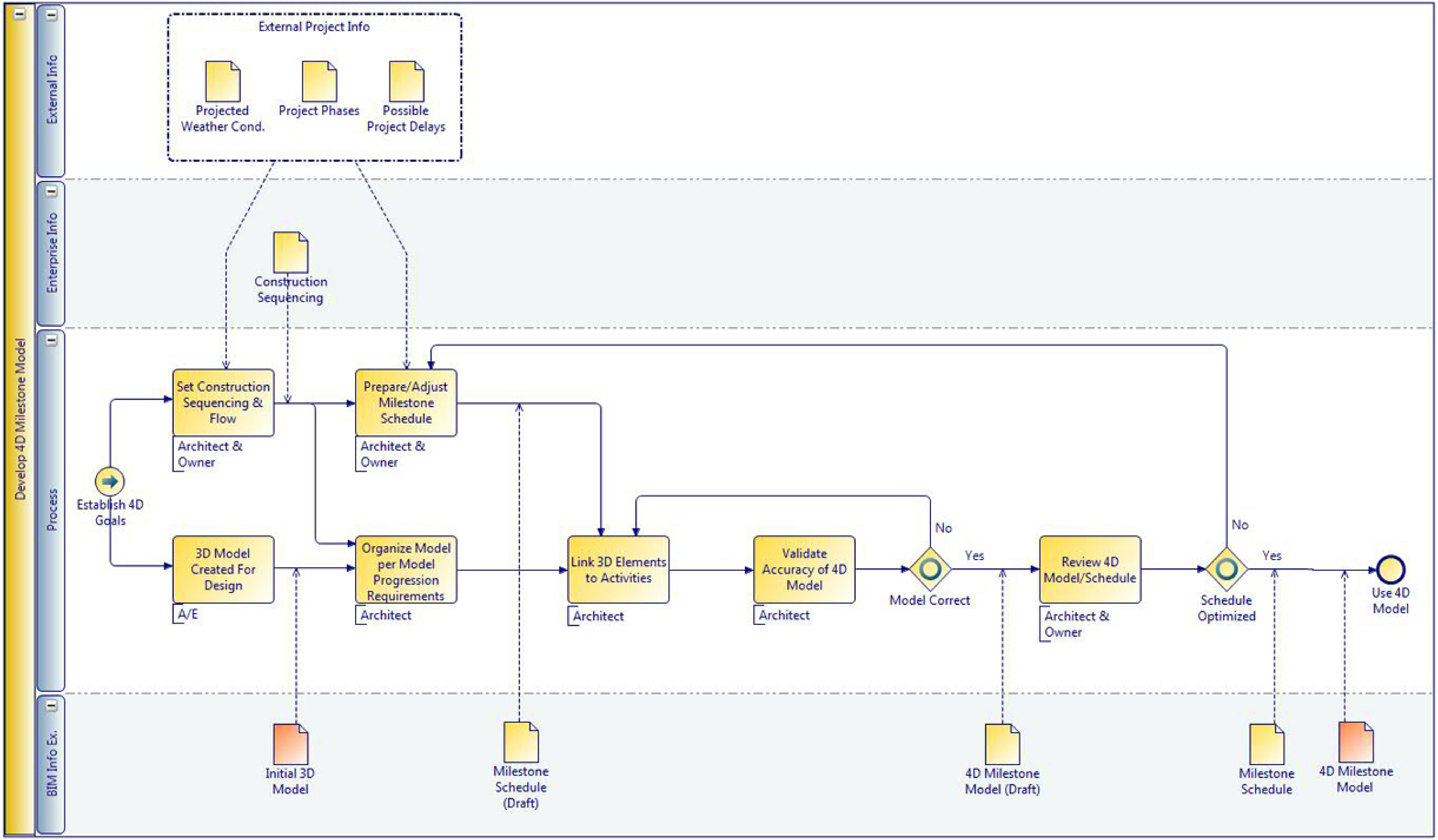
Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
I132	Floor Finishes Lev 2 Seq 12-17	6	21-Jul-09	28-Jul-09	0
Level 1 Interiors		120	09-Mar-09	21-Aug-09	38
I133	Ductwork Mains Lev 1 Seq 01-6	7	09-Mar-09	17-Mar-09	30
I134	Ductwork Mains Lev 1 Seq 07-11	10	18-Mar-09	31-Mar-09	30
I135	Inerior Metal Studs Lev 1 Seq 01-6	6	26-Mar-09	02-Apr-09	28
I136	Ductwork Mains Lev 1 Seq 12-17	6	01-Apr-09	08-Apr-09	45
I137	Inerior Metal Studs Lev 1 Seq 07-11	9	03-Apr-09	15-Apr-09	28
I138	MEP Rough-In Lev 1 Seq 01-6	6	08-Apr-09	15-Apr-09	28
I139	Inerior Metal Studs Lev 1 Seq 12-17	6	16-Apr-09	23-Apr-09	40
I140	MEP Rough-In Lev 1 Seq 07-11	9	16-Apr-09	28-Apr-09	28
I141	MEP Rough-In Lev 1 Seq 12-17	6	29-Apr-09	06-May-09	37
I142	Permanent HVAC System	0		06-May-09	115
I143	Drywall Lev 1 Seq 01-6	9	11-May-09	21-May-09	11
I144	Drywall Lev 1 Seq 07-11	12	22-May-09	08-Jun-09	11
I145	Paint Lev 1 Seq 01-6	6	01-Jun-09	08-Jun-09	11
I146	Drywall Lev 1 Seq 12-17	9	09-Jun-09	19-Jun-09	14
I147	Paint Lev 1 Seq 07-11	9	09-Jun-09	19-Jun-09	11
I148	Ceiling Grid Lev 1 Seq 01-6	5	16-Jun-09	22-Jun-09	9
I149	Paint Lev 1 Seq 12-17	6	22-Jun-09	29-Jun-09	14
I150	Ceiling Grid Lev 1 Seq 07-11	5	23-Jun-09	29-Jun-09	10
I151	Light Fixtures & GRDs Lev 1 Seq 01-6	5	23-Jun-09	29-Jun-09	9
I152	Ceiling Grid Lev 1 Seq 12-17	5	30-Jun-09	06-Jul-09	14
I153	Light Fixtures & GRDs Lev 1 Seq 07-11	5	30-Jun-09	06-Jul-09	10
I154	Millwork Lev 1 Seq 01-6	6	03-Jul-09	10-Jul-09	6
I155	Light Fixtures & GRDs Lev 1 Seq 12-17	5	07-Jul-09	13-Jul-09	14
I156	Millwork Lev 1 Seq 07-11	6	13-Jul-09	20-Jul-09	6
I157	Hang Doors Lev 1 Seq 01-6	3	16-Jul-09	20-Jul-09	6
I158	Millwork Lev 1 Seq 12-17	6	21-Jul-09	28-Jul-09	9
I159	Hang Doors Lev 1 Seq 07-11	6	21-Jul-09	28-Jul-09	6
I160	Hang Doors Lev 1 Seq 12-17	3	29-Jul-09	31-Jul-09	9
I161	Floor Finishes Lev 1 Seq 01-6	6	29-Jul-09	05-Aug-09	0
I162	Floor Finishes Lev 1 Seq 07-11	6	06-Aug-09	13-Aug-09	0
I163	Floor Finishes Lev 1 Seq 12-17	6	14-Aug-09	21-Aug-09	0
Completion & Closeout		67	14-Jul-09	14-Oct-09	0
A109	Testing & Air Balancing	15	14-Jul-09	03-Aug-09	52
A110	Substantial Completion	0		21-Aug-09	0
A111	Punchlist	28	24-Aug-09	30-Sep-09	0
A112	Owner Move-In	10	01-Oct-09	14-Oct-09	0

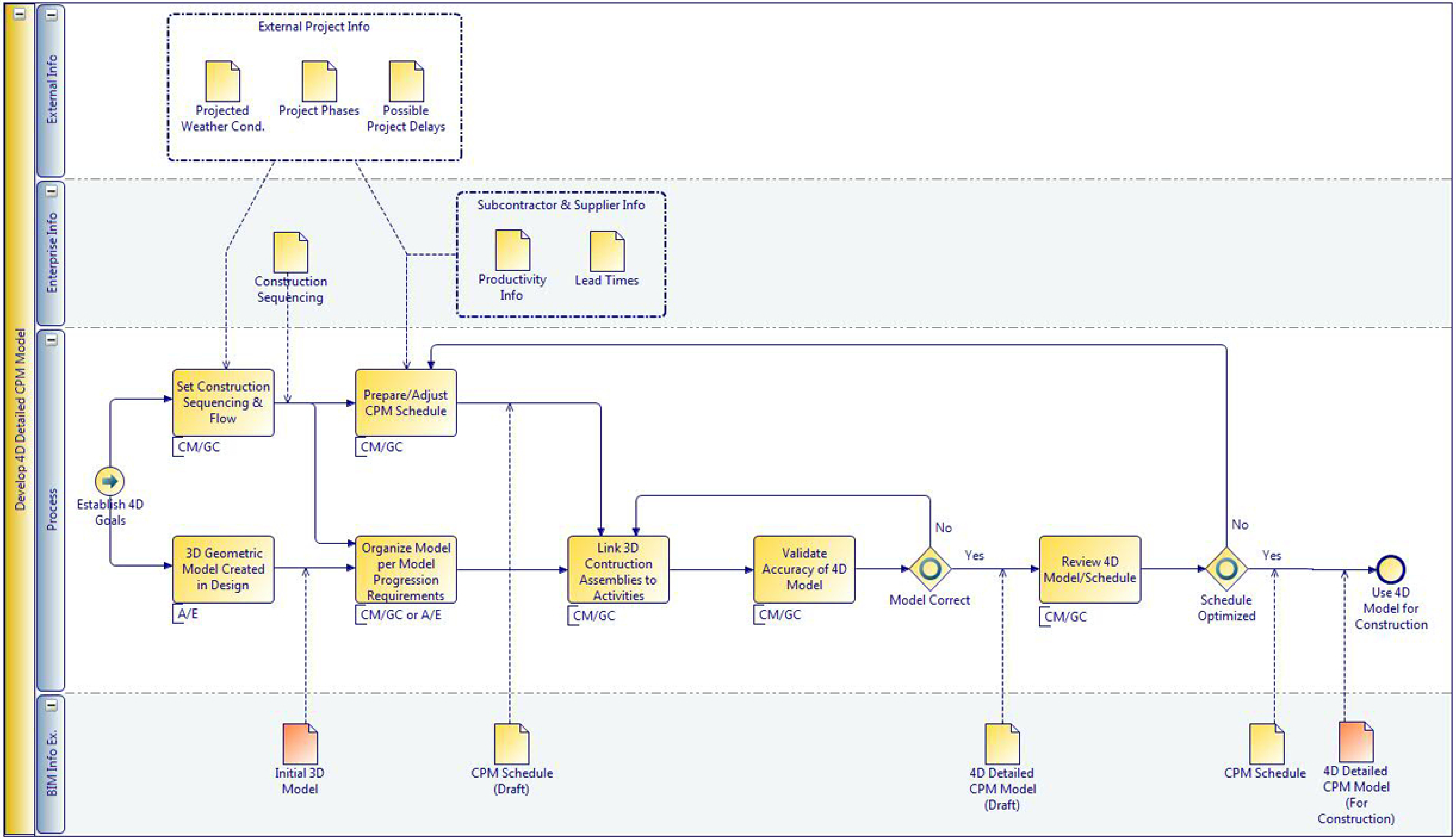


🟦 Actual Work 🟥 Critical Remaining Work ▬ Summary
🟩 Remaining Work ◆ ◆ Milestone

Appendix B: 4D Process Maps


Develop 4D Model for Phase
External Info
Enterprise Info
Process
BIM Info Ex.
External Project Info
Projected Weather Cond.
Project Phases
Possible Project Delays
Subcontractor & Supplier Info
Productivity Info
Lead Times
Construction Sequencing
Set Construction Sequencing & Flow
Agent by Phase
Prepare/Adjust Schedule
Agent by Phase
Establish 4D Goals
Establish Model Progression Requirements
All Parites
Create New or Modify Previous 3D Model
Agent by BIM use
Link 3D Elements to Activities
Agent by Phase
Validate Accuracy of 4D Model
Agent by Phase
No
Yes
Model Correct
Review 4D Model/Schedule
Agent by Phase
No
Yes
Schedule Optimized
Use 4D Model
3D Model
Schedule (Draft)
4D Model (Draft)
Schedule
4D Model

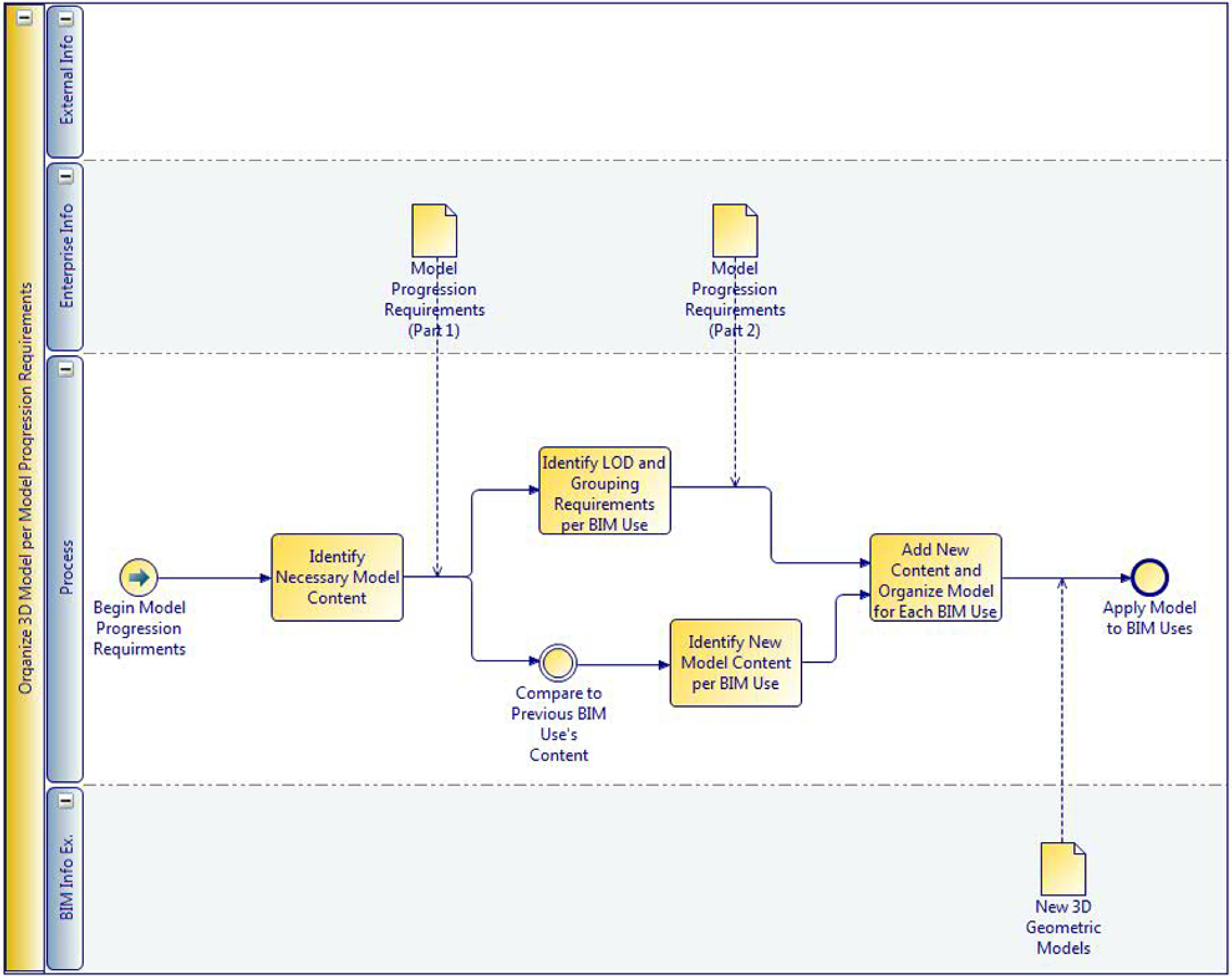

Develop 4D Milestone Model
External Info
Enterprise Info
Process
BIM Info Ex.
External Project Info
Projected Weather Cond.
Project Phases
Possible Project Delays
Construction Sequencing
Establish 4D Goals
Set Construction Sequencing & Flow
Architect & Owner
Prepare/Adjust Milestone Schedule
Architect & Owner
3D Model Created For Design
A/E
Organize Model per Model Progression Requirements
Architect
Link 3D Elements to Activities
Architect
Validate Accuracy of 4D Model
Architect
No
Yes
Model Correct
Review 4D Model/Schedule
Architect & Owner
No
Yes
Schedule Optimized
Use 4D Model
Initial 3D Model
Milestone Schedule (Draft)
4D Milestone Model (Draft)
Milestone Schedule
4D Milestone Model


Develop 4D Detailed CPM Model
External Info
Enterprise Info
Process
BIM Info Ex.
External Project Info
Projected Weather Cond.
Project Phases
Possible Project Delays
Subcontractor & Supplier Info
Construction Sequencing
Productivity Info
Lead Times
Establish 4D Goals
Set Construction Sequencing & Flow
CM/GC
Prepare/Adjust CPM Schedule
CM/GC
3D Geometric Model Created in Design
A/E
Organize Model per Model Progression Requirements
CM/GC or A/E
Link 3D Contruction Assemblies to Activities
CM/GC
Validate Accuracy of 4D Model
CM/GC
No
Yes
Model Correct
Review 4D Model/Schedule
CM/GC
No
Yes
Schedule Optimized
Use 4D Model for Construction
Initial 3D Model
CPM Schedule (Draft)
4D Detailed CPM Model (Draft)
CPM Schedule
4D Detailed CPM Model (For Construction)

Appendix C: Model Progression Requirements

Model Progression Requirements

Identify Model Content (Part 1)	Identify Model Content Requirements (Part 2)							
Model Content	Use 1:		Use 2:		Use 3:		Use 4:	
Foundations	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping
Basement Construction	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping
Superstructure	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping
Exterior Closure	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping
Roofing	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping
Interior Construction	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping
Staircases	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping
Interior Finishes	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping
Conveying Systems	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping
Plumbing	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping
HVAC	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping
Fire Protection	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping
Electrical	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping
Equipment	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping
Furnishings	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping
Special Construction	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping
Building Sitework	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping
Construction Systems and Equipment	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping
Temporary Safety and Security	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping
Temporary Facilities & Weather Protect.	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping
Construction Activity Space	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping
Project Information	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping
Facilty Spaces	LOD	Grouping	LOD	Grouping	LOD	Grouping	LOD	Grouping


Organize 3D Model per Model Progression Requirements
External Info
Enterprise Info
Process
BIM Info Ex.
Model Progression Requirements (Part 1)
Model Progression Requirements (Part 2)
Begin Model Progression Requirments
Identify Necessary Model Content
Identify LOD and Grouping Requirements per BIM Use
Compare to Previous BIM Use's Content
Identify New Model Content per BIM Use
Add New Content and Organize Model for Each BIM Use
Apply Model to BIM Uses
New 3D Geometric Models

Model Progression Requirements - Detroit Integrated Transportation Campus

Identify Model Content (Part 1)	Identify Model Content Requirements (Part 2)					
Model Content	Use 1: 3D Design Coordination		Use 2: 4D Milestone Model		Use 3: 4D Detailed CPM Model	
Foundations	LOD	Grouping	LOD	Grouping	LOD	Grouping
Standard Foundations	N/A	N/A	Modeled as Activity Space - Foundations	All Foundations as one Activity	Modeled as Activity Space - Foundations	Divide by Sequence
Slab on Grade	Slab Assembly - One Element	Slabs By Type	Slab Assembly - One Element	Group with 2nd Floor Slab	Slab Assembly - One Element	Divide by Pour
Basement Construction	LOD	Grouping	LOD	Grouping	LOD	Grouping
Basement Walls	N/A	N/A	N/A	N/A	N/A	N/A
Superstructure	LOD	Grouping	LOD	Grouping	LOD	Grouping
Floor Construction	Slab Assembly - One Element Structural Steel - Size and Length No Connections	Slabs Divided By Type Structural Steel Divided by piece	Slab Assembly - One Element Beams & Columns - Size and Length No Connections	Group with Slab on Grade; Structural Steel - Group with All Structural Steel	Slab Assembly - One Element Structural Steel - Size and Length No Connections	Slabs - Divide by Pour; Structural Steel - Group with Roof Steel by Sequence
Roof Construction	Slab Assembly - One Element Structural Steel - Size and Length No Connections	Slabs Divided By Type Structural Steel Divided by piece	Slab Assembly - One Element Beams & Columns - Size and Length No Connections	Whole Roof - Group Together; Structural Steel - Group with All Structural Steel	Slab Assembly - One Element Structural Steel - Size and Length No Connections	Slabs - Divide by Pour; Structural Steel - Group with Floor Steel by Sequence
Exterior Closure	LOD	Grouping	LOD	Grouping	LOD	Grouping
Exterior Walls	Wall Assembly - One Element	Divided by Type and Span	Wall Assembly - One Element	Whole Exterior Façade - Group Together	Wall Assembly - One Element	Divide by Sequence
Exterior Windows	Unitary Window - One Element Curtain Wall Window - One Element	Unitary Windows Individually Curtian Wall Windows Divided by Span	Unitary Window - One Element Curtain Wall Window - One Element	Group with Exterior Façade	Unitary Window - One Element Curtain Wall Window - One Element	Group with Doors ; Group Unitary Windows by Sequence and Divide Curtain Wall Windows by Sequence
Exteriror Doors	Door Assembly	Each Door Assembly Grouped as One Doors Diveded Individually	Door Assembly	Group with Exterior Façade	Door Assembly	Group with Windows; Group by Sequence
Roofing	LOD	Grouping	LOD	Grouping	LOD	Grouping
Roof Coverings	N/A	N/A	N/A	N/A	Included in Roof Slab Assembly; Represent Activity by Color in 4D	Divide by Sequence
Roof Openings	Opening In Slab	Individually	N/A	N/A	Included in Slab Assemblies	See Slab Grouping
Interior Construction	LOD	Grouping	LOD	Grouping	LOD	Grouping
Partitions	Wall Assembly - One Element	Divided by Type and Span	Wall Assembly - One Element	Group with Interior Work Divided by Floor	Wall Assembly - One Element; Represent Different Wall Activities by Color in 4D	Group and Divide by Sequence
Interior Doors	Door Assembly	Each Door Assembly Grouped as One Doors Diveded Individually	Door Assembly	Group with Interior Work Divided by Floor	Door Assembly	Group by Sequence
Staircases	LOD	Grouping	LOD	Grouping	LOD	Grouping
Stair Construction	Stair Structure and Railings	Structure Individually Railings Individually	Stair Structure	Group with All Structural Steel	Stair Structure	Stair Structures Individually
C30 - Interior Finishes	LOD	Grouping	LOD	Grouping	LOD	Grouping
Wall Finishes	Within Wall Assembly	Grouped with Wall	Included in Wall Assembly	Group with Interior Work Divided by Floor	Included in Wall Assembly; Represent Activity by Color in 4D	Group and Divide by Sequence
Floor Finishes	Within Floor Assembly	Grouped with Floor	Included in Floor Assembly	Group with Interior Work Divided by Floor	Included in Floor Assembly; Represent Activity by Color in 4D	Divide by Sequence
Ceiling Finishes	Within Ceiling Assembly	Grouped with Ceiling	Included in Ceiling Assembly	Group with Interior Work Divided by Floor	Included in Ceiling Assembly; Represent Activity by Color in 4D	Group and Divde by Sequence
Conveying Systems	LOD	Grouping	LOD	Grouping	LOD	Grouping
Elevators	Elevator Shaft Only	Individually	Elevator Shaft Only	Group with Structural Steel	Elevator Shaft Only	N/A
Plumbing	LOD	Grouping	LOD	Grouping	LOD	Grouping
Plumbing Fixtures	Assembly	Individually	Model as Activity Space - Interior Work	Group with Interior Work Divided by Floor	Model as Activity Space - Millwork	See Activity Space - Millwork
Water Distribution	N/A	N/A	Model as Activity Space - Interior Work	Group with Interior Work Divided by Floor	Model as Activity Space - MEP Rough-In	See Activity Space - MEP Rough-In

Model Progression Requirements - Detroit Integrated Transportation Campus

Identify Model Content (Part 1)	Identify Model Content Requirements (Part 2)					
Model Content	Use 1: 3D Design Coordination		Use 2: 4D Milestone Model		Use 3: 4D Detailed CPM Model	
Sanitary Waste	N/A	N/A	Model as Activity Space - Interior Work	Group with Interior Work Divided by Floor	Model as Activity Space - MEP Rough-In	See Activity Space - MEP Rough-In
Rain Water Drainage	N/A	N/A	Model as Activity Space - Interior Work	Group with Interior Work Divided by Floor	Model as Activity Space - MEP Rough-In	See Activity Space - MEP Rough-In
HVAC	LOD	Grouping	LOD	Grouping	LOD	Grouping
Heat Generating Systems	N/A	N/A	N/A	N/A	HVAC Rooftop Units	Group with Cooling Systems
Cooling Generating Systems	N/A	N/A	N/A	N/A	HVAC Rooftop Units	Group with Heat Generating Systems
Distribution Systems	N/A	N/A	Model as Activity Space - Interior Work	Group with Interior Work Divided by Floor	Model as Activity Space - Ductwork Mains	See Activity Space - Ductwork Mains
Terminal & Pacage Units	N/A	N/A	Model as Activity Space - Interior Work	Group with Interior Work Divided by Floor	Model as Activity Space - MEP Rough-In	See Activity Space - MEP Rough-In
Controls & Instruments	N/A	N/A	Model as Activity Space - Interior Work	Group with Interior Work Divided by Floor	Model as Activity Space - Light Fixtures and GRD's	See Activity Space - Light Fixtures and GRD's
Testing & Balancing	N/A	N/A	Model as Activity Space - MEP Testing & Balancing	Group as One	Model as Activity Space - MEP Testing and Balancing	See Activity Space - MEP Testing and Balancing
Fire Protection	LOD	Grouping	LOD	Grouping	LOD	Grouping
Sprinkler System	N/A	N/A	Model as Activity Space - Interior Work	Group with Interior Work Divided by Floor	Model as Activity Space - MEP Rough-In	See Activity Space - MEP Rough-In
Electrical	LOD	Grouping	LOD	Grouping	LOD	Grouping
Electrical Service & Distribution	N/A	N/A	Model as Activity Space - Interior Work	Group with Interior Work Divided by Floor	Model as Activity Space - MEP Rough-In	Model as Activity Space - MEP Rough-In
Lighting & Branch Wiring	N/A	N/A	Model as Activity Space - Interior Work	Group with Interior Work Divided by Floor	Model as Activity Space - Light Fixtures and GRD's	See Activity Space - Light Fixtures and GRD's
Equipment	LOD	Grouping	LOD	Grouping	LOD	Grouping
Institutional Equipment	N/A	N/A	N/A	N/A	N/A	N/A
Furnishings	LOD	Grouping	LOD	Grouping	LOD	Grouping
Fixed Funishings & Millwork	Assembly by Unit	Individually	Model as Activity Space - Interior Work	Group with Interior Work Divided by Floor	Model as Activity Space - Millwork	See Activity Space - Millwork
Special Construction	LOD	Grouping	LOD	Grouping	LOD	Grouping
Vertical and Horizontal Sun Screens	Support and Sceens, No Connections	Individually	N/A	N/A	N/A	N/A
Building Sitework	LOD	Grouping	LOD	Grouping	LOD	Grouping
Site Demolition	N/A	N/A	Building Site - One Element	Group With Site Earthwork	Building Site - One Element; Represent Activity by Color in 4D	All Site Demolition
Site Earthwork	N/A	N/A	Building Site - One Element	Group With Site Demolition	Building Site - One Element; Represent Activity by Color in 4D	All Site Earthwork
Underground Utilities	N/A	N/A	N/A	N/A	Model as Activity Space - Underground Utilities	See Activity Space - Underground Utilities
Landscaping	N/A	N/A	N/A	N/A	Building Site - One Element; Represent Activity by Color in 4D	All Site Landscaping
Construction Systems and Equipment	LOD	Grouping	LOD	Grouping	LOD	Grouping
Cranes	N/A	N/A	N/A	N/A	Model a Crane at each lifting location	One crane location grouped with each Steel Sequence
Scaffolding	N/A	N/A	N/A	N/A	Model as simple scaffolding at brick location	Group with Brick Façade; Divide by Sequence
Site Dumpsters	N/A	N/A	N/A	N/A	N/A	N/A
Site Vehicles	N/A	N/A	N/A	N/A	Model generic vehicles in parking space	Not associated with any construction activity
Temporary Safety and Security	LOD	Grouping	LOD	Grouping	LOD	Grouping

Model Progression Requirements - Detroit Integrated Transportation Campus

Identify Model Content (Part 1)	Identify Model Content Requirements (Part 2)					
Model Content	Use 1: 3D Design Coordination		Use 2: 4D Milestone Model		Use 3: 4D Detailed CPM Model	
Site Fence	N/A	N/A	N/A	N/A	Model as Generic Site Fence	Group with Site Earthwork
Temporary Facilities & Weather Protect.	LOD	Grouping	LOD	Grouping	LOD	Grouping
Site Trailors	N/A	N/A	N/A	N/A	Model Generic Trailors in Trailor Space	Associated with Site Mobilization Activity
Portable Toilets	N/A	N/A	N/A	N/A	N/A	N/A
Construction Activity Space	LOD	Grouping	LOD	Grouping	LOD	Grouping
Underground Utilities	N/A	N/A	N/A	N/A	x	Divide by Sequence
Ductwork Mains	N/A	N/A	Rectangular Masses	Group with Interior Work Divided by Floor	x	Divide by Sequence
MEP Testing & Balancing	N/A	N/A	Rectangular Masses	Whole Building	x	Divide by Sequence
MEP Rough-In	N/A	N/A	Rectangular Masses	Group with Interior Work Divided by Floor	x	Divide by Sequence
Light Fixtures and GRD's	N/A	N/A	Rectangular Masses	Group with Interior Work Divided by Floor	x	Divide by Sequence
Millwork	N/A	N/A	Rectangular Masses	Group with Interior Work Divided by Floor	x	Divide by Sequence
Foundation Excavation	N/A	N/A	N/A	N/A	x	Divide by Sequence
Interior Work	N/A	N/A	Rectangular Masses	Divided by Floor	N/A	N/A
Project Information	LOD	Grouping	LOD	Grouping	LOD	Grouping
Schedule	N/A	N/A	Executive level Master Summary Controll Schedule	Diveded by Activity	Detailed Integrated Schedule	Divide by Activity
Facility Room Designations	Room Name, Number, and SF	By Space Type	N/A	N/A	N/A	N/A
Facilty Spaces	LOD	Grouping	LOD	Grouping	LOD	Grouping
Rooms & Cooridors	Designation and Boundaries	By Space Type	N/A	N/A	N/A	N/A

Appendix D: Precast Structural Calculations

Basic Wind Speed (3-Second Gust) : 90 MPH

Wind Importance Factor : 1.15

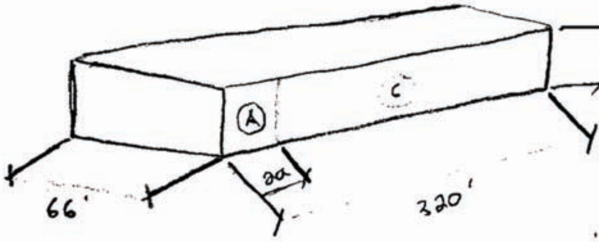
Exposure Category : B

Internal Pressure Coefficient : +/- .18

Components and Cladding per Code Requirements (Values listed based on 100 sq. ft effective wind area)

a. Interior Zone : 16 PSF

b. Exterior Zone & Corner Zone : 18 PSF

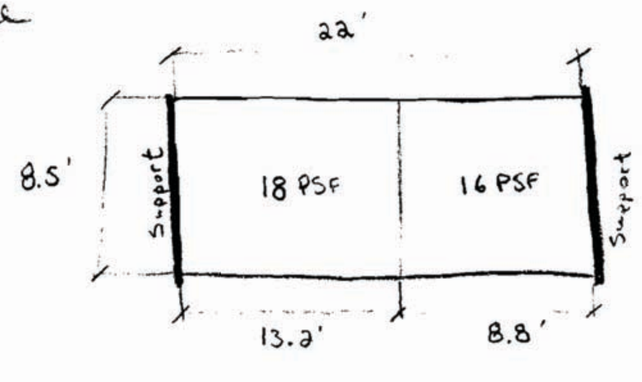


$2a = 66' \times .2 = 13.2'$ (least)

Ⓐ $P_{s30} = 12.8$ Ⓒ $P_{s30} = 8.5$

An end zone panel in zone Ⓐ will be analyzed for windload as it has the longest span and the greatest wind pressure.

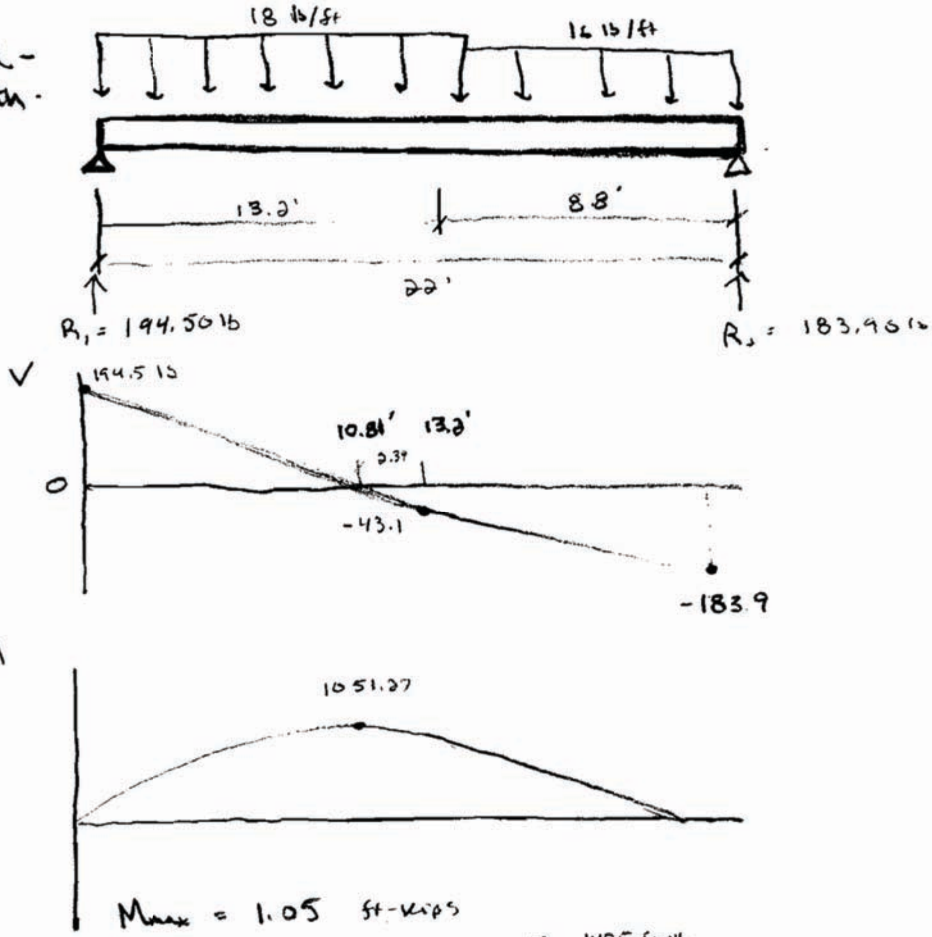
Panel



18 PSF × 1' section = 18 lb/ft

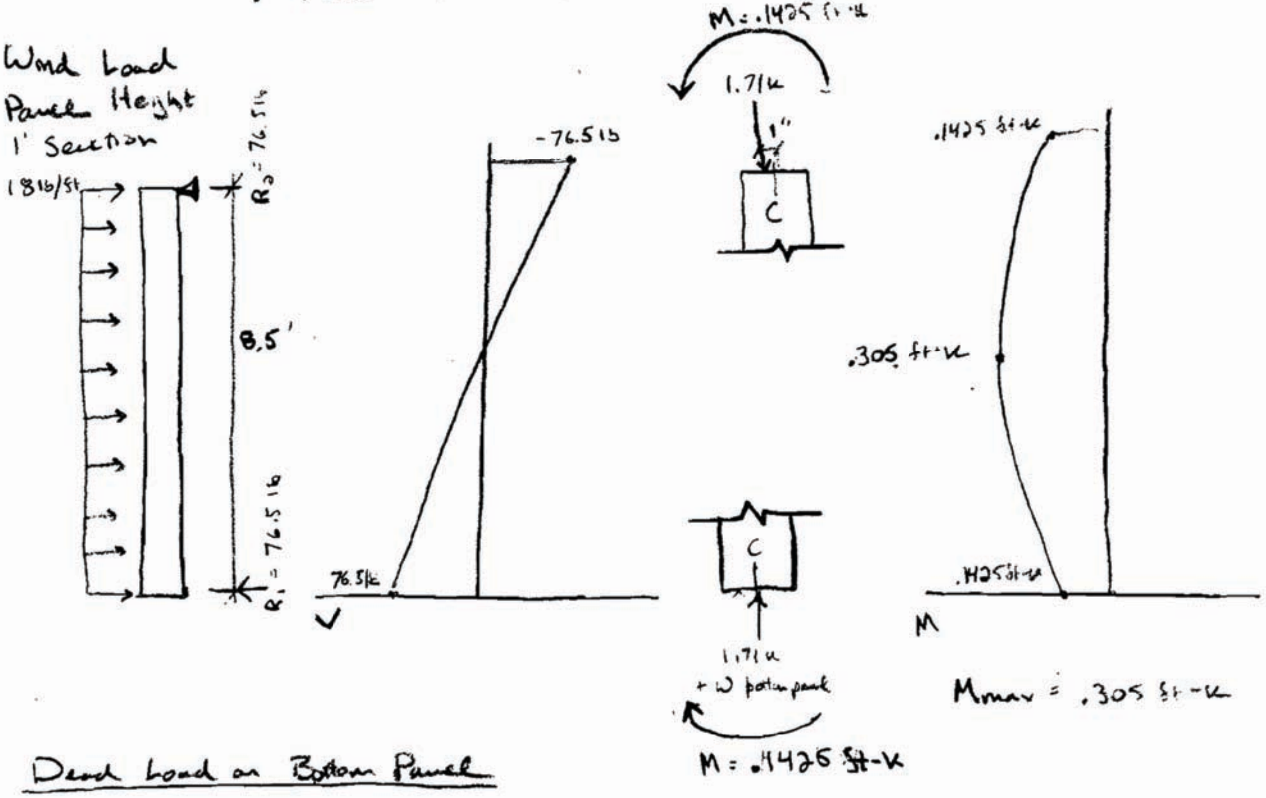
16 PSF × 1' section = 16 lb/ft

Wind Load -
Panel Width -
1' Section



M_{max} = 1.05 ft-kips

Wind Load
Panel Height
1' Section



M_{max} = .305 ft-k

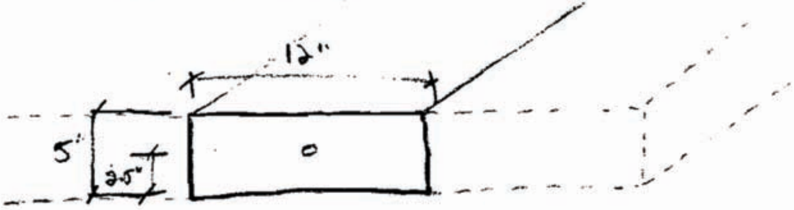
Dead Load on Bottom Panel

17' x 22' x .67' x .150 kips/ft³ = 37.6 kips

37.6 kips / 22' = 1.71 kips / ft

Reaction @ Panel base = 1.71 + [(8.5)(.67')(.150)] = 2.56 kips

Flexure Check
of Panel Height (8.5')
as a 1' beam



f'c = 5000 psi β_1 = .80   Mu = .305 ft-k ϕ = .9
= 3.66 in-k
d = 2.5"   h = 5"   b = 12"   fy steel = 60 ksi

Minimum Steel

$$A_s \ge \frac{3\sqrt{f'c}}{f_y}\,bd = \frac{3\sqrt{5000}}{60\times 1000}(2.5)(12) = .106 \text{ in}^2$$

$$\ge \frac{200\,bd}{f_y} = \frac{200\,(2.5)(12)}{60\times 1000} = .1 \text{ in}^2$$

ϕM_n * use # 4 bars @ 1' - A_s = .20 in²

$$M_n = A_s f_y (d - a/2)$$

$$a = \frac{A_s f_y}{.85 f'c\, b} = \frac{.20\,(60\text{ ksi})}{.85\,(5\text{ ksi})(12")} = .236"$$

$$M_n = (.20)(60)(2.5 - .236/2) = 28.59\text{ "k}$$

$$= 2.38\text{ 'k}$$

$$\boxed{\phi M_n = 2.14\text{ 'k}}$$

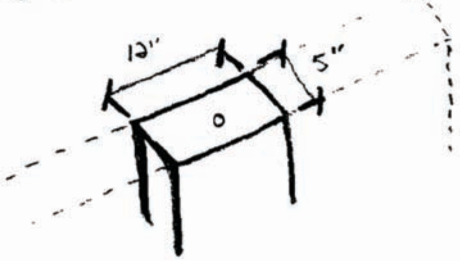
= 25.68 in-kips

Minimum thickness for Deflection

simply supported solid one-way slabs

$$\ell/20 = 8.5(12)/20 = 5.1"$$

Compressive Design
at Panel Height
as a 1' beam



$f'_c = 5000\,psi$ $\beta_1 = .80$ $\phi = .65$

$h = 5"$ $b = 12"$ f_y steel $= 60ksi$ $P_u = 2.56$ kips

$$P_n = .85 f'_c A_c + A_s f_y$$

$A_s = .20 \, in^2$ (from flexural design at panel height)

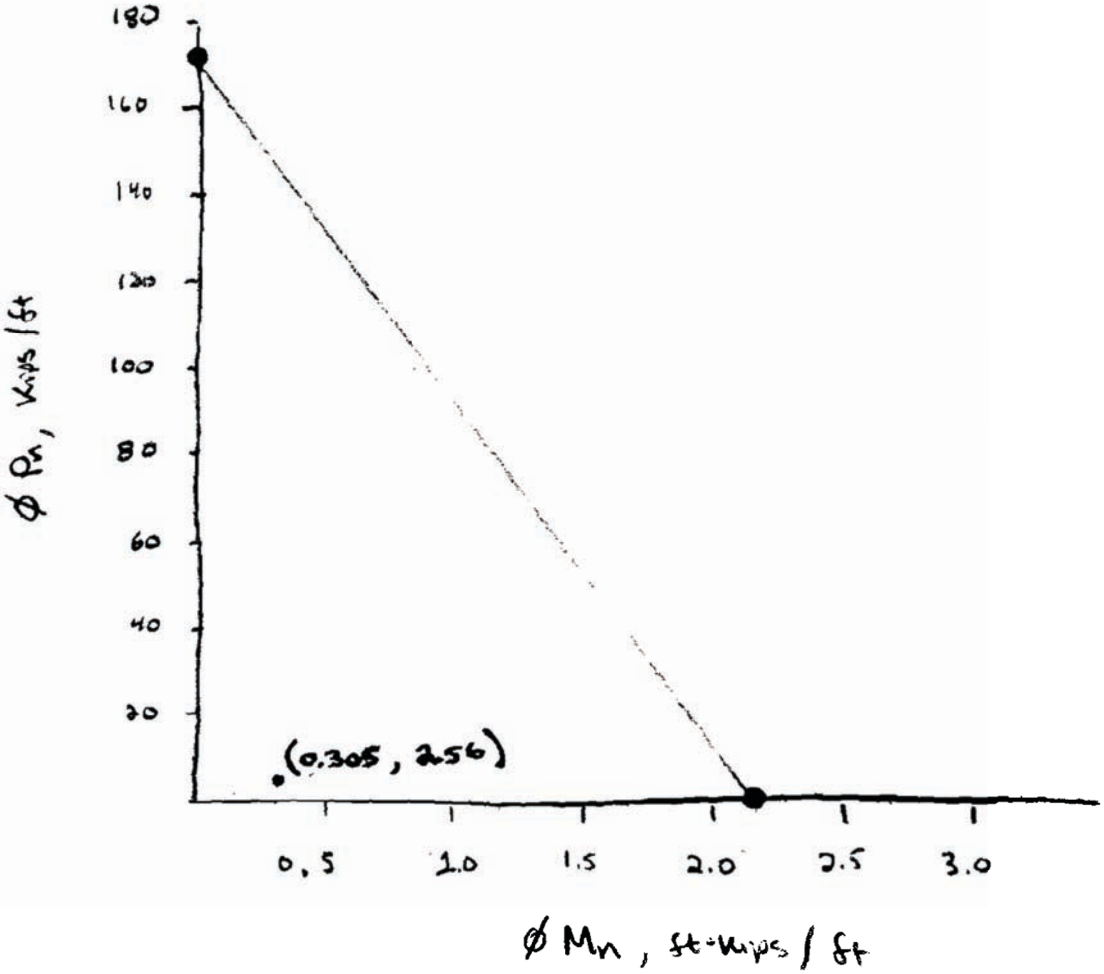
$A_c = (12" \times 5") - A_s = 59.8 \, in^2$

$$P_n = .85 (5\,ksi)\, 59.8\,in^2 + .20\,in^2 (60\,ksi)$$

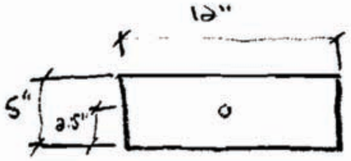
$$= 266 \text{ kips}$$

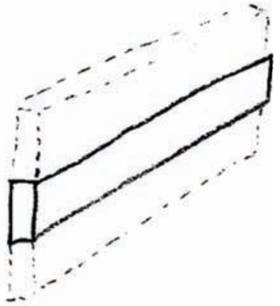
$$\boxed{\phi P_n = 173 \text{ kips}}$$

Interaction Curve for Precast, Reinforced Concrete Wall Panel



Flexural Design
of Panel Width (22')
as a 1' beam





$f'_c = 5000\text{psi}$ $\beta_1 = .80$ $M_u = 1.05 \text{ ft}\cdot\text{k}$

$d = 2.5"$ $h = 5"$ $b = 12"$ f_y steel $= 60\text{ksi}$

Minimum Steel

From Flexural Design of Panel Width (same parameters)

$A_s \geq .106 \text{ in}^2$

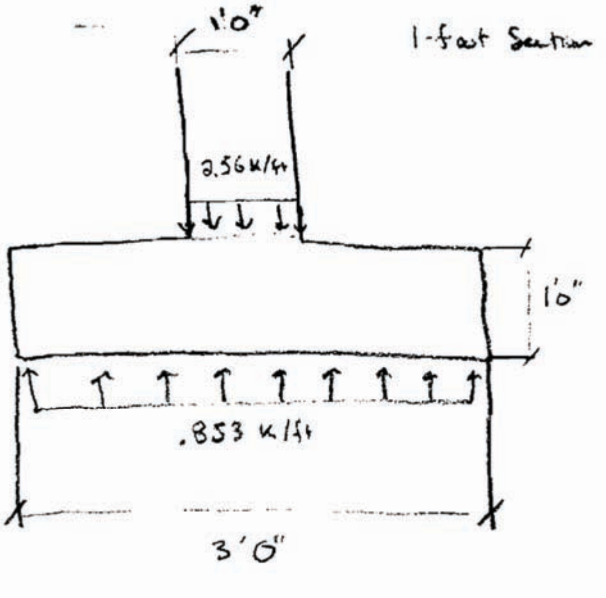
* use #4 bars @ 1' - $A_s = .20 \text{ in}^2$

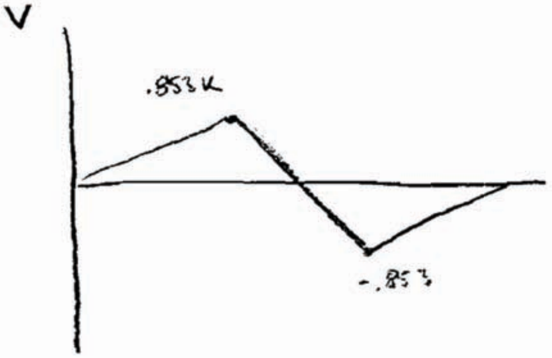
ϕM_n

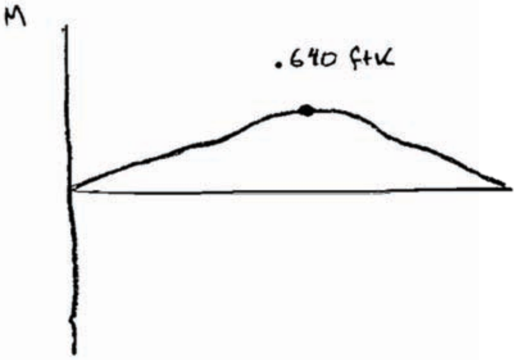
From Flexural Design of Panel Width (same parameters)

$\boxed{\phi M_n = 2.14 '\text{k}}$

Strip Footing Design Check







Shear

$$V_c = 2\sqrt{f'_c}\; bd$$

$$= 2\sqrt{3000}\;(12")(12")$$

$$= 15.8k$$

$$(.5)\phi V_n = (.75)(15.8k)(.5)$$

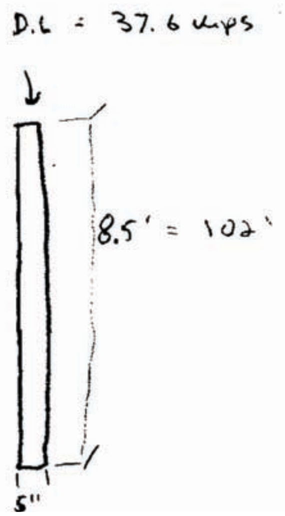
$$= 5.92K$$

$$V_u = .853K \leq \tfrac{1}{2}\phi V_n = 5.92K \therefore OK$$

Second - Order Analysis of an Uncracked - Member

5 in. thick, 20 ft wide wall panel

Assumptions



Concrete : $f_c' = 5000$ psi
$E_c = 4300$ ksi

$P_u = 1.2D + 1.6L + .8W = 1.2(37.6) = 45.12$ kips
$I_g = bh^3/12 = 240(5)^3/12 = 2500 \text{ in.}^4$
Additional wind load = 16 psf

$w_u = 16\,(22')\,(.8) = 282$ lb/ft

$$EI_{eff} = \frac{.70\,E_c\,I_g}{1+\beta_d} = \frac{.70\,(4300)\,(2500 \text{ in}^4)}{1.0} = 7.53 \times 10^6 \text{ kip-in.}^2$$

Deflection due to wind

$$\frac{5 w_u l^4}{384\,EI} = \frac{5\left(\frac{.282}{12}\right)(102)^4}{384\,(7.53 \times 10^6)} = .004 \text{ in}$$

Deflection due to $P_u e$

$$\Delta_i = \frac{P_u\,e\,l^2}{16\,EI} = \frac{45.12\,(1)\,(102)^2}{16\,(7.53 \times 10^6)} = .004 \text{in}$$

Initial midspan bow including eccentricity and wind

$$e = 1.0 + .004 + .004 = 1.008$$

Deflection due to P-Δ moment at midspan

$$\Delta = \frac{P e l^2}{8EI} = \frac{(45.12)\,e\,(102)^2}{8\,(7.53 \times 10^6)} = .008e$$

First Iteration

$$\Delta = .008\,(1.008) = .008$$

Second

$$e = 1.008 + .008 = 1.016$$

$$\Delta = .008\,(1.016) = .008 \text{ (convergence)}$$

$$M_u = \frac{45.12(1)}{2} + 45.12\,(1.016) + \frac{\left(\frac{.282}{12}\right)(102)^2}{8} = 99 \text{ kip-in.}$$

$$M_u y / I = 99\,(2.5)(1000) / 2500 = -99 \text{ psi}$$

Half Panel wt : $[100\,(4.25) / 5\,(12)]\,(1.2) = 8.5$ psi

Dead Load : $37.6\,(1000)(1.2) / [5\,(240)] = 37.6$ psi

Net Stress (tension) : -52.9 psi

$$f_r = 7.5\sqrt{f'_c} = 7.5\sqrt{5000} = 530 \text{ psi} > 52.9 \text{ psi}$$

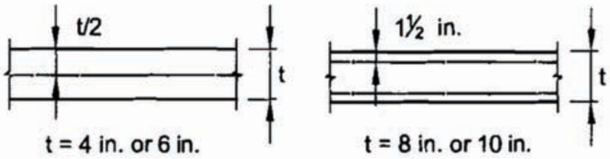
Therefore, analysis is valid

$P_u = 45.12 / 22 = 2.05$ kips/ft

$M_u = 99 / [(12)(22)] = .375$ kip-ft/ft

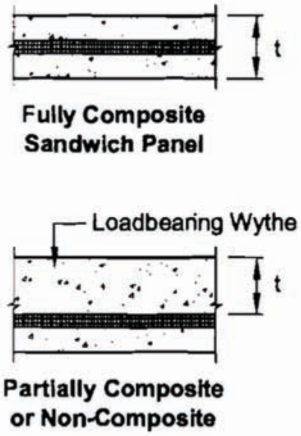
Point is below interaction curve for 5" partially developed strand ∴ OK

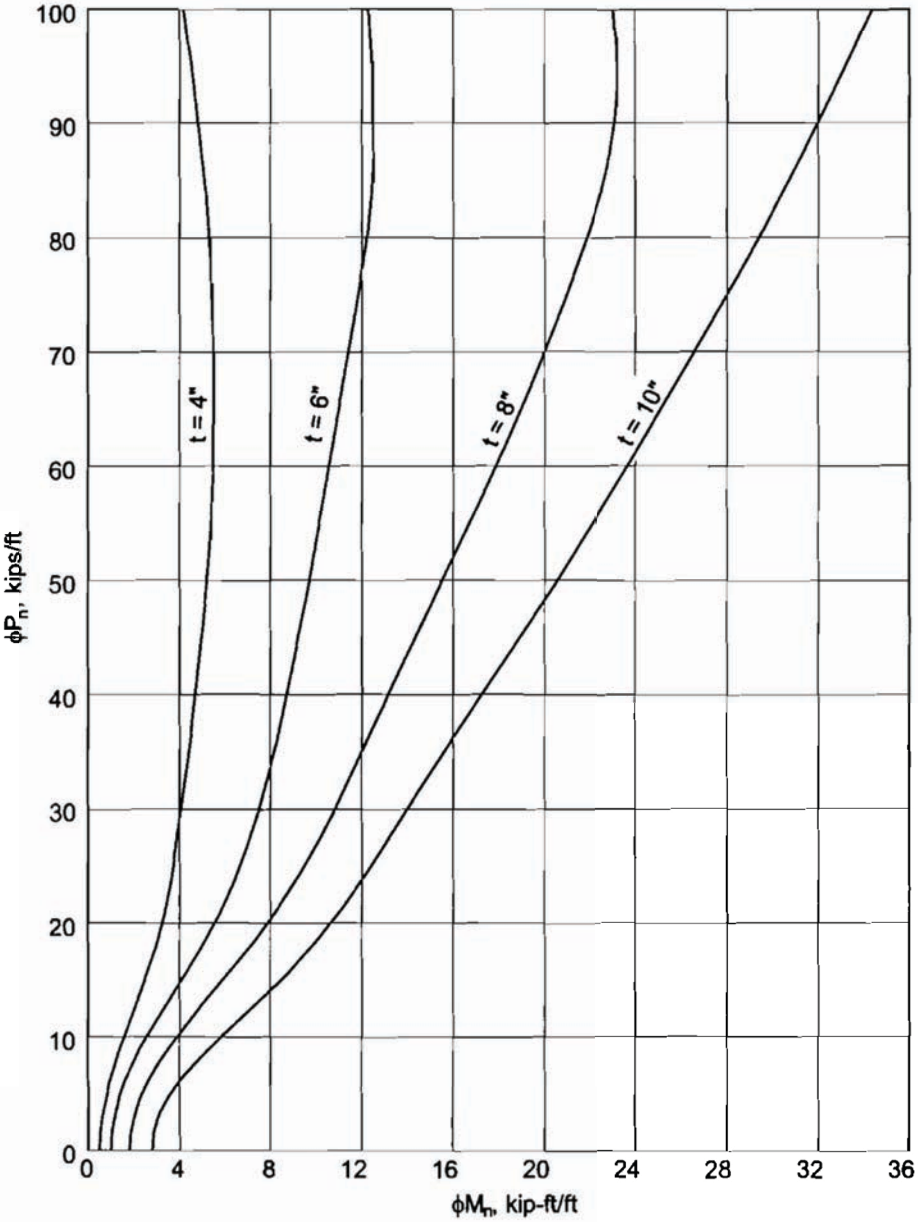
Figure 2.7.6 **Partial interaction curves for precast, reinforced concrete wall panels**



Curves Based on Minimum
Vertical Reinforcement $\rho = 0.10\%$
$f'_c = 5000$ psi; $f_y = 60{,}000$ psi

t, in.	Full Interaction Curve Data			
	ϕP_c	ϕP_{nb}	ϕM_{nb}	ϕM_c
4	134	67	5.5	0.5
6	202	100	12.4	1.0
8	269	131	22.6	1.8
10	336	164	35.5	2.8





Appendix E: Precast R-Value Calculations

The next analysis that was performed was the **Steady State Isothermal Analysis Method #1:**

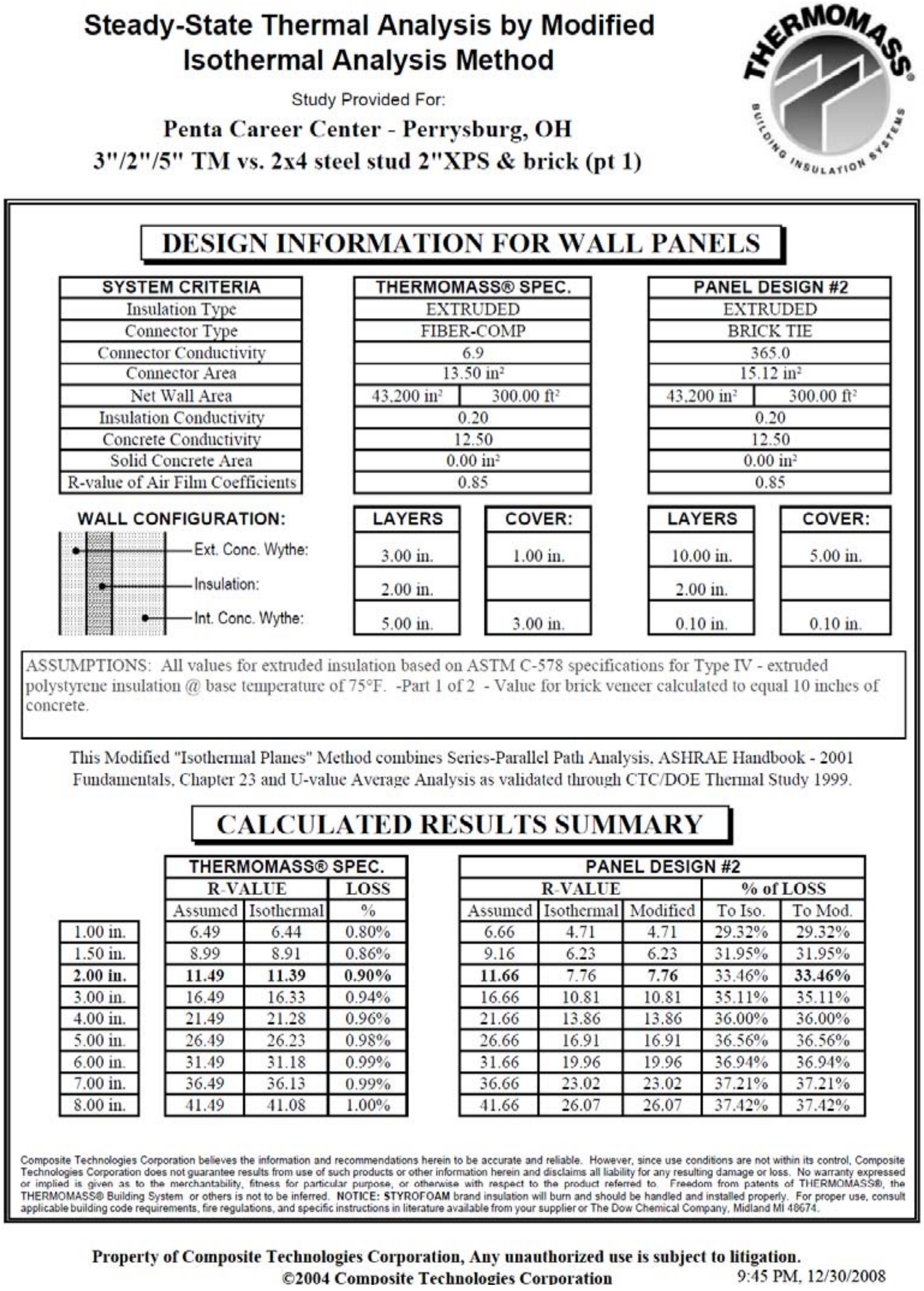
Using a series-parallel method of calculation, Isothermal Analysis predicts the effects of irregular sized and spaced penetrations through an insulation layer. Individually, steel or concrete have significant effects on the insulation layer and can be predicted with this analysis method.

The Isothermal Analysis by itself has been proven a bit aggressive when figuring the effects of solid concrete sections and therefore has been tempered with U-Value average to account for the restricted conduction zones affected by solid concrete.

The steady state thermal analysis shows the total isothermal R-value for the wall, with the ability to factor in thermal breaks such as metal ties or solid concrete sections.

You will notice in the findings shown in the Isothermal Analysis that the THERMOMASS wall panel has a material R-Value of **R-11.49**. The Isothermal Analysis shows **.90%** thermal loss in this wall panel with the use of fiber composite connectors. The overall material R-Value of the THERMOMASS wall consists of an **R-11.39**.

The competing wall system which consists of 2X4 steel studs (16” oc), 2” XPS insulation, full exterior brick w/ brick ties connected back to the steel studs. Due to the thermal conductivity of the brick ties this assumed R-11.66 wall actually performs at an **R-7.76** (33% reduction).



Steady-State Thermal Analysis by Modified Isothermal Analysis Method

Study Provided For:

Penta Career Center - Perrysburg, OH
3"/2"/5" TM vs. 2x4 steel stud 2"XPS & brick (pt 1)

DESIGN INFORMATION FOR WALL PANELS

SYSTEM CRITERIA	THERMOMASS® SPEC.		PANEL DESIGN #2	
Insulation Type	EXTRUDED		EXTRUDED	
Connector Type	FIBER-COMP		BRICK TIE	
Connector Conductivity	6.9		365.0	
Connector Area	13.50 in²		15.12 in²	
Net Wall Area	43,200 in²	300.00 ft²	43,200 in²	300.00 ft²
Insulation Conductivity	0.20		0.20	
Concrete Conductivity	12.50		12.50	
Solid Concrete Area	0.00 in²		0.00 in²	
R-value of Air Film Coefficients	0.85		0.85	

WALL CONFIGURATION:	LAYERS	COVER:	LAYERS	COVER:
Ext. Conc. Wythe:	3.00 in.	1.00 in.	10.00 in.	5.00 in.
Insulation:	2.00 in.		2.00 in.	
Int. Conc. Wythe:	5.00 in.	3.00 in.	0.10 in.	0.10 in.

ASSUMPTIONS: All values for extruded insulation based on ASTM C-578 specifications for Type IV - extruded polystyrene insulation @ base temperature of 75°F. -Part 1 of 2 - Value for brick veneer calculated to equal 10 inches of concrete.

This Modified "Isothermal Planes" Method combines Series-Parallel Path Analysis, ASHRAE Handbook - 2001 Fundamentals, Chapter 23 and U-value Average Analysis as validated through CTC/DOE Thermal Study 1999.

CALCULATED RESULTS SUMMARY

	THERMOMASS® SPEC.			PANEL DESIGN #2				
	R-VALUE		LOSS	R-VALUE			% of LOSS	
	Assumed	Isothermal	%	Assumed	Isothermal	Modified	To Iso.	To Mod.
1.00 in.	6.49	6.44	0.80%	6.66	4.71	4.71	29.32%	29.32%
1.50 in.	8.99	8.91	0.86%	9.16	6.23	6.23	31.95%	31.95%
2.00 in.	**11.49**	**11.39**	**0.90%**	**11.66**	7.76	**7.76**	33.46%	**33.46%**
3.00 in.	16.49	16.33	0.94%	16.66	10.81	10.81	35.11%	35.11%
4.00 in.	21.49	21.28	0.96%	21.66	13.86	13.86	36.00%	36.00%
5.00 in.	26.49	26.23	0.98%	26.66	16.91	16.91	36.56%	36.56%
6.00 in.	31.49	31.18	0.99%	31.66	19.96	19.96	36.94%	36.94%
7.00 in.	36.49	36.13	0.99%	36.66	23.02	23.02	37.21%	37.21%
8.00 in.	41.49	41.08	1.00%	41.66	26.07	26.07	37.42%	37.42%

9:45 PM, 12/30/2008

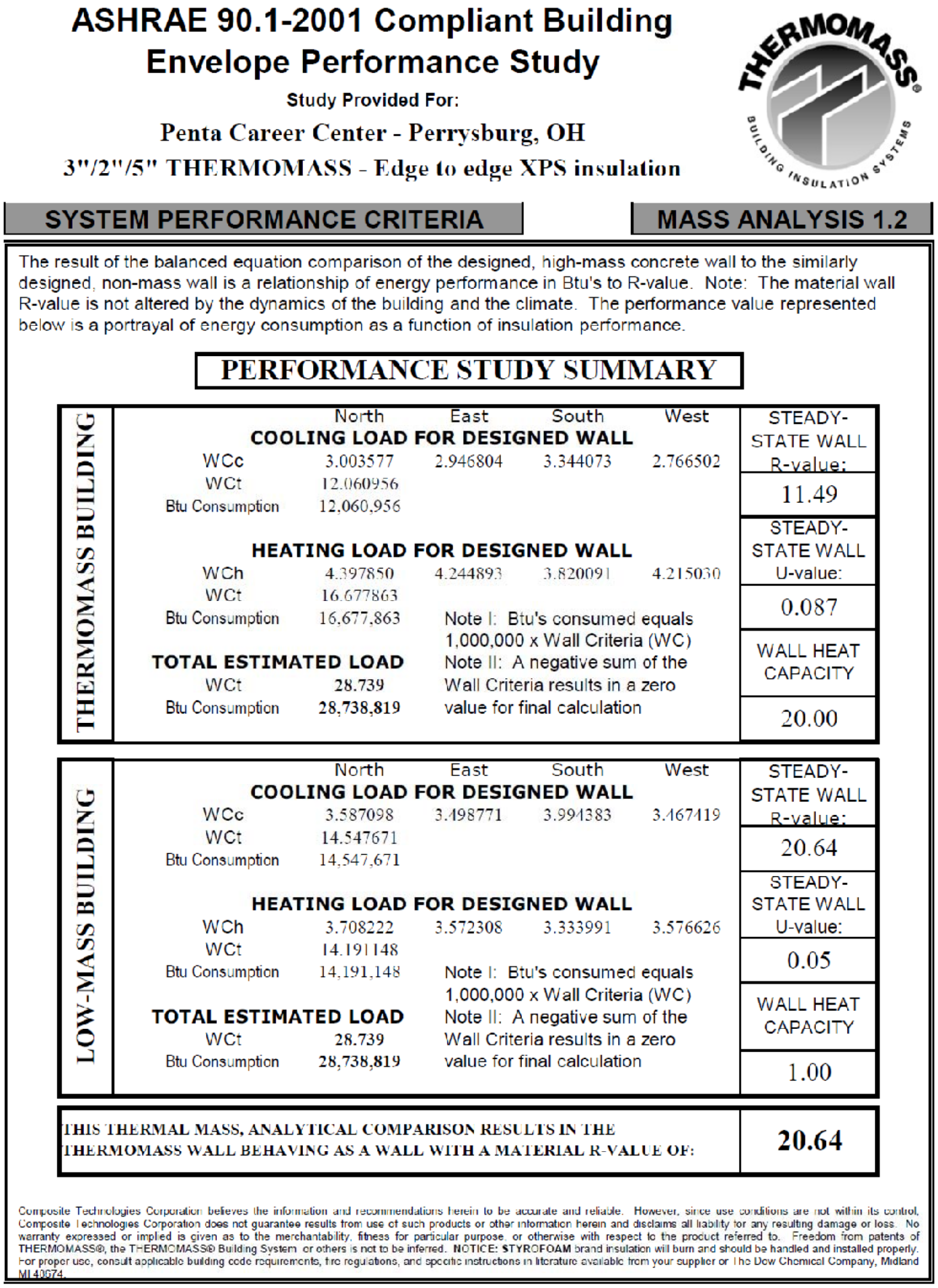
Performance Mass Analysis:

A precast concrete sandwich wall panel system constructed with The THERMOMASS Insulation System maximizes the thermal mass effect of concrete, thereby reducing the heating and cooling loads and providing an R-Value greater than what can be expected by the material alone (R-11.49) or by which code requires.

When utilizing climate data for Perrysburg, OH the proposed 3-in exterior concrete / 2-in extruded polystyrene insulation / 5-in interior concrete THERMOMASS Wall Panel performs at **R-20.64**.

This is determined by taking into account climate data, building orientation, occupancy type, and facility type. ASHRAE/IESNA Standard 90.1-1989: System Performance Criteria is the standard calculation used.

This criteria determines the R-Value performance and the heating and cooling load adjustments for the effects of concrete mass within the building envelope. The results of the analysis are detailed in image to the right.



ASHRAE 90.1-2001 Compliant Building Envelope Performance Study

Study Provided For:

Penta Career Center - Perrysburg, OH

3"/2"/5" THERMOMASS - Edge to edge XPS insulation

SYSTEM PERFORMANCE CRITERIA | **MASS ANALYSIS 1.2**

The result of the balanced equation comparison of the designed, high-mass concrete wall to the similarly designed, non-mass wall is a relationship of energy performance in Btu's to R-value. Note: The material wall R-value is not altered by the dynamics of the building and the climate. The performance value represented below is a portrayal of energy consumption as a function of insulation performance.

PERFORMANCE STUDY SUMMARY

THERMOMASS BUILDING

	North	East	South	West
COOLING LOAD FOR DESIGNED WALL				
WCc	3.003577	2.946804	3.344073	2.766502
WCt	12.060956			
Btu Consumption	12,060,956			
HEATING LOAD FOR DESIGNED WALL				
WCh	4.397850	4.244893	3.820091	4.215030
WCt	16.677863			
Btu Consumption	16,677,863			
TOTAL ESTIMATED LOAD				
WCt	**28.739**			
Btu Consumption	**28,738,819**			

Note I: Btu's consumed equals 1,000,000 x Wall Criteria (WC)
Note II: A negative sum of the Wall Criteria results in a zero value for final calculation

STEADY-STATE WALL R-value:	11.49
STEADY-STATE WALL U-value:	0.087
WALL HEAT CAPACITY	20.00

LOW-MASS BUILDING

	North	East	South	West
COOLING LOAD FOR DESIGNED WALL				
WCc	3.587098	3.498771	3.994383	3.467419
WCt	14.547671			
Btu Consumption	14,547,671			
HEATING LOAD FOR DESIGNED WALL				
WCh	3.708222	3.572308	3.333991	3.576626
WCt	14.191148			
Btu Consumption	14,191,148			
TOTAL ESTIMATED LOAD				
WCt	**28.739**			
Btu Consumption	**28,738,819**			

Note I: Btu's consumed equals 1,000,000 x Wall Criteria (WC)
Note II: A negative sum of the Wall Criteria results in a zero value for final calculation

STEADY-STATE WALL R-value:	20.64
STEADY-STATE WALL U-value:	0.05
WALL HEAT CAPACITY	1.00

THIS THERMAL MASS, ANALYTICAL COMPARISON RESULTS IN THE THERMOMASS WALL BEHAVING AS A WALL WITH A MATERIAL R-VALUE OF:	**20.64**

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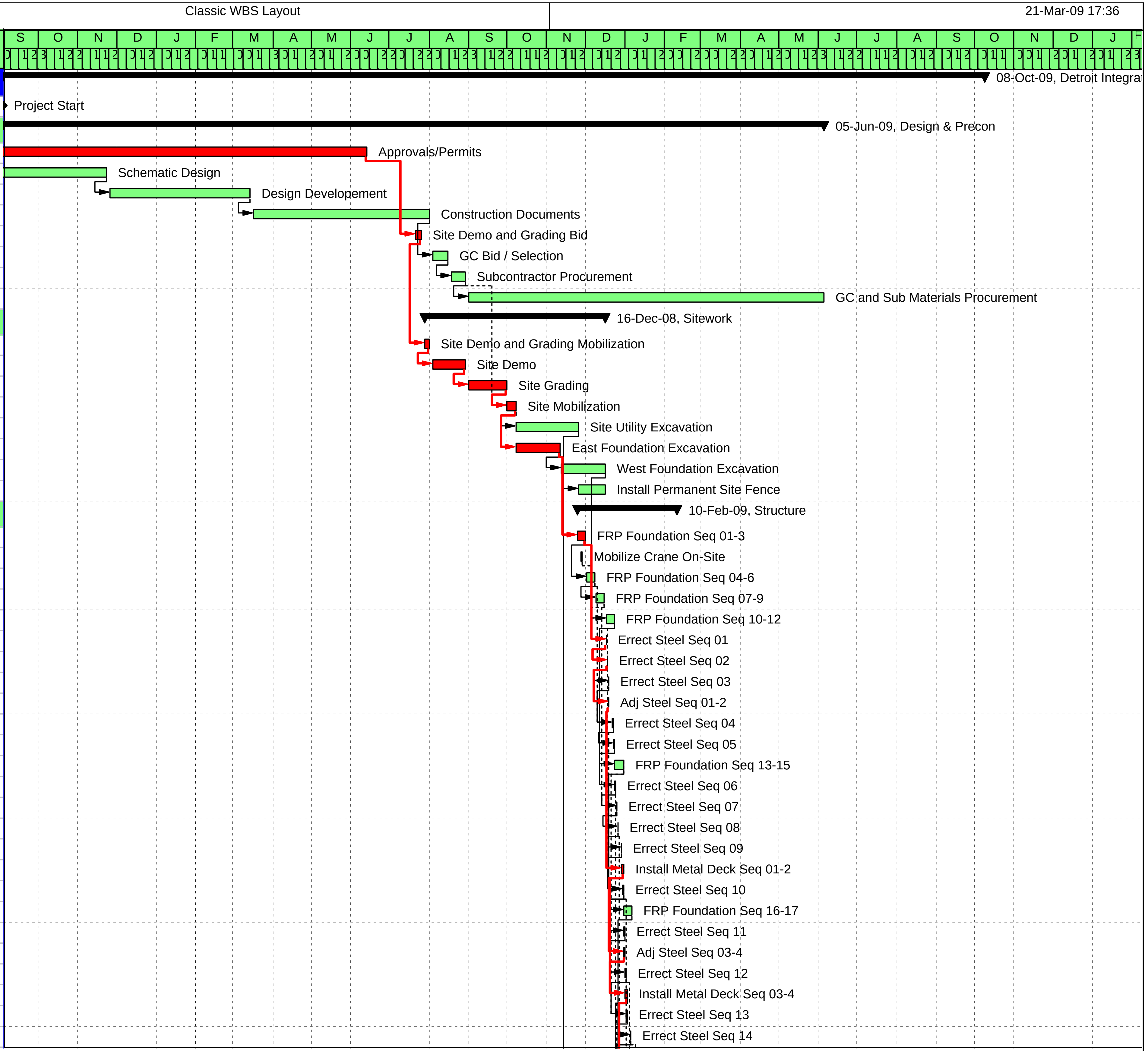
Appendix F: Precast Project Schedule

DITC | Classic WBS Layout | 21-Mar-09 17:36

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
Detroit Integrated Transportation ...		549	03-Sep-07	08-Oct-09	0
A100	Project Start	0	03-Sep-07		0
Design & Precon		460	03-Sep-07	05-Jun-09	89
A101	Approvals/Permits	205	03-Sep-07	13-Jun-08	0
A102	Schematic Design	60	03-Sep-07	23-Nov-07	22
A103	Design Developement	80	26-Nov-07	14-Mar-08	22
A104	Construction Documents	100	17-Mar-08	01-Aug-08	22
A105	Site Demo and Grading Bid	5	21-Jul-08	25-Jul-08	0
A106	GC Bid / Selection	10	04-Aug-08	15-Aug-08	22
A107	Subcontractor Procurement	10	18-Aug-08	29-Aug-08	22
A108	GC and Sub Materials Procurement	200	01-Sep-08	05-Jun-09	89
Sitework		102	28-Jul-08	16-Dec-08	212
C100	Site Demo and Grading Mobilization	5	28-Jul-08	01-Aug-08	0
C101	Site Demo	20	04-Aug-08	29-Aug-08	0
C102	Site Grading	22	01-Sep-08	30-Sep-08	0
C103	Site Mobilization	5	01-Oct-08	07-Oct-08	0
C104	Site Utility Excavation	35	08-Oct-08	25-Nov-08	207
C105	East Foundation Excavation	25	08-Oct-08	11-Nov-08	0
C106	West Foundation Excavation	25	12-Nov-08	16-Dec-08	19
C107	Install Permanent Site Fence	15	26-Nov-08	16-Dec-08	212
Structure		56	25-Nov-08	10-Feb-09	172
S100	FRP Foundation Seq 01-3	5	25-Nov-08	01-Dec-08	0
S103	Mobilize Crane On-Site	2	27-Nov-08*	28-Nov-08	12
S101	FRP Foundation Seq 04-6	5	02-Dec-08	08-Dec-08	15
S102	FRP Foundation Seq 07-9	5	09-Dec-08	15-Dec-08	20
S104	FRP Foundation Seq 10-12	5	17-Dec-08	23-Dec-08	19
S105	Errect Steel Seq 01	1	17-Dec-08	17-Dec-08	0
S106	Errect Steel Seq 02	1	18-Dec-08	18-Dec-08	0
S107	Errect Steel Seq 03	1	19-Dec-08	19-Dec-08	6
S108	Adj Steel Seq 01-2	1	19-Dec-08	19-Dec-08	0
S109	Errect Steel Seq 04	1	22-Dec-08	22-Dec-08	6
S111	Errect Steel Seq 05	1	23-Dec-08	23-Dec-08	14
S112	FRP Foundation Seq 13-15	5	24-Dec-08	30-Dec-08	19
S113	Errect Steel Seq 06	1	24-Dec-08	24-Dec-08	14
S115	Errect Steel Seq 07	1	25-Dec-08	25-Dec-08	15
S117	Errect Steel Seq 08	1	26-Dec-08	26-Dec-08	15
S118	Errect Steel Seq 09	1	29-Dec-08	29-Dec-08	16
S110	Install Metal Deck Seq 01-2	2	29-Dec-08	30-Dec-08	0
S120	Errect Steel Seq 10	1	30-Dec-08	30-Dec-08	16
S122	FRP Foundation Seq 16-17	5	31-Dec-08	06-Jan-09	19
S123	Errect Steel Seq 11	1	31-Dec-08	31-Dec-08	17
S114	Adj Steel Seq 03-4	1	31-Dec-08	31-Dec-08	0
S124	Errect Steel Seq 12	1	01-Jan-09	01-Jan-09	17
S116	Install Metal Deck Seq 03-4	2	01-Jan-09	02-Jan-09	0
S126	Errect Steel Seq 13	1	02-Jan-09	02-Jan-09	18
S128	Errect Steel Seq 14	1	05-Jan-09	05-Jan-09	18



🟦 Actual Work 🟥 Critical Remaining Work ▬ Summary
🟩 Remaining Work ◆ ◆ Milestone

Shane Goodman - Thesis Report

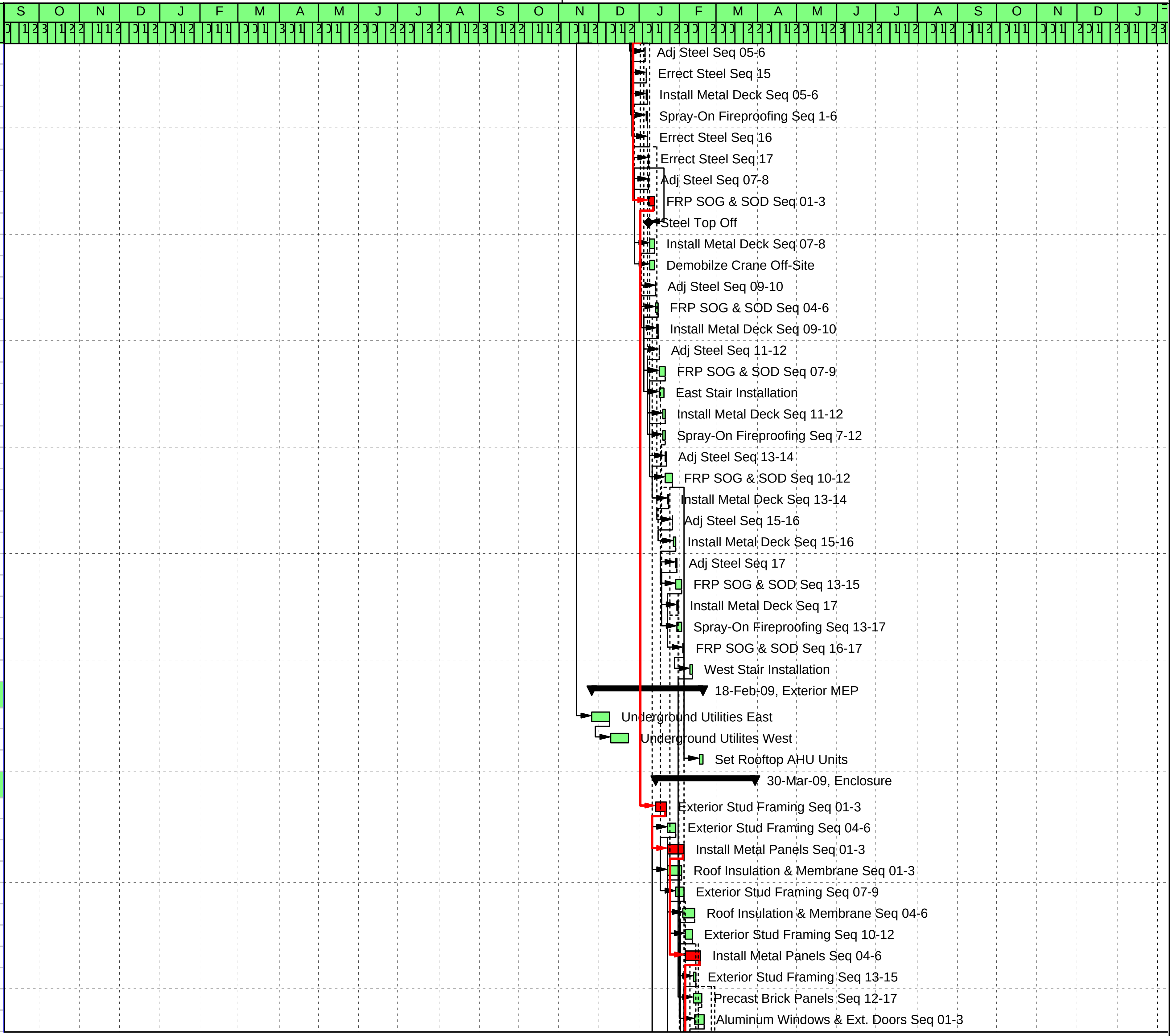
TASK filter: All Activities

DITC

Classic WBS Layout

21-Mar-09 17:36

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
S119	Adj Steel Seq 05-6	1	05-Jan-09	05-Jan-09	7
S129	Errect Steel Seq 15	1	06-Jan-09	06-Jan-09	19
S121	Install Metal Deck Seq 05-6	2	06-Jan-09	07-Jan-09	7
S150	Spray-On Fireproofing Seq 1-6	2	06-Jan-09	07-Jan-09	192
S131	Errect Steel Seq 16	1	07-Jan-09	07-Jan-09	19
S133	Errect Steel Seq 17	1	08-Jan-09	08-Jan-09	193
S125	Adj Steel Seq 07-8	1	08-Jan-09	08-Jan-09	7
S141	FRP SOG & SOD Seq 01-3	3	08-Jan-09	12-Jan-09	0
S134	Steel Top Off	0		08-Jan-09	195
S127	Install Metal Deck Seq 07-8	2	09-Jan-09	12-Jan-09	7
S136	Demobilze Crane Off-Site	2	09-Jan-09	12-Jan-09	193
S130	Adj Steel Seq 09-10	1	13-Jan-09	13-Jan-09	7
S144	FRP SOG & SOD Seq 04-6	3	13-Jan-09	15-Jan-09	9
S132	Install Metal Deck Seq 09-10	2	14-Jan-09	15-Jan-09	7
S135	Adj Steel Seq 11-12	1	16-Jan-09	16-Jan-09	7
S146	FRP SOG & SOD Seq 07-9	3	16-Jan-09	20-Jan-09	9
S147	East Stair Installation	2	16-Jan-09	19-Jan-09	188
S137	Install Metal Deck Seq 11-12	2	19-Jan-09	20-Jan-09	7
S152	Spray-On Fireproofing Seq 7-12	2	19-Jan-09	20-Jan-09	185
S138	Adj Steel Seq 13-14	1	21-Jan-09	21-Jan-09	7
S148	FRP SOG & SOD Seq 10-12	4	21-Jan-09	26-Jan-09	9
S139	Install Metal Deck Seq 13-14	2	22-Jan-09	23-Jan-09	7
S140	Adj Steel Seq 15-16	1	26-Jan-09	26-Jan-09	7
S142	Install Metal Deck Seq 15-16	2	27-Jan-09	28-Jan-09	7
S143	Adj Steel Seq 17	1	29-Jan-09	29-Jan-09	8
S149	FRP SOG & SOD Seq 13-15	3	29-Jan-09	02-Feb-09	7
S145	Install Metal Deck Seq 17	1	30-Jan-09	30-Jan-09	8
S153	Spray-On Fireproofing Seq 13-17	2	30-Jan-09	02-Feb-09	178
S151	FRP SOG & SOD Seq 16-17	2	03-Feb-09	04-Feb-09	7
S154	West Stair Installation	2	09-Feb-09	10-Feb-09	7
Exterior MEP		61	26-Nov-08	18-Feb-09	166
M100	Underground Utilities East	10	26-Nov-08	09-Dec-08	207
M101	Underground Utilites West	10	10-Dec-08	23-Dec-08	207
M102	Set Rooftop AHU Units	3	16-Feb-09	18-Feb-09	166
Enclosure		55	13-Jan-09	30-Mar-09	138
F100	Exterior Stud Framing Seq 01-3	7	13-Jan-09	21-Jan-09	0
F101	Exterior Stud Framing Seq 04-6	5	22-Jan-09	28-Jan-09	5
F104	Install Metal Panels Seq 01-3	10	22-Jan-09	04-Feb-09	0
F102	Roof Insulation & Membrane Seq 01-3	8	22-Jan-09	02-Feb-09	138
F103	Exterior Stud Framing Seq 07-9	5	29-Jan-09	04-Feb-09	8
F105	Roof Insulation & Membrane Seq 04-6	8	03-Feb-09	12-Feb-09	138
F106	Exterior Stud Framing Seq 10-12	4	05-Feb-09	10-Feb-09	12
F108	Install Metal Panels Seq 04-6	8	05-Feb-09	16-Feb-09	0
F107	Exterior Stud Framing Seq 13-15	3	11-Feb-09	13-Feb-09	17
F129	Precast Brick Panels Seq 12-17	5	11-Feb-09	17-Feb-09	7
F117	Aluminum Windows & Ext. Doors Seq 0...	6	12-Feb-09	19-Feb-09	10



🟦 Actual Work
🟥 Critical Remaining Work
▬ Summary
🟩 Remaining Work ◆
◆ Milestone

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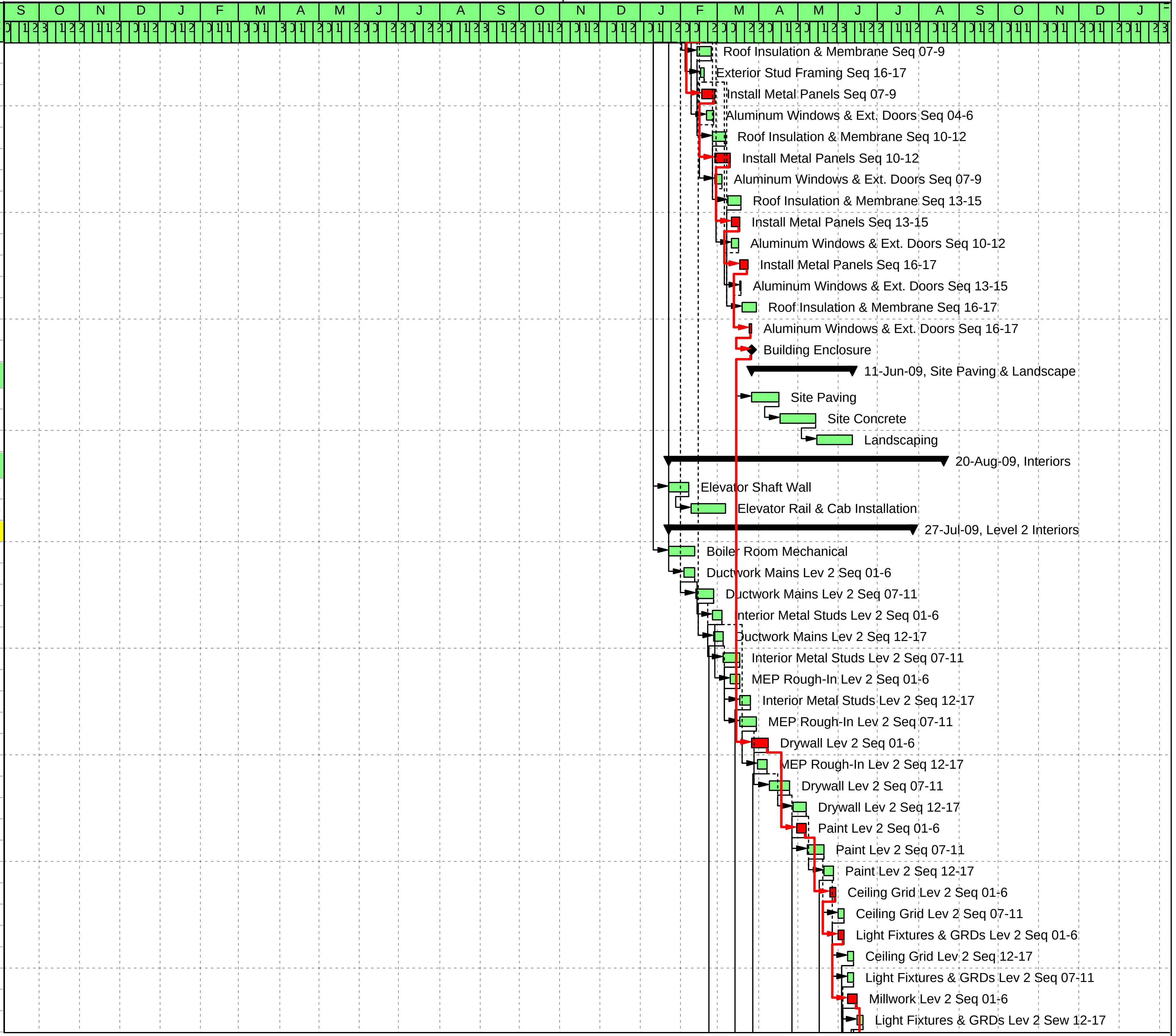
TASK filter: All Activities

DITC	Classic WBS Layout	21-Mar-09 17:36

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
F110	Roof Insulation & Membrane Seq 07-9	8	13-Feb-09	24-Feb-09	138
F112	Exterior Stud Framing Seq 16-17	3	16-Feb-09	18-Feb-09	19
F113	Install Metal Panels Seq 07-9	8	17-Feb-09	26-Feb-09	0
F119	Aluminum Windows & Ext. Doors Seq 0...	4	20-Feb-09	25-Feb-09	10
F114	Roof Insulation & Membrane Seq 10-12	8	25-Feb-09	06-Mar-09	138
F116	Install Metal Panels Seq 10-12	8	27-Feb-09	10-Mar-09	0
F122	Aluminum Windows & Ext. Doors Seq 0...	4	27-Feb-09	04-Mar-09	9
F118	Roof Insulation & Membrane Seq 13-15	8	09-Mar-09	18-Mar-09	138
F120	Install Metal Panels Seq 13-15	5	11-Mar-09	17-Mar-09	0
F124	Aluminum Windows & Ext. Doors Seq 1...	4	11-Mar-09	16-Mar-09	5
F123	Install Metal Panels Seq 16-17	5	18-Mar-09	24-Mar-09	0
F125	Aluminum Windows & Ext. Doors Seq 1...	1	18-Mar-09	18-Mar-09	4
F121	Roof Insulation & Membrane Seq 16-17	8	19-Mar-09	30-Mar-09	138
F126	Aluminum Windows & Ext. Doors Seq 1...	2	25-Mar-09	26-Mar-09	0
F127	Building Enclosure	0		26-Mar-09	0
Site Paving & Landscape		55	27-Mar-09	11-Jun-09	85
C108	Site Paving	15	27-Mar-09	16-Apr-09	85
C109	Site Concrete	20	17-Apr-09	14-May-09	85
C110	Landscaping	20	15-May-09	11-Jun-09	85
Interiors		151	22-Jan-09	20-Aug-09	35
I100	Elevator Shaft Wall	12	22-Jan-09	06-Feb-09	154
I101	Elevator Rail & Cab Installation	20	09-Feb-09	06-Mar-09	154
Level 2 Interiors		133	22-Jan-09	27-Jul-09	53
I102	Boiler Room Mechanical	15	22-Jan-09	11-Feb-09	171
I103	Ductwork Mains Lev 2 Seq 01-6	7	03-Feb-09	11-Feb-09	7
I104	Ductwork Mains Lev 2 Seq 07-11	10	12-Feb-09	25-Feb-09	23
I106	Interior Metal Studs Lev 2 Seq 01-6	6	25-Feb-09	04-Mar-09	7
I105	Ductwork Mains Lev 2 Seq 12-17	6	26-Feb-09	05-Mar-09	30
I107	Interior Metal Studs Lev 2 Seq 07-11	9	05-Mar-09	17-Mar-09	18
I108	MEP Rough-In Lev 2 Seq 01-6	6	10-Mar-09	17-Mar-09	7
I109	Interior Metal Studs Lev 2 Seq 12-17	6	18-Mar-09	25-Mar-09	27
I110	MEP Rough-In Lev 2 Seq 07-11	9	18-Mar-09	30-Mar-09	18
I112	Drywall Lev 2 Seq 01-6	9	27-Mar-09	08-Apr-09	0
I111	MEP Rough-In Lev 2 Seq 12-17	6	31-Mar-09	07-Apr-09	24
I113	Drywall Lev 2 Seq 07-11	12	09-Apr-09	24-Apr-09	11
I115	Drywall Lev 2 Seq 12-17	9	27-Apr-09	07-May-09	11
I114	Paint Lev 2 Seq 01-6	6	30-Apr-09	07-May-09	0
I116	Paint Lev 2 Seq 07-11	9	08-May-09	20-May-09	11
I118	Paint Lev 2 Seq 12-17	6	21-May-09	28-May-09	11
I117	Ceiling Grid Lev 2 Seq 01-6	5	25-May-09	29-May-09	0
I119	Ceiling Grid Lev 2 Seq 07-11	5	01-Jun-09	05-Jun-09	7
I120	Light Fixtures & GRDs Lev 2 Seq 01-6	5	01-Jun-09	05-Jun-09	0
I121	Ceiling Grid Lev 2 Seq 12-17	5	08-Jun-09	12-Jun-09	8
I122	Light Fixtures & GRDs Lev 2 Seq 07-11	5	08-Jun-09	12-Jun-09	7
I123	Millwork Lev 2 Seq 01-6	6	08-Jun-09	15-Jun-09	0
I124	Light Fixtures & GRDs Lev 2 Sew 12-17	5	15-Jun-09	19-Jun-09	8



🟦 Actual Work	🟥 Critical Remaining Work	▼ Summary
🟩 Remaining Work ◆	◆ Milestone	

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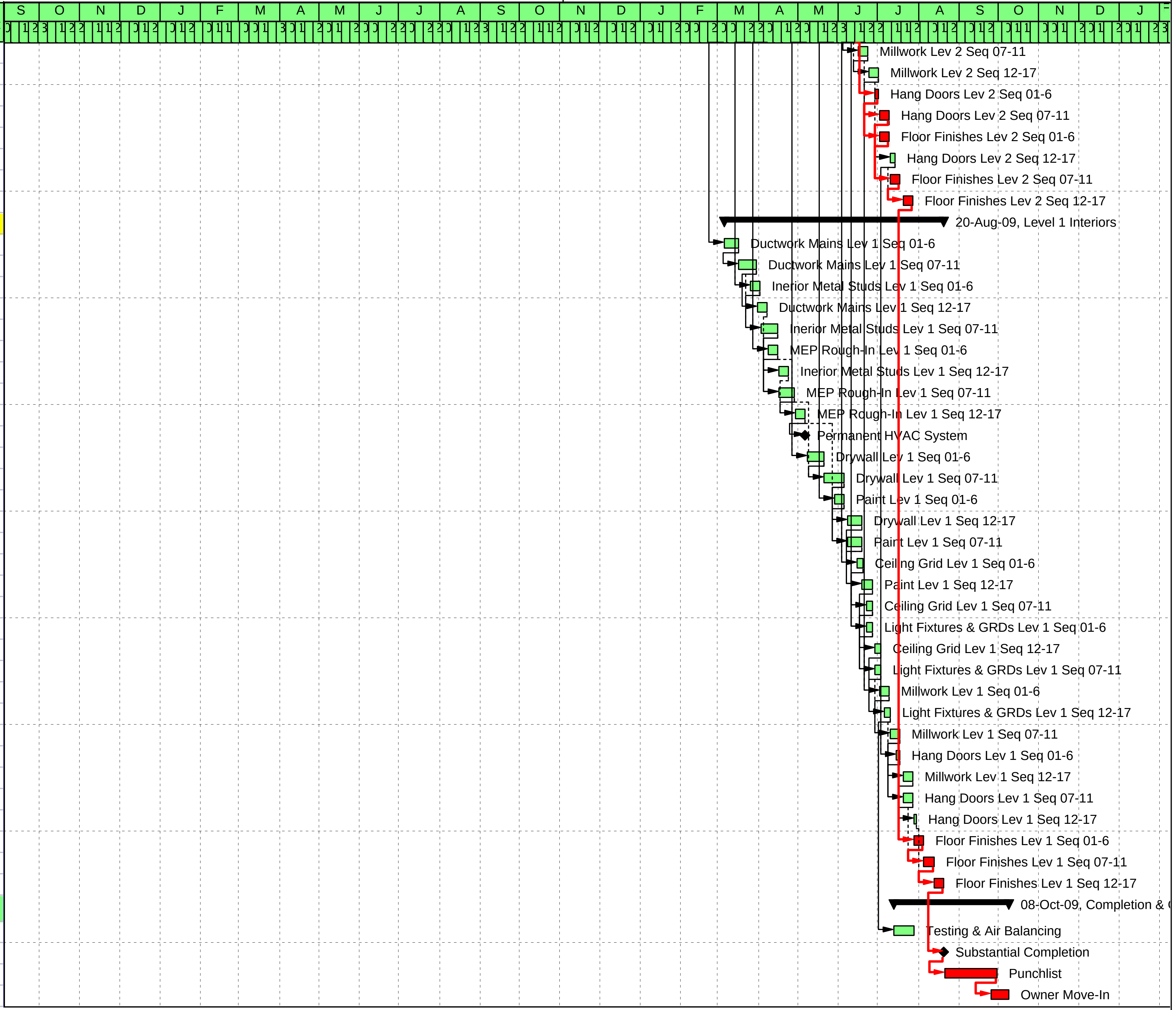
TASK filter: All Activities

DITC | Classic WBS Layout | 21-Mar-09 17:36

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
I125	Millwork Lev 2 Seq 07-11	6	16-Jun-09	23-Jun-09	6
I126	Millwork Lev 2 Seq 12-17	6	24-Jun-09	01-Jul-09	6
I127	Hang Doors Lev 2 Seq 01-6	3	29-Jun-09	01-Jul-09	0
I128	Hang Doors Lev 2 Seq 07-11	6	02-Jul-09	09-Jul-09	0
I129	Floor Finishes Lev 2 Seq 01-6	6	02-Jul-09	09-Jul-09	0
I130	Hang Doors Lev 2 Seq 12-17	3	10-Jul-09	14-Jul-09	3
I131	Floor Finishes Lev 2 Seq 07-11	6	10-Jul-09	17-Jul-09	0
I132	Floor Finishes Lev 2 Seq 12-17	6	20-Jul-09	27-Jul-09	0
Level 1 Interiors		**120**	**06-Mar-09**	**20-Aug-09**	**35**
I133	Ductwork Mains Lev 1 Seq 01-6	7	06-Mar-09	16-Mar-09	30
I134	Ductwork Mains Lev 1 Seq 07-11	10	17-Mar-09	30-Mar-09	30
I135	Inerior Metal Studs Lev 1 Seq 01-6	6	26-Mar-09	02-Apr-09	27
I136	Ductwork Mains Lev 1 Seq 12-17	6	31-Mar-09	07-Apr-09	45
I137	Inerior Metal Studs Lev 1 Seq 07-11	9	03-Apr-09	15-Apr-09	27
I138	MEP Rough-In Lev 1 Seq 01-6	6	08-Apr-09	15-Apr-09	27
I139	Inerior Metal Studs Lev 1 Seq 12-17	6	16-Apr-09	23-Apr-09	39
I140	MEP Rough-In Lev 1 Seq 07-11	9	16-Apr-09	28-Apr-09	27
I141	MEP Rough-In Lev 1 Seq 12-17	6	29-Apr-09	06-May-09	36
I142	Permanent HVAC System	0		06-May-09	111
I143	Drywall Lev 1 Seq 01-6	9	08-May-09	20-May-09	11
I144	Drywall Lev 1 Seq 07-11	12	21-May-09	05-Jun-09	11
I145	Paint Lev 1 Seq 01-6	6	29-May-09	05-Jun-09	11
I146	Drywall Lev 1 Seq 12-17	9	08-Jun-09	18-Jun-09	14
I147	Paint Lev 1 Seq 07-11	9	08-Jun-09	18-Jun-09	11
I148	Ceiling Grid Lev 1 Seq 01-6	5	15-Jun-09	19-Jun-09	9
I149	Paint Lev 1 Seq 12-17	6	19-Jun-09	26-Jun-09	14
I150	Ceiling Grid Lev 1 Seq 07-11	5	22-Jun-09	26-Jun-09	10
I151	Light Fixtures & GRDs Lev 1 Seq 01-6	5	22-Jun-09	26-Jun-09	9
I152	Ceiling Grid Lev 1 Seq 12-17	5	29-Jun-09	03-Jul-09	14
I153	Light Fixtures & GRDs Lev 1 Seq 07-11	5	29-Jun-09	03-Jul-09	10
I154	Millwork Lev 1 Seq 01-6	6	02-Jul-09	09-Jul-09	6
I155	Light Fixtures & GRDs Lev 1 Seq 12-17	5	06-Jul-09	10-Jul-09	14
I156	Millwork Lev 1 Seq 07-11	6	10-Jul-09	17-Jul-09	6
I157	Hang Doors Lev 1 Seq 01-6	3	15-Jul-09	17-Jul-09	6
I158	Millwork Lev 1 Seq 12-17	6	20-Jul-09	27-Jul-09	9
I159	Hang Doors Lev 1 Seq 07-11	6	20-Jul-09	27-Jul-09	6
I160	Hang Doors Lev 1 Seq 12-17	3	28-Jul-09	30-Jul-09	9
I161	Floor Finishes Lev 1 Seq 01-6	6	28-Jul-09	04-Aug-09	0
I162	Floor Finishes Lev 1 Seq 07-11	6	05-Aug-09	12-Aug-09	0
I163	Floor Finishes Lev 1 Seq 12-17	6	13-Aug-09	20-Aug-09	0
Completion & Closeout		**64**	**13-Jul-09**	**08-Oct-09**	**0**
A109	Testing & Air Balancing	12	13-Jul-09	28-Jul-09	49
A110	Substantial Completion	0		20-Aug-09	0
A111	Punchlist	28	21-Aug-09	29-Sep-09	0
A112	Owner Move-In	10	25-Sep-09	08-Oct-09	0



🟦 Actual Work
🟥 Critical Remaining Work
▬ Summary
🟩 Remaining Work ◆
◆ Milestone

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TASK filter: All Activities

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Appendix G: IrisWall Take-off

Replacement Wall Takeoff

First Floor

Wall Length (Feet)	Wall Type	Frame Type	Frame Width (Feet)
8.5	N3A	147-1 (2)	5
15	N3A		
15	N3A		
7	N3A	143-1 (1)	3
15	N3		
4	N3A	142-1 (2)	5
4.5	N2	113-1 (1)	3
15	N2		
2.5	N1		
2	N1	112A-1 (1)	4
3.5	N3A	112-2 (2)	5
2.5	N3A		
40	N3A		
2.5	N3A		
1.5	N3A	112-1 (2)	5
15	S1		
30	S1		
15	S1		
5	N3A	110-1 (2)	5
7	N2	109-1 (1)	3
11	N3A		
11	N3A		
12	N3A		
15	N3A	123-1 (2)	5
12	S1		
7	S1	124-1 (1)	3
15	S1		
2	N2	125-2 (1)	3
10	N2		
16	N3A		

Second Floor

Wall Length (Feet)	Wall Type	Frame Type	Frame Width (Feet)
10	N3A	231-1 (2)	5
15	N3A		
10	N3A	230-1 (2)	5
14	N3A		
15	N3A		
10	N3A	228-1 (2)	5
15	N3A		
5	N3A	227-1 (2)	5
5	N3A	210-1 (2)	5
15	N3A		
5	N3A	209-1 (2)	5
15	N3A		
20	N3A	208-1 (2)	5
		208-2 (2)	5
15	N3A		
7	N3A	207-1 (1)	3
14	N2		
1	N3A	206-1 (2)	5
2.5	N3A		
28	N3A		
2.5	N1		
2.5	N1		
2.5	N1		
1	N3A	206-2 (2)	5
15	N3A		
8	N3		
2.5	N3		
1	N3	205-1 (2)	5
2.5	N3		
49	N3	205-2 (2)	5
11	N3A		
11	N3A		
18	N3A		
4	N3A	217-3 (1)	3
15	S1		
7	S1	220-1 (1)	3
16	S1		
20	N3A	221-1 (2)	5
		221-2 (2)	5
15	N3A		
13	N3A	222-1 (2)	5

Environmental Wall Systems

Financial Analysis & Cash Flow Detail 03/09/09

Project Name: ***Detroit Integrated Transportation Campus***

WORKSHEET DATA SUMMARY

Total Lineal Footage:	786	**60**	**MONTH PAYBACK PERIOD**
Initial Cost per LF of Fixed Partition:	**$85.00**	**12.2%**	**INTERNAL RATE OF RETURN**
Initial Cost per LF of IrisWall Movable System:	**$150.00**	**4.9%**	**RATE OF RETURN AFTER TAX**
		$83,269	**TOTAL CUMULATIVE COMPARATIVE CASH FLOWS**
Relocation Cost per LF of Fixed Partition:	**$100.00**		
Relocation Cost per LF of IrisWall Movable System:	**$25.00**		
TOTAL INITIAL COSTS OF FIXED PARTITION:	**$66,810**		
TOTAL INITIAL COSTS OF IRISWALL:	**$117,900**		
ANNUAL COST TO CHANGE FIXED PARTITION:	**$7,860**		
ANNUAL COST TO CHANGE IrisWall:	**$1,965**		
MOVE RATE:	**10%**		
INFLATION RATE:	**5%**	**34.00%**	Federal Tax Rate
DISCOUNT RATE:	**8%**	**6.47%**	State Tax Rate

Environmental Wall Systems, Inc.

Financial Analysis & Cash Flow Detail 03/09/09

0

Project Name: ***Detroit Integrated Transportation Campus***

FIXED PARTITION			Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Initial Cost	66810		-66810	3.175 %	3.175 %	3.175 %	3.175 %	3.175 %	3.175 %	3.175 %	3.175 %	3.175 %	3.175 %
			0	2121	2121	2121	2121	2121	2121	2121	2121	2121	2121
Federal & State Tax Rate	40.5												
Subtotal Tax Benifit			0	858	858	858	858	858	858	858	858	858	858
Cost to Change													
Total Initial LF	786	LF			Cost Esc.								
Move Rate	10	%			5								
LF Relocated Per Year	79	LF			Percent								
LF Cost To Relocate	($100.00)	/LF			Per Year								
Total Cost / Yr.	($7,860)	/YR											
Less Tax @	40	%											
Subtotal Less Tax	($4,679)		0	-4679	-4913	-5159	-5417	-5688	-5972	-6271	-6584	-6913	-7259
Total Cash Flow			**-66810**	**-3821**	**-4055**	**-4300**	**-4558**	**-4829**	**-5114**	**-5412**	**-5726**	**-6055**	**-6401**

Movable Wall			Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Initial Cost	117900		-117900	14.29%	24.49%	17.49%	12.49%	8.93%	8.92%	8.93%	4.46%		
			0	16848	28874	20621	14726	10528	10517	10528	5258	0	0
Federal & State Tax Rate	40.5												
Subtotal Tax Benifit				6818	11685	8345	5959	4261	4256	4261	2128	0	0
Cost to Change													
Total Initial LF	786	LF			Cost Esc.								
Move Rate	10	%			5								
LF Relocated Per Year	79	LF			Percent								
LF Cost To Relocate	($25.00)	/LF			Per Year								
Total Cost / Yr.	($1,965)	/YR											
Less Tax @	40.5	%											
Subtotal Less Tax	($1,170)		0	-1170	-1228	-1290	-1354	-1422	-1493	-1568	-1646	-1728	-1815
Total Cash Flow			**-117900**	**5648**	**10456**	**7055**	**4605**	**2839**	**2763**	**2693**	**482**	**-1728**	**-1815**

COMPARATIVE	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
CASH FLOWS AFTER TAX Movable Wall - Fixed	-51090	9469	14511	11356	9163	7668	7876	8105	6208	4327	4586
CUMULATIVE AFTER TAX Movable Wall - Fixed	-51090	-41621	-27110	-15754	-6591	1077	8953	17059	23266	27593	32179

PAYBACK PERIOD **60** **MONTHS** INTERNAL RATE OF RETURN (@IRR) 12.2% RATE OF RETURN (@RATE): 5

CUMULATIVE COMPARATIVE CASH FLOWS: $83,269

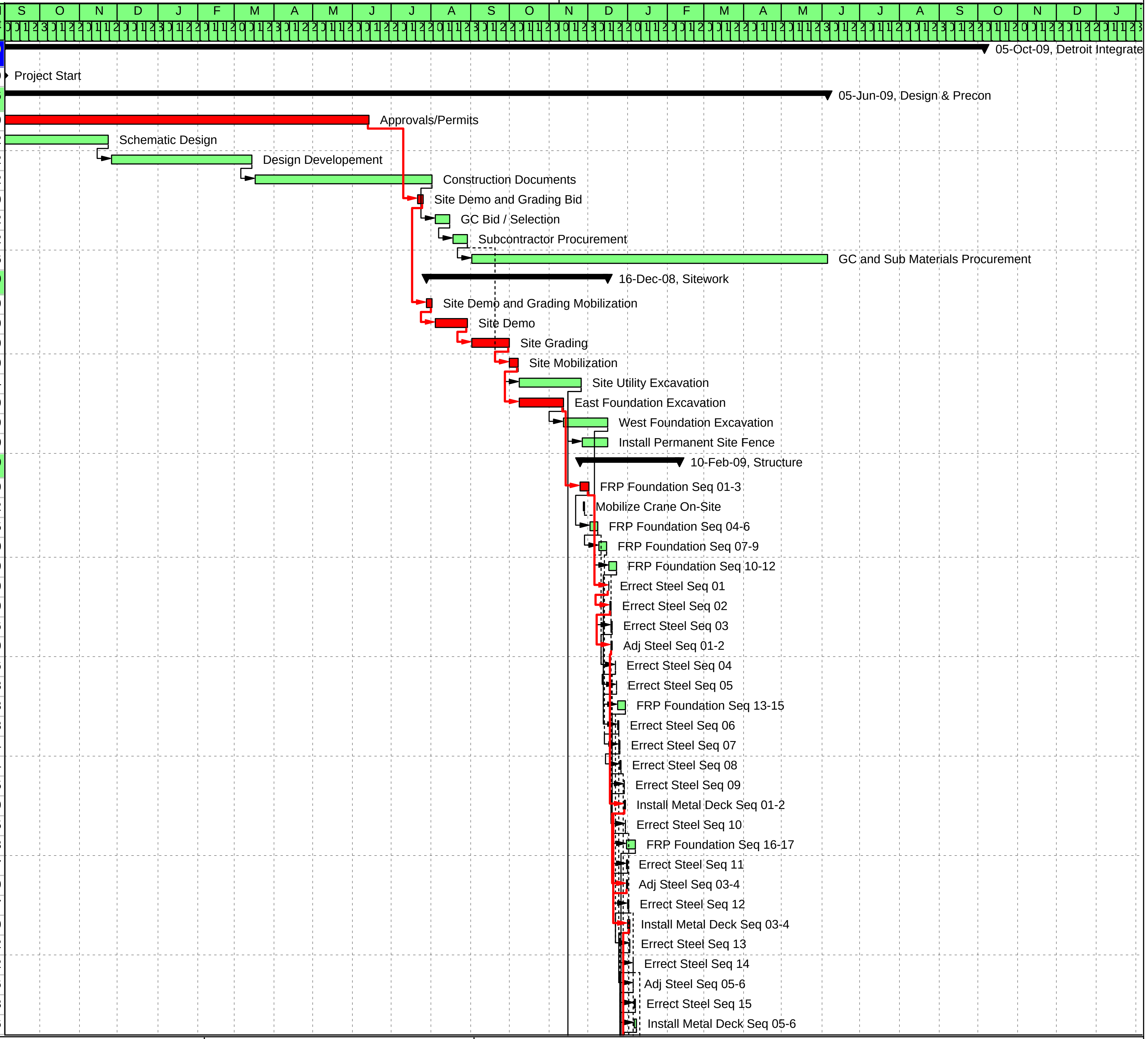
Appendix H: IrisWall Project Schedule

DITC with IrisWall

Classic WBS Layout

09-Mar-09 20:14

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
Detroit Integrated Transportation ...		546	03-Sep-07	05-Oct-09	0
A100	Project Start	0	03-Sep-07		0
Design & Precon		460	03-Sep-07	05-Jun-09	86
A101	Approvals/Permits	205	03-Sep-07	13-Jun-08	0
A102	Schematic Design	60	03-Sep-07	23-Nov-07	22
A103	Design Developement	80	26-Nov-07	14-Mar-08	22
A104	Construction Documents	100	17-Mar-08	01-Aug-08	22
A105	Site Demo and Grading Bid	5	21-Jul-08	25-Jul-08	0
A106	GC Bid / Selection	10	04-Aug-08	15-Aug-08	22
A107	Subcontractor Procurement	10	18-Aug-08	29-Aug-08	22
A108	GC and Sub Materials Procurement	200	01-Sep-08	05-Jun-09	86
Sitework		102	28-Jul-08	16-Dec-08	209
C100	Site Demo and Grading Mobilization	5	28-Jul-08	01-Aug-08	0
C101	Site Demo	20	04-Aug-08	29-Aug-08	0
C102	Site Grading	22	01-Sep-08	30-Sep-08	0
C103	Site Mobilization	5	01-Oct-08	07-Oct-08	0
C104	Site Utility Excavation	35	08-Oct-08	25-Nov-08	204
C105	East Foundation Excavation	25	08-Oct-08	11-Nov-08	0
C106	West Foundation Excavation	25	12-Nov-08	16-Dec-08	19
C107	Install Permanent Site Fence	15	26-Nov-08	16-Dec-08	209
Structure		56	25-Nov-08	10-Feb-09	169
S100	FRP Foundation Seq 01-3	5	25-Nov-08	01-Dec-08	0
S103	Mobilize Crane On-Site	2	27-Nov-08*	28-Nov-08	12
S101	FRP Foundation Seq 04-6	5	02-Dec-08	08-Dec-08	15
S102	FRP Foundation Seq 07-9	5	09-Dec-08	15-Dec-08	20
S104	FRP Foundation Seq 10-12	5	17-Dec-08	23-Dec-08	19
S105	Errect Steel Seq 01	1	17-Dec-08	17-Dec-08	0
S106	Errect Steel Seq 02	1	18-Dec-08	18-Dec-08	0
S107	Errect Steel Seq 03	1	19-Dec-08	19-Dec-08	6
S108	Adj Steel Seq 01-2	1	19-Dec-08	19-Dec-08	0
S109	Errect Steel Seq 04	1	22-Dec-08	22-Dec-08	6
S111	Errect Steel Seq 05	1	23-Dec-08	23-Dec-08	13
S112	FRP Foundation Seq 13-15	5	24-Dec-08	30-Dec-08	33
S113	Errect Steel Seq 06	1	24-Dec-08	24-Dec-08	13
S115	Errect Steel Seq 07	1	25-Dec-08	25-Dec-08	14
S117	Errect Steel Seq 08	1	26-Dec-08	26-Dec-08	14
S118	Errect Steel Seq 09	1	29-Dec-08	29-Dec-08	15
S110	Install Metal Deck Seq 01-2	2	29-Dec-08	30-Dec-08	0
S120	Errect Steel Seq 10	1	30-Dec-08	30-Dec-08	15
S122	FRP Foundation Seq 16-17	5	31-Dec-08	06-Jan-09	33
S123	Errect Steel Seq 11	1	31-Dec-08	31-Dec-08	17
S114	Adj Steel Seq 03-4	1	31-Dec-08	31-Dec-08	0
S124	Errect Steel Seq 12	1	01-Jan-09	01-Jan-09	17
S116	Install Metal Deck Seq 03-4	2	01-Jan-09	02-Jan-09	0
S126	Errect Steel Seq 13	1	02-Jan-09	02-Jan-09	32
S128	Errect Steel Seq 14	1	05-Jan-09	05-Jan-09	32
S119	Adj Steel Seq 05-6	1	05-Jan-09	05-Jan-09	6
S129	Errect Steel Seq 15	1	06-Jan-09	06-Jan-09	33
S121	Install Metal Deck Seq 05-6	2	06-Jan-09	07-Jan-09	6



🟦 Actual Work　🟥 Critical Remaining Work　▼ Summary

🟩 Remaining Work ◆　◆ Milestone

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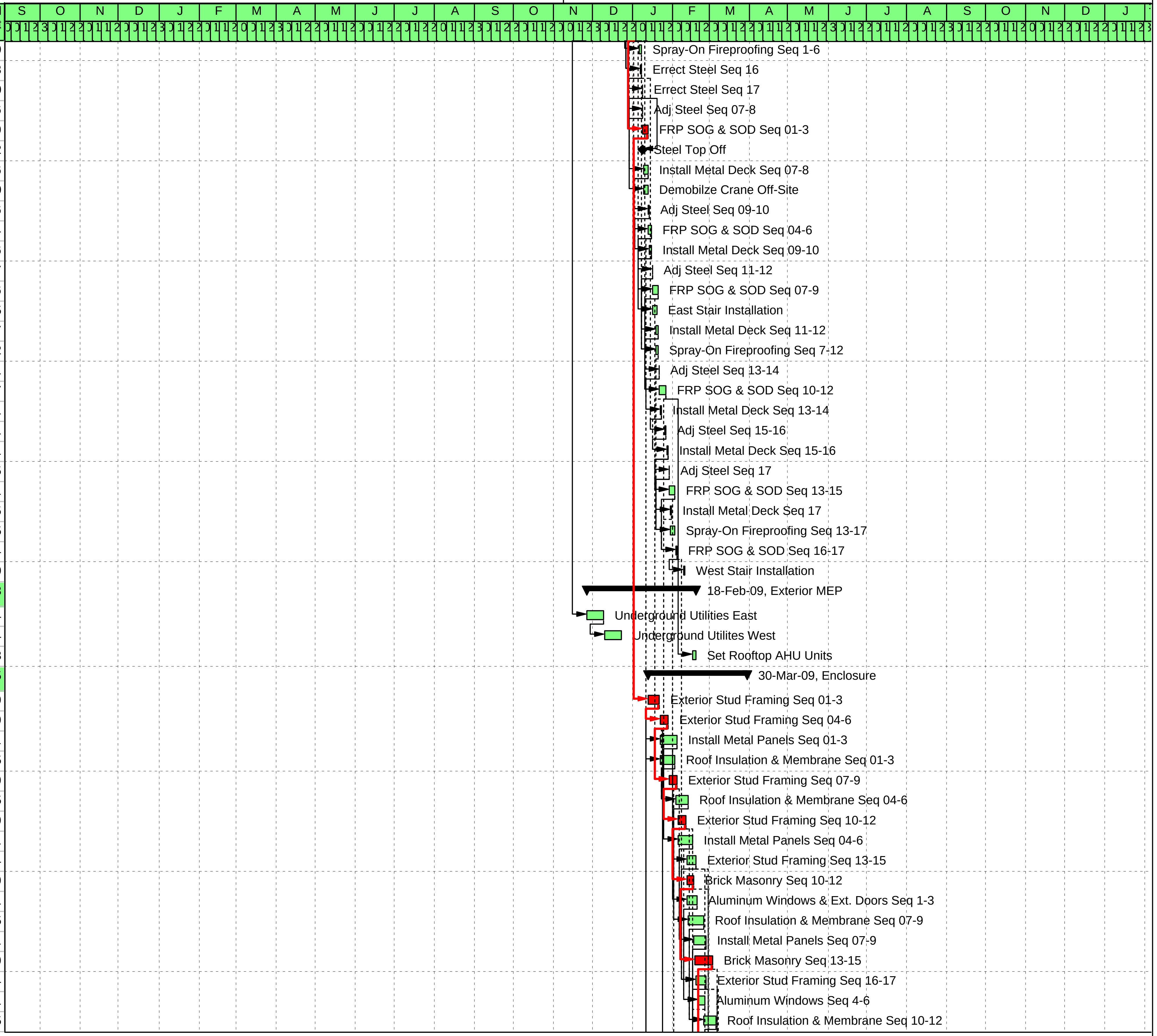
TASK filter: All Activities

DITC with IrisWall

Classic WBS Layout

09-Mar-09 20:14

Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
S150	Spray-On Fireproofing Seq 1-6	2	06-Jan-09	07-Jan-09	189
S131	Errect Steel Seq 16	1	07-Jan-09	07-Jan-09	33
S133	Errect Steel Seq 17	1	08-Jan-09	08-Jan-09	190
S125	Adj Steel Seq 07-8	1	08-Jan-09	08-Jan-09	6
S141	FRP SOG & SOD Seq 01-3	3	08-Jan-09	12-Jan-09	0
S134	Steel Top Off	0		08-Jan-09	192
S127	Install Metal Deck Seq 07-8	2	09-Jan-09	12-Jan-09	6
S136	Demobilze Crane Off-Site	2	09-Jan-09	12-Jan-09	190
S130	Adj Steel Seq 09-10	1	13-Jan-09	13-Jan-09	6
S144	FRP SOG & SOD Seq 04-6	3	13-Jan-09	15-Jan-09	4
S132	Install Metal Deck Seq 09-10	2	14-Jan-09	15-Jan-09	6
S135	Adj Steel Seq 11-12	1	16-Jan-09	16-Jan-09	7
S146	FRP SOG & SOD Seq 07-9	3	16-Jan-09	20-Jan-09	6
S147	East Stair Installation	2	16-Jan-09	19-Jan-09	185
S137	Install Metal Deck Seq 11-12	2	19-Jan-09	20-Jan-09	7
S152	Spray-On Fireproofing Seq 7-12	2	19-Jan-09	20-Jan-09	182
S138	Adj Steel Seq 13-14	1	21-Jan-09	21-Jan-09	21
S148	FRP SOG & SOD Seq 10-12	4	21-Jan-09	26-Jan-09	7
S139	Install Metal Deck Seq 13-14	2	22-Jan-09	23-Jan-09	21
S140	Adj Steel Seq 15-16	1	26-Jan-09	26-Jan-09	21
S142	Install Metal Deck Seq 15-16	2	27-Jan-09	28-Jan-09	21
S143	Adj Steel Seq 17	1	29-Jan-09	29-Jan-09	25
S149	FRP SOG & SOD Seq 13-15	3	29-Jan-09	02-Feb-09	21
S145	Install Metal Deck Seq 17	1	30-Jan-09	30-Jan-09	25
S153	Spray-On Fireproofing Seq 13-17	2	30-Jan-09	02-Feb-09	175
S151	FRP SOG & SOD Seq 16-17	2	03-Feb-09	04-Feb-09	24
S154	West Stair Installation	2	09-Feb-09	10-Feb-09	169
Exterior MEP		61	26-Nov-08	18-Feb-09	163
M100	Underground Utilities East	10	26-Nov-08	09-Dec-08	204
M101	Underground Utilites West	10	10-Dec-08	23-Dec-08	204
M102	Set Rooftop AHU Units	3	16-Feb-09	18-Feb-09	163
Enclosure		55	13-Jan-09	30-Mar-09	135
F100	Exterior Stud Framing Seq 01-3	7	13-Jan-09	21-Jan-09	0
F101	Exterior Stud Framing Seq 04-6	5	22-Jan-09	28-Jan-09	0
F104	Install Metal Panels Seq 01-3	10	22-Jan-09	04-Feb-09	1
F102	Roof Insulation & Membrane Seq 01-3	8	22-Jan-09	02-Feb-09	135
F103	Exterior Stud Framing Seq 07-9	5	29-Jan-09	04-Feb-09	0
F105	Roof Insulation & Membrane Seq 04-6	8	03-Feb-09	12-Feb-09	135
F106	Exterior Stud Framing Seq 10-12	5	05-Feb-09	11-Feb-09	0
F108	Install Metal Panels Seq 04-6	8	05-Feb-09	16-Feb-09	1
F107	Exterior Stud Framing Seq 13-15	5	12-Feb-09	18-Feb-09	14
F109	Brick Masonry Seq 10-12	4	12-Feb-09	17-Feb-09	0
F117	Aluminum Windows & Ext. Doors Seq 1-3	6	12-Feb-09	19-Feb-09	11
F110	Roof Insulation & Membrane Seq 07-9	8	13-Feb-09	24-Feb-09	135
F113	Install Metal Panels Seq 07-9	8	17-Feb-09	26-Feb-09	1
F111	Brick Masonry Seq 13-15	10	18-Feb-09	03-Mar-09	0
F112	Exterior Stud Framing Seq 16-17	6	19-Feb-09	26-Feb-09	14
F119	Aluminum Windows Seq 4-6	4	20-Feb-09	25-Feb-09	11
F114	Roof Insulation & Membrane Seq 10-12	8	25-Feb-09	06-Mar-09	135



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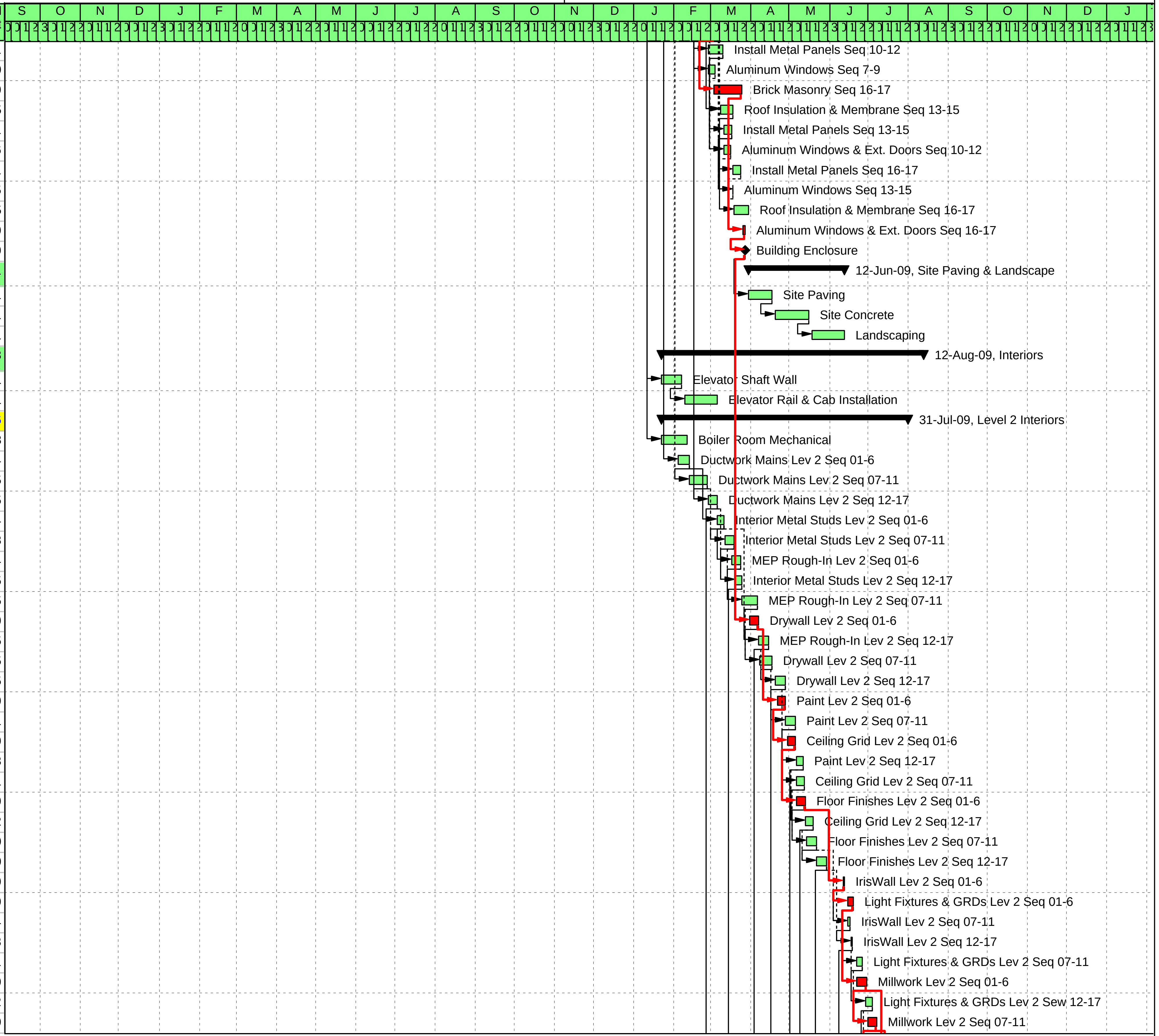
Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
F116	Install Metal Panels Seq 10-12	8	27-Feb-09	10-Mar-09	1
F122	Aluminum Windows Seq 7-9	4	27-Feb-09	04-Mar-09	10
F115	Brick Masonry Seq 16-17	16	04-Mar-09	25-Mar-09	0
F118	Roof Insulation & Membrane Seq 13-15	8	09-Mar-09	18-Mar-09	135
F120	Install Metal Panels Seq 13-15	5	11-Mar-09	17-Mar-09	1
F124	Aluminum Windows & Ext. Doors Seq 1...	4	11-Mar-09	16-Mar-09	6
F123	Install Metal Panels Seq 16-17	5	18-Mar-09	24-Mar-09	1
F125	Aluminum Windows Seq 13-15	1	18-Mar-09	18-Mar-09	5
F121	Roof Insulation & Membrane Seq 16-17	8	19-Mar-09	30-Mar-09	135
F126	Aluminum Windows & Ext. Doors Seq 1...	2	26-Mar-09	27-Mar-09	0
F127	Building Enclosure	0		27-Mar-09	0
Site Paving & Landscape		55	30-Mar-09	12-Jun-09	81
C108	Site Paving	15	30-Mar-09	17-Apr-09	81
C109	Site Concrete	20	20-Apr-09	15-May-09	81
C110	Landscaping	20	18-May-09	12-Jun-09	81
Interiors		145	22-Jan-09	12-Aug-09	38
I100	Elevator Shaft Wall	12	22-Jan-09	06-Feb-09	151
I101	Elevator Rail & Cab Installation	20	09-Feb-09	06-Mar-09	151
Level 2 Interiors		137	22-Jan-09	31-Jul-09	46
I102	Boiler Room Mechanical	15	22-Jan-09	11-Feb-09	168
I103	Ductwork Mains Lev 2 Seq 01-6	7	04-Feb-09	12-Feb-09	4
I104	Ductwork Mains Lev 2 Seq 07-11	10	13-Feb-09	26-Feb-09	35
I105	Ductwork Mains Lev 2 Seq 12-17	6	27-Feb-09	06-Mar-09	35
I106	Interior Metal Studs Lev 2 Seq 01-6	4	06-Mar-09	11-Mar-09	4
I107	Interior Metal Studs Lev 2 Seq 07-11	6	12-Mar-09	19-Mar-09	28
I108	MEP Rough-In Lev 2 Seq 01-6	6	17-Mar-09	24-Mar-09	4
I109	Interior Metal Studs Lev 2 Seq 12-17	4	20-Mar-09	25-Mar-09	35
I110	MEP Rough-In Lev 2 Seq 07-11	9	25-Mar-09	06-Apr-09	25
I112	Drywall Lev 2 Seq 01-6	6	31-Mar-09	07-Apr-09	0
I111	MEP Rough-In Lev 2 Seq 12-17	6	07-Apr-09	14-Apr-09	25
I113	Drywall Lev 2 Seq 07-11	8	08-Apr-09	17-Apr-09	25
I115	Drywall Lev 2 Seq 12-17	6	20-Apr-09	27-Apr-09	25
I114	Paint Lev 2 Seq 01-6	4	22-Apr-09	27-Apr-09	0
I116	Paint Lev 2 Seq 07-11	6	28-Apr-09	05-May-09	21
I117	Ceiling Grid Lev 2 Seq 01-6	5	29-Apr-09	05-May-09	0
I118	Paint Lev 2 Seq 12-17	4	06-May-09	11-May-09	23
I119	Ceiling Grid Lev 2 Seq 07-11	5	06-May-09	12-May-09	21
I129	Floor Finishes Lev 2 Seq 01-6	6	06-May-09	13-May-09	0
I121	Ceiling Grid Lev 2 Seq 12-17	5	13-May-09	19-May-09	22
I131	Floor Finishes Lev 2 Seq 07-11	6	14-May-09	21-May-09	20
I132	Floor Finishes Lev 2 Seq 12-17	6	22-May-09	29-May-09	20
I168	IrisWall Lev 2 Seq 01-6	2	11-Jun-09	12-Jun-09	0
I120	Light Fixtures & GRDs Lev 2 Seq 01-6	5	15-Jun-09	19-Jun-09	0
I172	IrisWall Lev 2 Seq 07-11	2	15-Jun-09	16-Jun-09	4
I173	IrisWall Lev 2 Seq 12-17	2	17-Jun-09	18-Jun-09	8
I122	Light Fixtures & GRDs Lev 2 Seq 07-11	5	22-Jun-09	26-Jun-09	1
I123	Millwork Lev 2 Seq 01-6	6	22-Jun-09	29-Jun-09	0
I124	Light Fixtures & GRDs Lev 2 Sew 12-17	5	29-Jun-09	03-Jul-09	2
I125	Millwork Lev 2 Seq 07-11	6	30-Jun-09	07-Jul-09	0



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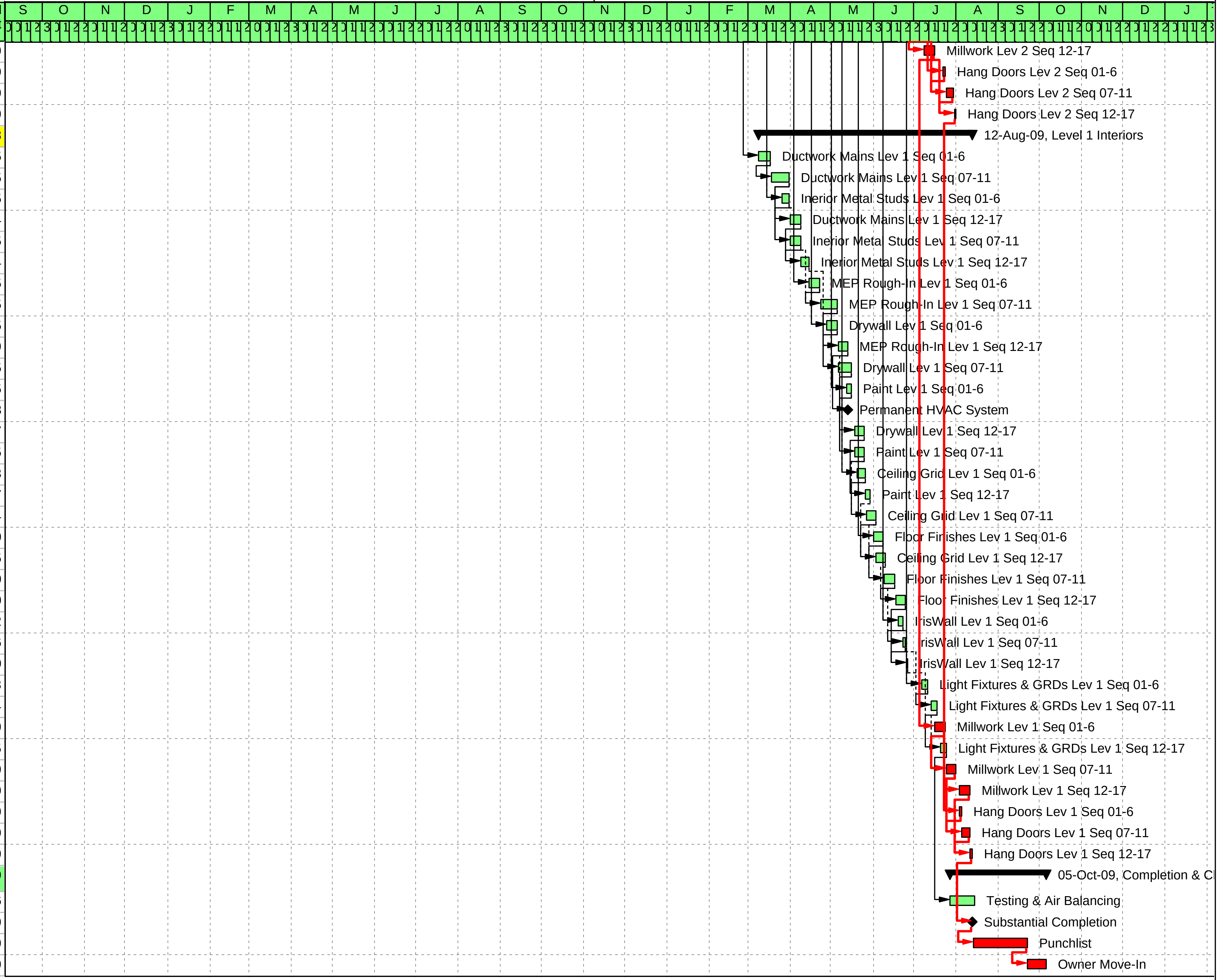
Activity ID	Activity Name	Original Duration	Start	Finish	Total Float
I126	Millwork Lev 2 Seq 12-17	6	08-Jul-09	15-Jul-09	0
I127	Hang Doors Lev 2 Seq 01-6	2	22-Jul-09	23-Jul-09	0
I128	Hang Doors Lev 2 Seq 07-11	4	24-Jul-09	29-Jul-09	0
I130	Hang Doors Lev 2 Seq 12-17	2	30-Jul-09	31-Jul-09	0
Level 1 Interiors		113	09-Mar-09	12-Aug-09	38
I133	Ductwork Mains Lev 1 Seq 01-6	7	09-Mar-09	17-Mar-09	35
I134	Ductwork Mains Lev 1 Seq 07-11	10	18-Mar-09	31-Mar-09	35
I135	Inerior Metal Studs Lev 1 Seq 01-6	4	26-Mar-09	31-Mar-09	35
I136	Ductwork Mains Lev 1 Seq 12-17	6	01-Apr-09	08-Apr-09	44
I137	Inerior Metal Studs Lev 1 Seq 07-11	6	01-Apr-09	08-Apr-09	35
I139	Inerior Metal Studs Lev 1 Seq 12-17	4	09-Apr-09	14-Apr-09	44
I138	MEP Rough-In Lev 1 Seq 01-6	6	15-Apr-09	22-Apr-09	25
I140	MEP Rough-In Lev 1 Seq 07-11	9	23-Apr-09	05-May-09	25
I143	Drywall Lev 1 Seq 01-6	6	28-Apr-09	05-May-09	25
I141	MEP Rough-In Lev 1 Seq 12-17	6	06-May-09	13-May-09	29
I144	Drywall Lev 1 Seq 07-11	8	06-May-09	15-May-09	25
I145	Paint Lev 1 Seq 01-6	4	12-May-09	15-May-09	25
I142	Permanent HVAC System	0		13-May-09	103
I146	Drywall Lev 1 Seq 12-17	6	18-May-09	25-May-09	27
I147	Paint Lev 1 Seq 07-11	6	18-May-09	25-May-09	25
I148	Ceiling Grid Lev 1 Seq 01-6	5	20-May-09	26-May-09	23
I149	Paint Lev 1 Seq 12-17	4	26-May-09	29-May-09	27
I150	Ceiling Grid Lev 1 Seq 07-11	5	27-May-09	02-Jun-09	24
I161	Floor Finishes Lev 1 Seq 01-6	6	01-Jun-09	08-Jun-09	20
I152	Ceiling Grid Lev 1 Seq 12-17	5	03-Jun-09	09-Jun-09	25
I162	Floor Finishes Lev 1 Seq 07-11	6	09-Jun-09	16-Jun-09	20
I163	Floor Finishes Lev 1 Seq 12-17	6	17-Jun-09	24-Jun-09	20
I165	IrisWall Lev 1 Seq 01-6	2	19-Jun-09	22-Jun-09	12
I170	IrisWall Lev 1 Seq 07-11	2	23-Jun-09	24-Jun-09	16
I175	IrisWall Lev 1 Seq 12-17	2	25-Jun-09	26-Jun-09	20
I151	Light Fixtures & GRDs Lev 1 Seq 01-6	5	06-Jul-09	10-Jul-09	3
I153	Light Fixtures & GRDs Lev 1 Seq 07-11	5	13-Jul-09	17-Jul-09	4
I154	Millwork Lev 1 Seq 01-6	6	16-Jul-09	23-Jul-09	0
I155	Light Fixtures & GRDs Lev 1 Seq 12-17	5	20-Jul-09	24-Jul-09	5
I156	Millwork Lev 1 Seq 07-11	6	24-Jul-09	31-Jul-09	0
I158	Millwork Lev 1 Seq 12-17	6	03-Aug-09	10-Aug-09	0
I157	Hang Doors Lev 1 Seq 01-6	2	03-Aug-09	04-Aug-09	0
I159	Hang Doors Lev 1 Seq 07-11	4	05-Aug-09	10-Aug-09	0
I160	Hang Doors Lev 1 Seq 12-17	2	11-Aug-09	12-Aug-09	0
Completion & Closeout		51	27-Jul-09	05-Oct-09	0
A109	Testing & Air Balancing	15	27-Jul-09	14-Aug-09	36
A110	Substantial Completion	0		12-Aug-09	0
A111	Punchlist	28	13-Aug-09	21-Sep-09	0
A112	Owner Move-In	10	22-Sep-09	05-Oct-09	0



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