CIVE 7220 - CONSTRUCTION MANAGEMENT

Fall 2020

Computerized Scheduling Assignment

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1. PROJECT INFORMATION

The project is to develop a computerized precedence network for a project consisting of the construction of 5 miles of 8" diameter pipeline. The project is a classic example of operations where repetition plays an important role. Major activities have been identified in an order as following:

- locating and clearing,
- excavation, together with pipe stringing,
- pipe laying,
- testing,
- backfilling.

The contractor wants to proceed with most of these basic tasks concurrently.

This project report has three main construction management phases. First phase focuses on the preliminary schedule of the construction. Second phase of this report includes more detailed schedule such as precedence diagram, and resource determination and schedule update after resource allocation under constraints. Last phase mainly emphasizes the project cost loading as well as the schedule control and updating.

2. CONSTRUCTION MANAGEMENT PHASE I

2.1.Schedule

The project has been divided into five one-mile sections for each activities which are labeled for each one mile. For instance, activities are labeled for the first mile as following:

- locating and clearing: **LC-1**
- excavation, together with pipe stringing: **EX-1 and SP-1**
- pipe laying: **LP-1**
- testing: **T-1**
- backfilling: **B-1**

The project is modelled as an overlapping activities. The project will proceed such that each activity of each mile cannot proceed until the same activity of that preceding mile has been completed. For example, locating and clearing (LC) mile-2 cannot proceed until LC mile-1 has been completed. Basic network is sketched for 5 miles of 8" diameter as shown below. Detailed precedence diagram will be presented under CM Phase 2 chapter.

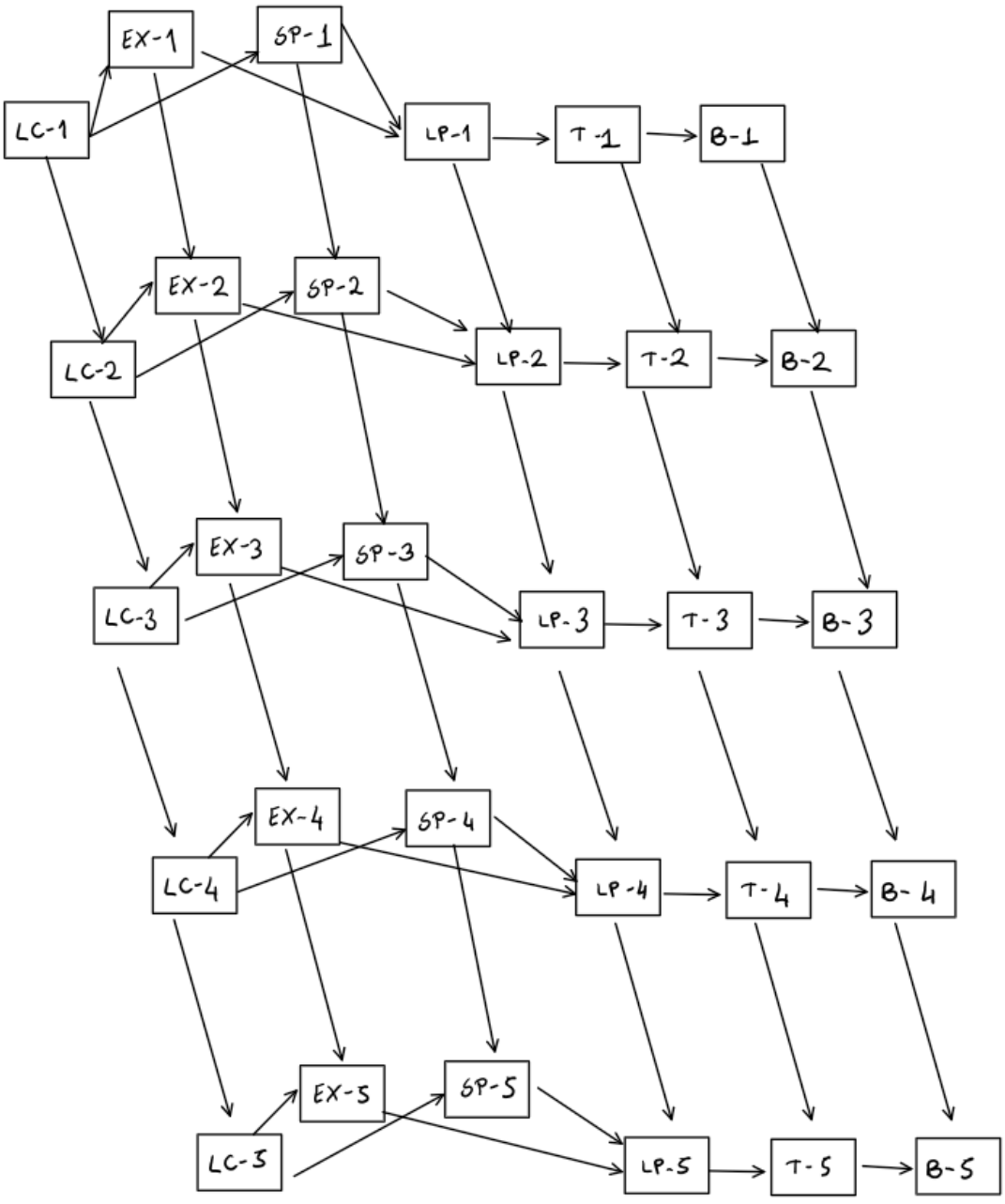


Figure 1: Basic Network for the Pipeline Project

3. CONSTRUCTION MANAGEMENT PHASE II

In terms of defining important dates of the project, the start date of the project is set as April 12, 2021. Memorial Day (05/31/2021), Independence Day (07/05/2021), and Labor Day (09/06/2021) are defined as nonworking days. Activity durations are defined as following table.

Activity	Duration in days per mile
Locate and clear	1
String pipe	2
Excavation	5
Lay pipe	8
Testing	1
Backfill	4

Table 1: Project Activity Durations

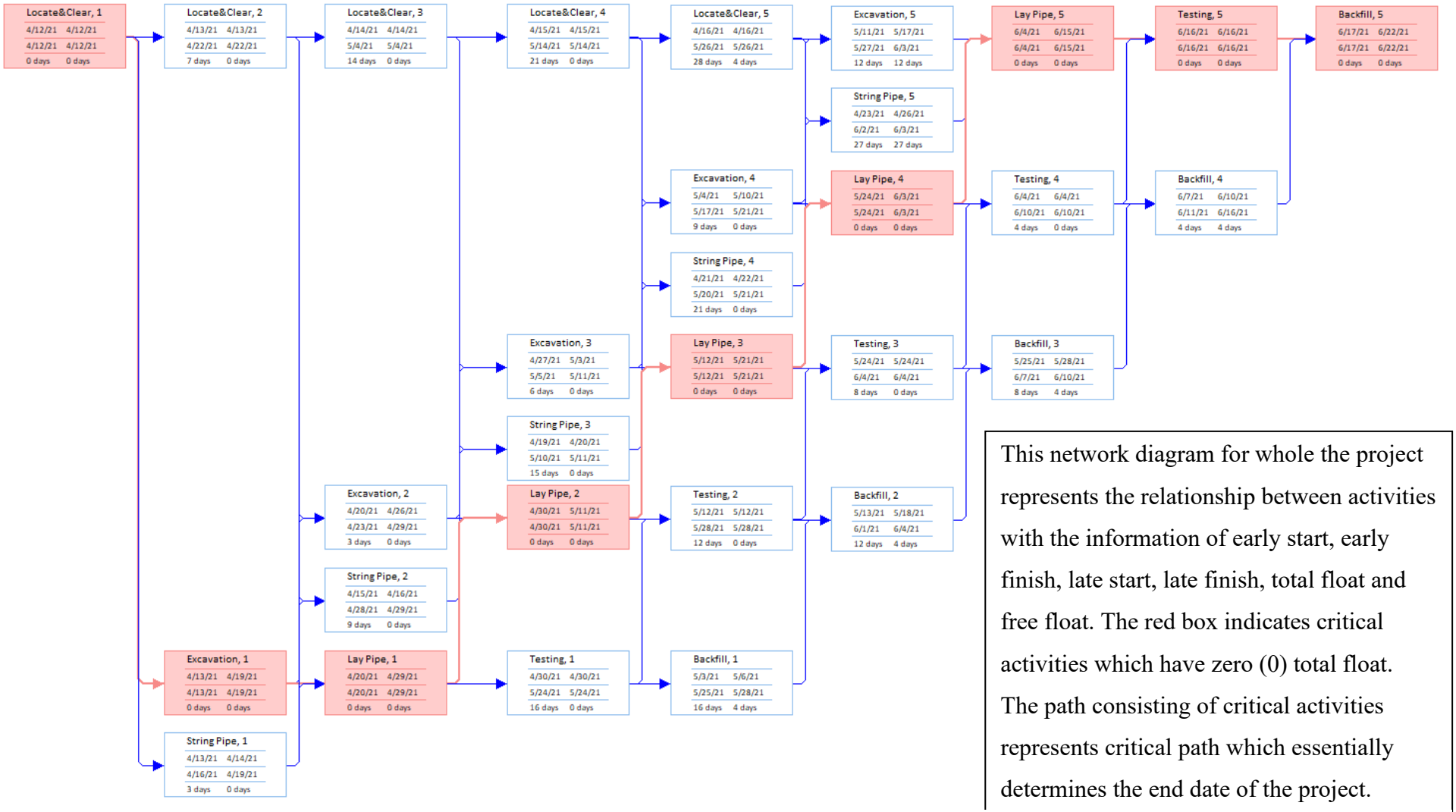
After each activity is established with their duration in the project as well as processor activities, the project duration is estimated as 51 day and forecasted finish date is June 22, 2021 by assuming there is **no resource constraint**. The project requires 12872 working hour and total project cost is estimated as $896,243.20. The project statistics is summarized as below table:

	Start	Finish
Current	Mon 4/12/21	Tue 6/22/21
Baseline	NA	NA
Actual	NA	NA
Variance	0d	0d

	Duration	Work	Cost
Current	51d	12,872h	$896,243.20
Baseline	0d	0h	$0.00
Actual	0d	0h	$0.00
Remaining	51d	12,872h	$896,243.20

Figure 2: Project Information Statistics

3.1. Precedence Diagram



This network diagram for whole the project represents the relationship between activities with the information of early start, early finish, late start, late finish, total float and free float. The red box indicates critical activities which have zero (0) total float. The path consisting of critical activities represents critical path which essentially determines the end date of the project.

Figure 3: Project Precedence Diagram

A detailed scheduled report with activities sorted based on descending total float is shown as below table. Total float shows how many days can be delayed for an activity without delaying total project duration. Therefore, total float of zero (0) for an activity means that if there is any delay of that activity, total duration of the project extends as well.

Name	Early Start	Early Finish	Late Start	Late Finish	Total Slack	Free Slack
Locate&Clear, 5	Fri 4/16/21	Fri 4/16/21	Wed 5/26/21	Wed 5/26/21	28 days	4 days
String Pipe, 5	Fri 4/23/21	Mon 4/26/21	Wed 6/2/21	Thu 6/3/21	27 days	27 days
Locate&Clear, 4	Thu 4/15/21	Thu 4/15/21	Fri 5/14/21	Fri 5/14/21	21 days	0 days
String Pipe, 4	Wed 4/21/21	Thu 4/22/21	Thu 5/20/21	Fri 5/21/21	21 days	0 days
Testing, 1	Fri 4/30/21	Fri 4/30/21	Mon 5/24/21	Mon 5/24/21	16 days	0 days
Backfill, 1	Mon 5/3/21	Thu 5/6/21	Tue 5/25/21	Fri 5/28/21	16 days	4 days
String Pipe, 3	Mon 4/19/21	Tue 4/20/21	Mon 5/10/21	Tue 5/11/21	15 days	0 days
Locate&Clear, 3	Wed 4/14/21	Wed 4/14/21	Tue 5/4/21	Tue 5/4/21	14 days	0 days
Excavation, 5	Tue 5/11/21	Mon 5/17/21	Thu 5/27/21	Thu 6/3/21	12 days	12 days
Testing, 2	Wed 5/12/21	Wed 5/12/21	Fri 5/28/21	Fri 5/28/21	12 days	0 days
Backfill, 2	Thu 5/13/21	Tue 5/18/21	Tue 6/1/21	Fri 6/4/21	12 days	4 days
Excavation, 4	Tue 5/4/21	Mon 5/10/21	Mon 5/17/21	Fri 5/21/21	9 days	0 days
String Pipe, 2	Thu 4/15/21	Fri 4/16/21	Wed 4/28/21	Thu 4/29/21	9 days	0 days
Testing, 3	Mon 5/24/21	Mon 5/24/21	Fri 6/4/21	Fri 6/4/21	8 days	0 days
Backfill, 3	Tue 5/25/21	Fri 5/28/21	Mon 6/7/21	Thu 6/10/21	8 days	4 days
Locate&Clear, 2	Tue 4/13/21	Tue 4/13/21	Thu 4/22/21	Thu 4/22/21	7 days	0 days
Excavation, 3	Tue 4/27/21	Mon 5/3/21	Wed 5/5/21	Tue 5/11/21	6 days	0 days
Testing, 4	Fri 6/4/21	Fri 6/4/21	Thu 6/10/21	Thu 6/10/21	4 days	0 days
Backfill, 4	Mon 6/7/21	Thu 6/10/21	Fri 6/11/21	Wed 6/16/21	4 days	4 days
Excavation, 2	Tue 4/20/21	Mon 4/26/21	Fri 4/23/21	Thu 4/29/21	3 days	0 days
String Pipe, 1	Tue 4/13/21	Wed 4/14/21	Fri 4/16/21	Mon 4/19/21	3 days	0 days
Locate&Clear, 1	Mon 4/12/21	Mon 4/12/21	Mon 4/12/21	Mon 4/12/21	0 days	0 days
Excavation, 1	Tue 4/13/21	Mon 4/19/21	Tue 4/13/21	Mon 4/19/21	0 days	0 days
Lay Pipe, 1	Tue 4/20/21	Thu 4/29/21	Tue 4/20/21	Thu 4/29/21	0 days	0 days
Lay Pipe, 2	Fri 4/30/21	Tue 5/11/21	Fri 4/30/21	Tue 5/11/21	0 days	0 days
Lay Pipe, 3	Wed 5/12/21	Fri 5/21/21	Wed 5/12/21	Fri 5/21/21	0 days	0 days
Lay Pipe, 4	Mon 5/24/21	Thu 6/3/21	Mon 5/24/21	Thu 6/3/21	0 days	0 days
Lay Pipe, 5	Fri 6/4/21	Tue 6/15/21	Fri 6/4/21	Tue 6/15/21	0 days	0 days
Testing, 5	Wed 6/16/21	Wed 6/16/21	Wed 6/16/21	Wed 6/16/21	0 days	0 days
Backfill, 5	Thu 6/17/21	Tue 6/22/21	Thu 6/17/21	Tue 6/22/21	0 days	0 days

Table 2: Detailed Scheduled Report Sorted Based on Descending Total Float

A detailed scheduled report with activities sorted based on earliest early start is shown as below table. Knowing early start date of an activity is significant for scheduling and planning purposes. The contractor can prepare necessary crew teams as well as resources for that activity.

Name	Early Start	Early Finish	Late Start	Late Finish	Total Slack	Free Slack
Locate&Clear, 1	Mon 4/12/21	Mon 4/12/21	Mon 4/12/21	Mon 4/12/21	0 days	0 days
Locate&Clear, 2	Tue 4/13/21	Tue 4/13/21	Thu 4/22/21	Thu 4/22/21	7 days	0 days
Excavation, 1	Tue 4/13/21	Mon 4/19/21	Tue 4/13/21	Mon 4/19/21	0 days	0 days
String Pipe, 1	Tue 4/13/21	Wed 4/14/21	Fri 4/16/21	Mon 4/19/21	3 days	0 days
Locate&Clear, 3	Wed 4/14/21	Wed 4/14/21	Tue 5/4/21	Tue 5/4/21	14 days	0 days
Locate&Clear, 4	Thu 4/15/21	Thu 4/15/21	Fri 5/14/21	Fri 5/14/21	21 days	0 days
String Pipe, 2	Thu 4/15/21	Fri 4/16/21	Wed 4/28/21	Thu 4/29/21	9 days	0 days
Locate&Clear, 5	Fri 4/16/21	Fri 4/16/21	Wed 5/26/21	Wed 5/26/21	28 days	4 days
String Pipe, 3	Mon 4/19/21	Tue 4/20/21	Mon 5/10/21	Tue 5/11/21	15 days	0 days
Excavation, 2	Tue 4/20/21	Mon 4/26/21	Fri 4/23/21	Thu 4/29/21	3 days	0 days
Lay Pipe, 1	Tue 4/20/21	Thu 4/29/21	Tue 4/20/21	Thu 4/29/21	0 days	0 days
String Pipe, 4	Wed 4/21/21	Thu 4/22/21	Thu 5/20/21	Fri 5/21/21	21 days	0 days
String Pipe, 5	Fri 4/23/21	Mon 4/26/21	Wed 6/2/21	Thu 6/3/21	27 days	27 days
Excavation, 3	Tue 4/27/21	Mon 5/3/21	Wed 5/5/21	Tue 5/11/21	6 days	0 days
Lay Pipe, 2	Fri 4/30/21	Tue 5/11/21	Fri 4/30/21	Tue 5/11/21	0 days	0 days
Testing, 1	Fri 4/30/21	Fri 4/30/21	Mon 5/24/21	Mon 5/24/21	16 days	0 days
Backfill, 1	Mon 5/3/21	Thu 5/6/21	Tue 5/25/21	Fri 5/28/21	16 days	4 days
Excavation, 4	Tue 5/4/21	Mon 5/10/21	Mon 5/17/21	Fri 5/21/21	9 days	0 days
Excavation, 5	Tue 5/11/21	Mon 5/17/21	Thu 5/27/21	Thu 6/3/21	12 days	12 days
Lay Pipe, 3	Wed 5/12/21	Fri 5/21/21	Wed 5/12/21	Fri 5/21/21	0 days	0 days
Testing, 2	Wed 5/12/21	Wed 5/12/21	Fri 5/28/21	Fri 5/28/21	12 days	0 days
Backfill, 2	Thu 5/13/21	Tue 5/18/21	Tue 6/1/21	Fri 6/4/21	12 days	4 days
Lay Pipe, 4	Mon 5/24/21	Thu 6/3/21	Mon 5/24/21	Thu 6/3/21	0 days	0 days
Testing, 3	Mon 5/24/21	Mon 5/24/21	Fri 6/4/21	Fri 6/4/21	8 days	0 days
Backfill, 3	Tue 5/25/21	Fri 5/28/21	Mon 6/7/21	Thu 6/10/21	8 days	4 days
Lay Pipe, 5	Fri 6/4/21	Tue 6/15/21	Fri 6/4/21	Tue 6/15/21	0 days	0 days
Testing, 4	Fri 6/4/21	Fri 6/4/21	Thu 6/10/21	Thu 6/10/21	4 days	0 days
Backfill, 4	Mon 6/7/21	Thu 6/10/21	Fri 6/11/21	Wed 6/16/21	4 days	4 days
Testing, 5	Wed 6/16/21	Wed 6/16/21	Wed 6/16/21	Wed 6/16/21	0 days	0 days
Backfill, 5	Thu 6/17/21	Tue 6/22/21	Thu 6/17/21	Tue 6/22/21	0 days	0 days

Table 3: Detailed Scheduled Report Sorted Based on Earliest Early Start

A detailed Gannt chart with the information of early start (ES) and early finish (EF) of the pipeline construction is presented as below figure. Gannt chart is very beneficial for simplifying the projects by showing activities displayed against time.

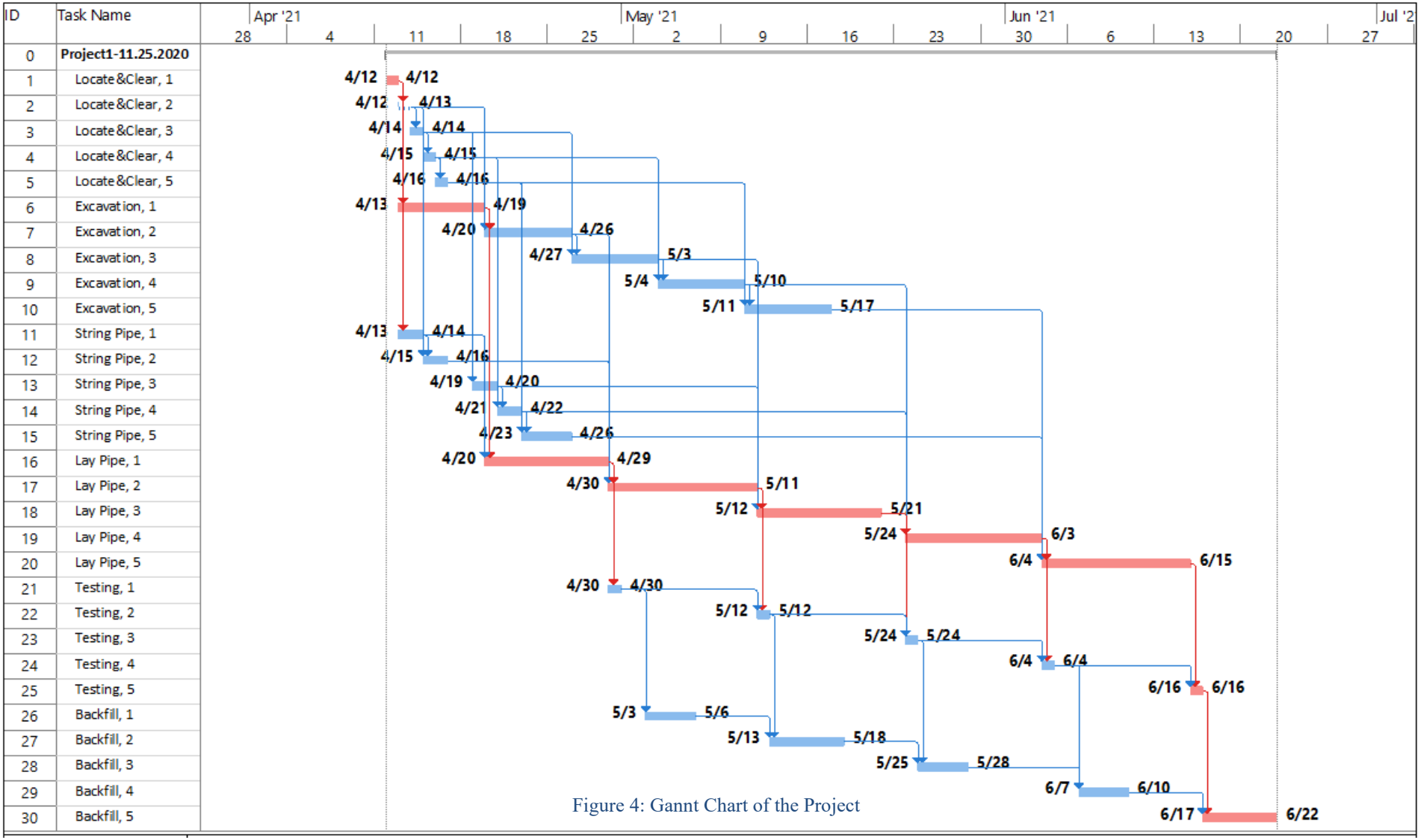


Figure 4: Gannt Chart of the Project

In addition to one general contractor, there are two subcontractor who are involved in this project. The project participants other than owner and design professional are as below

- **General Contractor:** GENERAL: clearing, excavating, pipe laying and backfilling
- **Subcontractor 1:** SurveyBoston: stringing
- **Subcontractor 2:** GeotechMass Inc: testing

The activities are assigned to general contractor and subcontractors as following table:

Name	Resource Names	Resource Group
Locate&Clear, 1	Locating&Clearing Laborer	Internal
Locate&Clear, 2	Locating&Clearing Laborer	Internal
Excavation, 1	Backhoe Loader[2],Laborer[2],Equipment Oper. (loader)[2]	Internal
Locate&Clear, 3	Locating&Clearing Laborer	Internal
Locate&Clear, 4	Locating&Clearing Laborer	Internal
Locate&Clear, 5	Locating&Clearing Laborer	Internal
String Pipe, 1	SurveyBoston	Subcontractor
Excavation, 2	Backhoe Loader[2],Laborer[2],Equipment Oper. (loader)[2]	Internal
Excavation, 3	Backhoe Loader[2],Laborer[2],Equipment Oper. (loader)[2]	Internal
String Pipe, 2	SurveyBoston	Subcontractor
Lay Pipe, 1	Crane[5],Laborer[5],Labor Foreman[5],Plumber[5],Plumber Apprentice[5],Equipment Oper. (crane)[5]	Internal
Excavation, 4	Backhoe Loader[2],Laborer[2],Equipment Oper. (loader)[2]	Internal
String Pipe, 3	SurveyBoston	Subcontractor
String Pipe, 4	SurveyBoston	Subcontractor
Excavation, 5	Backhoe Loader[2],Laborer[2],Equipment Oper. (loader)[2]	Internal
String Pipe, 5	SurveyBoston	Subcontractor
Lay Pipe, 2	Crane[5],Laborer[5],Labor Foreman[5],Plumber[5],Plumber Apprentice[5],Equipment Oper. (crane)[5]	Internal
Testing, 1	GeoTechMass	Subcontractor
Backfill, 1	Vibrating Plate[3],Laborer[6],Labor Foreman[3]	Internal
Lay Pipe, 3	Crane[5],Laborer[5],Labor Foreman[5],Plumber[5],Plumber Apprentice[5],Equipment Oper. (crane)[5]	Internal
Testing, 2	GeoTechMass	Subcontractor
Backfill, 2	Vibrating Plate[3],Laborer[6],Labor Foreman[3]	Internal
Lay Pipe, 4	Crane[5],Laborer[5],Labor Foreman[5],Plumber[5],Plumber Apprentice[5],Equipment Oper. (crane)[5]	Internal
Testing, 3	GeoTechMass	Subcontractor
Backfill, 3	Vibrating Plate[3],Laborer[6],Labor Foreman[3]	Internal
Lay Pipe, 5	Crane[5],Laborer[5],Labor Foreman[5],Plumber[5],Plumber Apprentice[5],Equipment Oper. (crane)[5]	Internal
Testing, 4	GeoTechMass	Subcontractor
Backfill, 4	Vibrating Plate[3],Laborer[6],Labor Foreman[3]	Internal
Testing, 5	GeoTechMass	Subcontractor
Backfill, 5	Vibrating Plate[3],Laborer[6],Labor Foreman[3]	Internal

Table 4: Activities Assigned to General and Sub-contractors

A detailed schedule report containing only backfilling activities which are sorted according to earliest LS is shown as below table and Gantt Chart.

Name	Early Start	Early Finish	Late Start	Late Finish	Total Slack	Free Slack
Backfill, 1	Mon 5/3/21	Thu 5/6/21	Tue 5/25/21	Fri 5/28/21	16 days	4 days
Backfill, 2	Thu 5/13/21	Tue 5/18/21	Tue 6/1/21	Fri 6/4/21	12 days	4 days
Backfill, 3	Tue 5/25/21	Fri 5/28/21	Mon 6/7/21	Thu 6/10/21	8 days	4 days
Backfill, 4	Mon 6/7/21	Thu 6/10/21	Fri 6/11/21	Wed 6/16/21	4 days	4 days
Backfill, 5	Thu 6/17/21	Tue 6/22/21	Thu 6/17/21	Tue 6/22/21	0 days	0 days

Table 5: Detailed Schedule for Backfilling

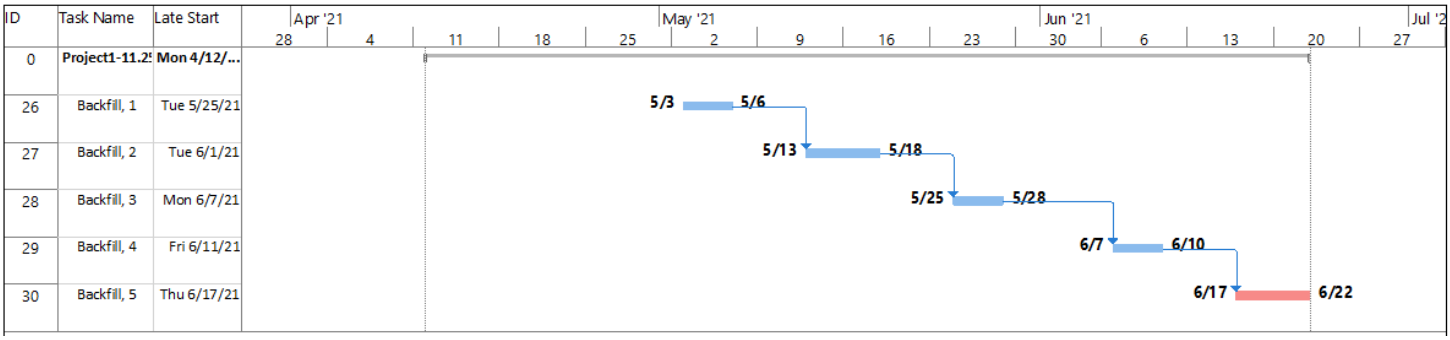


Figure 5: Gannt Chart for Backfilling Activity

Activity of backfilling mile-5 is critical activity in order not to extend the project duration because that activity is on the critical path and any delay of that activity affects the duration of the project.

When only consider the late start dates of the backfilling activities, backfilling activities should start 5/25/2021 at latest and can be performed less than in a month (5/25-6/17).

A Gannt chart is presented with early start and early finish dates in order to track subcontractor activities which are stringing the pipe and testing.

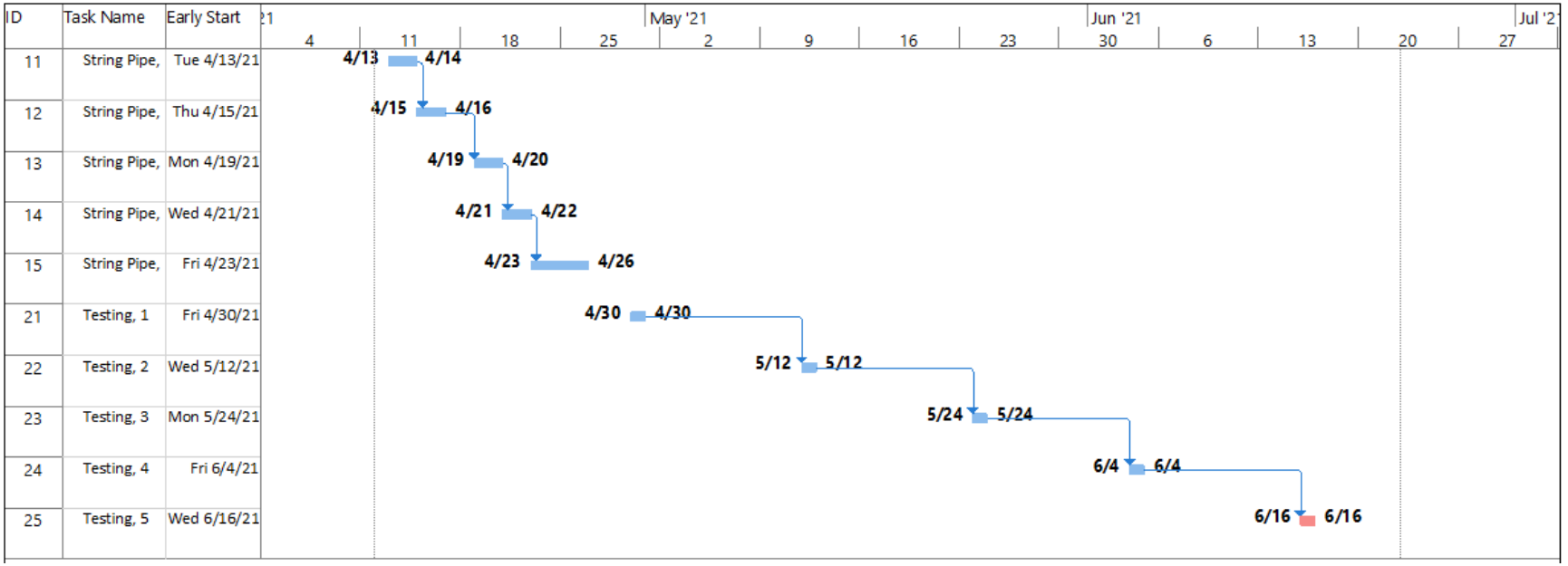


Figure 6: Gannt Chart for Subcontractor Activities

Testing mile-5 is on the critical path; therefore, it has to be paid attention to that subcontractor work in order to prevent any delays for project duration.

3.2. Resource Loading

The objective of this chapter is to load the network diagram developed with manpower and equipment requirements. There are three main activities considered for labor and equipment use which are excavation, laying pipe and backfilling.

3.2.1. Excavation Work

Before determining necessary crew team and estimating required number of crew team for excavation, the volume of excavation work is estimated as below:

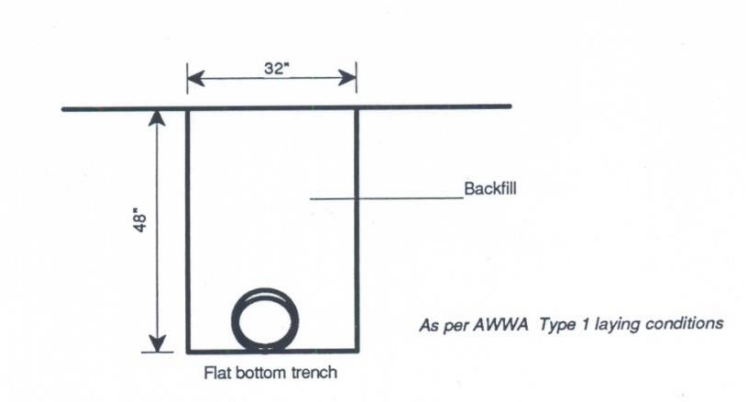


Figure 7: Sketch of Trench

Volume of Excavation for **each mile** $= \frac{48}{36} \text{x} \frac{32}{36} \text{x}\ 1760 = 2086\ \text{yd}^3$ for each mile

In order to find typical crew requirement for excavation, the RSMeans Data 2020 is used as following:

31 23 Excavation and Fill

31 23 16 – Excavation

31 23 16.13 Excavating, Trench

0010	**EXCAVATING, TRENCH**									
0011	Or continuous footing									
0020	Common earth with no sheeting or dewatering included									
0050	1' to 4' deep, 3/8 C.Y. excavator	B-11C	150	.107	B.C.Y.		5.25	1.43	6.68	9.45
0060	1/2 C.Y. excavator	B-11M	200	.080			3.95	1.16	5.11	7.20
0090	4' to 6' deep, 1/2 C.Y. excavator	"	200	.080			3.95	1.16	5.11	7.20
0100	5/8 C.Y. excavator	B-12Q	250	.064			3.24	2.39	5.63	7.50
0110	3/4 C.Y. excavator	B-12F	300	.053			2.70	2.31	5.01	6.60

Table 6: RSMeans Data for Excavation

Calculation of # of crew team (Crew B-11M) needed for one-mile excavation work

Daily Output from RS Means Data $= 200\ \text{yd}^3$

# of Labor Hours $\rightarrow \frac{2086}{200} = 10.4$ days for **one mile** excavation for **one crew**

Duration of each mile $\rightarrow 5$ days, # of crew needed $= \frac{10.4}{5} \cong 2$

2 crew team is needed in order to complete one mile excavation in 5 day duration.

3.2.2. Laying-Pipe Work

In order to find typical crew requirement for 8" diameter laying pipe, the RSMeans Data 2020 is used as following:

33 14 Water Utility Transmission and Distribution

33 14 13 – Public Water Utility Distribution Piping

33 14 13.15 Water Supply, Ductile Iron Pipe

0010	**WATER SUPPLY, DUCTILE IRON PIPE**	R331113-80									
0020	Not including excavation or backfill										
2000	Pipe, class 50 water piping, 18' lengths										
2020	Mechanical joint, 4" diameter	B-21A	200	.200	L.F.	42.50	10.45	2.14	55.09	64.50
2040	6" diameter		160	.250		51	13.05	2.68	66.73	78.50
2060	8" diameter		133.33	.300		53.50	15.70	3.21	72.41	86
2080	10" diameter		114.29	.350		71	18.30	3.75	93.05	110
2100	12" diameter		105.26	.380		90.50	19.85	4.07	114.42	134

Table 7: RSMeans Data for Laying Pipe

Calculation of # of crew team (Crew B-21A) needed for one-mile laying pipe

Daily Output from RS Means Data $= 133.33\ ft$

Needed # of Labor Hours $\rightarrow \frac{5280}{133.33} = 39.6$ days for **one mile** laying pipe for **one crew**

Duration of each mile $\rightarrow 8$ days, # of crew needed $= \frac{39.6}{8} \cong 5$

5 crew team is needed in order to complete one mile laying pipe work in 8 day duration.

3.2.3. Backfilling Work

In order to find typical crew requirement for backfilling, the RSMeans Data 2020 is used as following:

31 23 Excavation and Fill

31 23 16 – Excavation

	31 23 16.13 Excavating, Trench	Crew	Daily Output	Labor-Hours	Unit	2020 Bare Costs Material	Labor	Equipment	Total	Total Incl O&P
1397	semi-stable material, 4' W	2 Clab	2400	.007	SF Wall	.28	.28		.56	.73
1398	Rent hydraulic shoring per day/S.F. wall, stable mat., 4' W					.32			.32	.36
1399	semi-stable material					.41			.41	.45
1400	By hand with pick and shovel 2' to 6' deep, light soil	1 Clab	8	1	B.C.Y.		42		42	63.50
1500	Heavy soil	"	4	2	"		84		84	127
1700	For tamping backfilled trenches, air tamp, add	A-1G	100	.080	E.C.Y.		3.37	.54	3.91	5.65
1900	Vibrating plate, add	B-18	180	.133	"		5.70	.92	6.62	9.55
2100	Trim sides and bottom for concrete pours, common earth		1500	.016	S.F.		.68	.11	.79	1.15

Table 8: RSMeans Data for Backfilling

Calculation of # of crew team (Crew B-18) needed for one-mile backfilling

Daily Output from RS Means Data $= 180\ \text{yd}^3$

# of Labor Hours $\rightarrow \frac{2086}{180} =$ 11.6 days for **one mile** backfilling for **one crew**

Duration of each mile $\rightarrow$ 4 days, # of crew needed $= \frac{11.6}{4} \cong 3$

3 crew team is needed in order to complete one mile backfilling in 4 day duration.

3.2.4. Resource Use for the Project

Every activity needs to be performed by its own unique crew team and required # of crew members for excavation, laying pipe and backfilling are summarized as below:

- **For excavation:** 2 crew team (Crew B-11M) is needed
  - 2 Laborer
  - 2 Equipment Operator
  - 2 Backhoe Loader

- **For laying pipe:** 5 crew team (Crew B-21A) is needed
  - 5 Laborer

- 5 Labor Foreman
- 5 Plumber
- 5 Plumber Apprentice
- 5 Equipment Operator
- 5 Crane

- **For backfilling:** 3 crew team (Crew B-18) is needed
  - 6 Laborer
  - 3 Labor Foreman
  - 3 Vibrating Plate

Without any constraint on resources, the histogram and cumulative resource graphs for laborer and crane are developed as below. Both histogram shows similar to normal distribution histogram which indicates that at the early and last stages of the construction, there is less need for laborer compared to the mid stage of the construction where most of the activities are performed. # of hours for crane does not change much because crane is only needed for the laying pipe activity; however, all three activities require laborer.

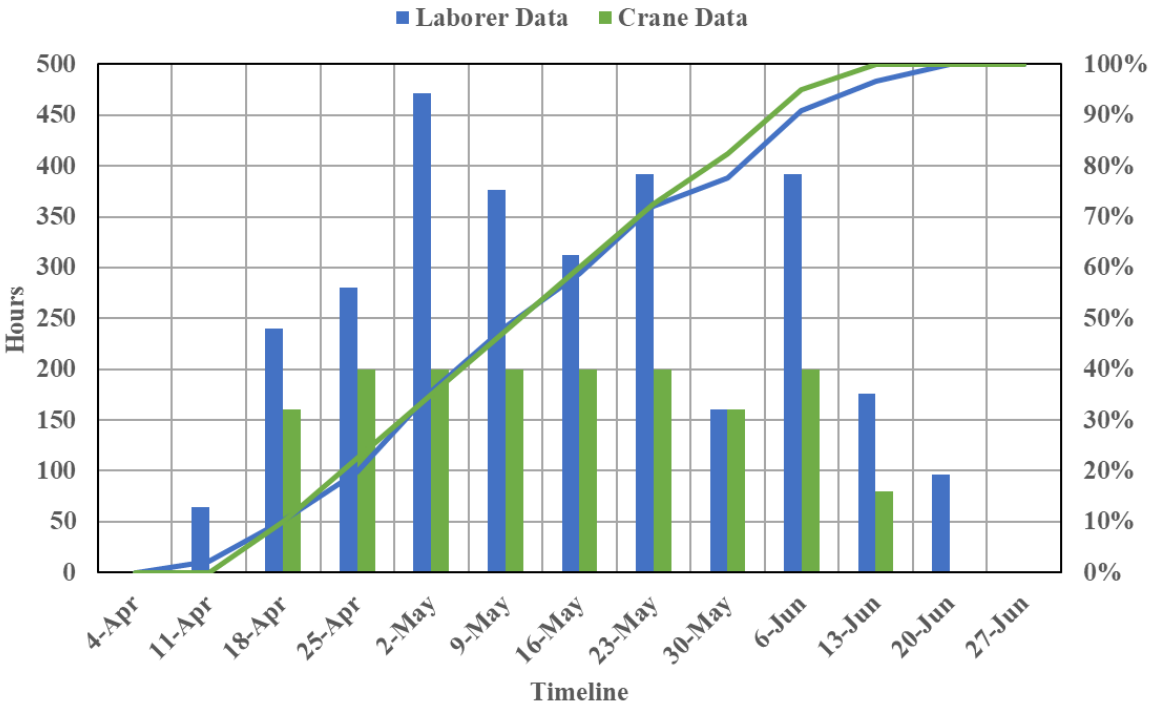


Figure 8: Resource Diagram for Laborer and Crane

3.3.Resource Allocation under Constraints

The construction project has a constraint of laborer resource and there are maximum eight (8) laborers that can work in a day during the project. After this constraint was inputted in the software, overallocated laborer resource can be shown as below histogram:

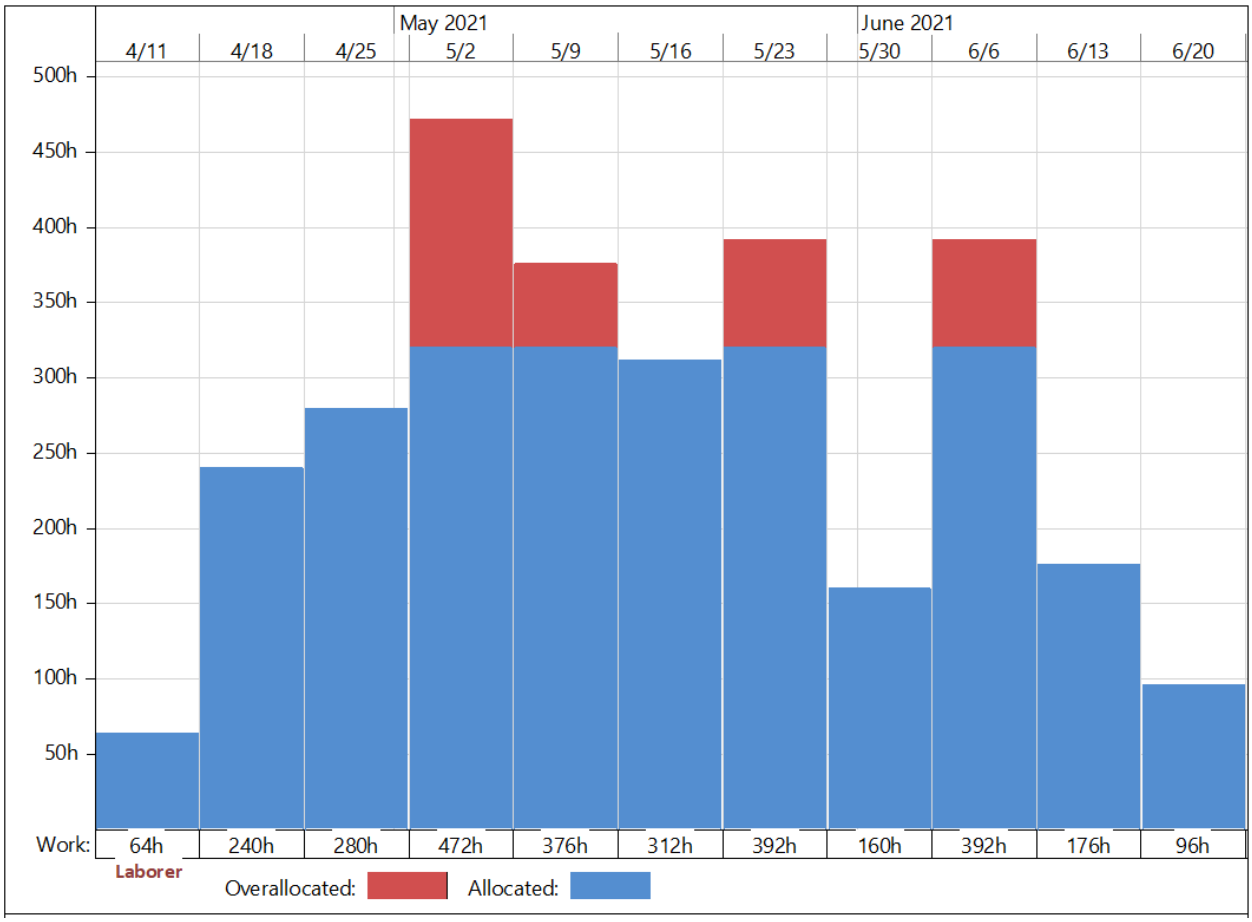
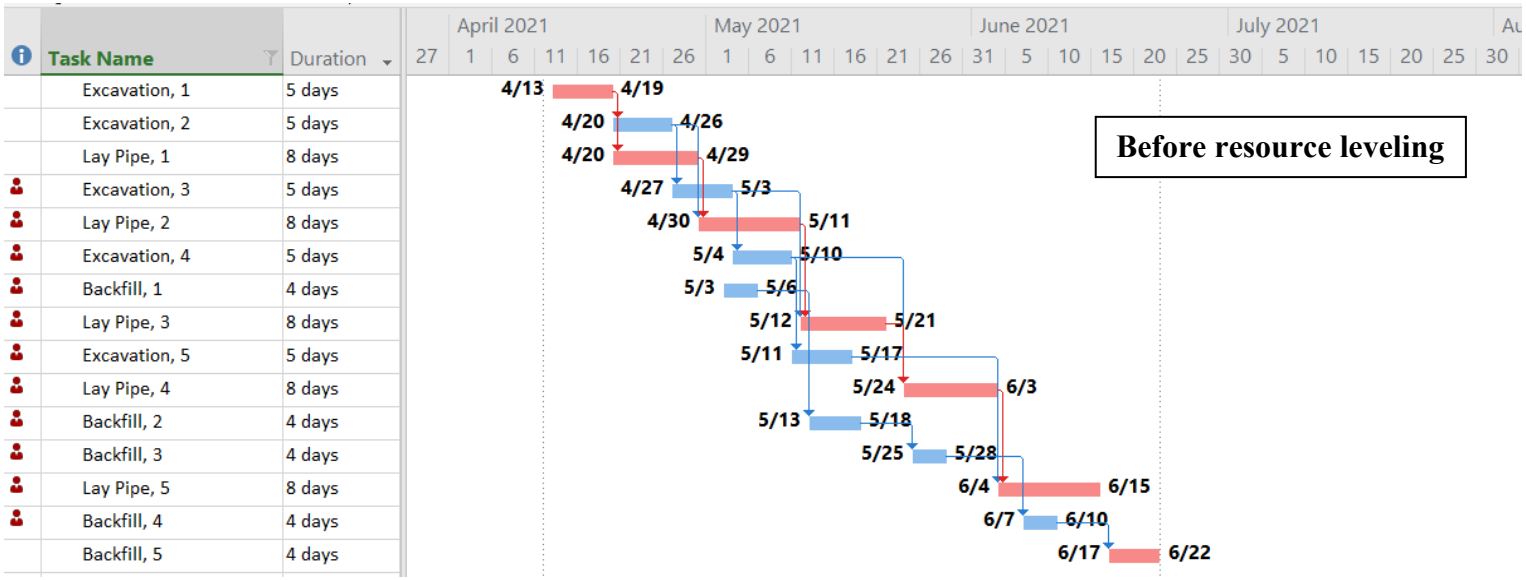


Figure 9: Resource Allocation for Laborer

In a week, there should be maximum 320 working hours (=8x40) allocated for laborer resource after constraint the laborer. First, second and third week of May as well as first week of June indicates overallocated laborer resources which needs to be leveling.

When the software is adjusted to level the resources, the new completion date of the project is set to 7/15/2021 from 6/22/2021. Gannt charts are presented before and after resource leveling as shown below:



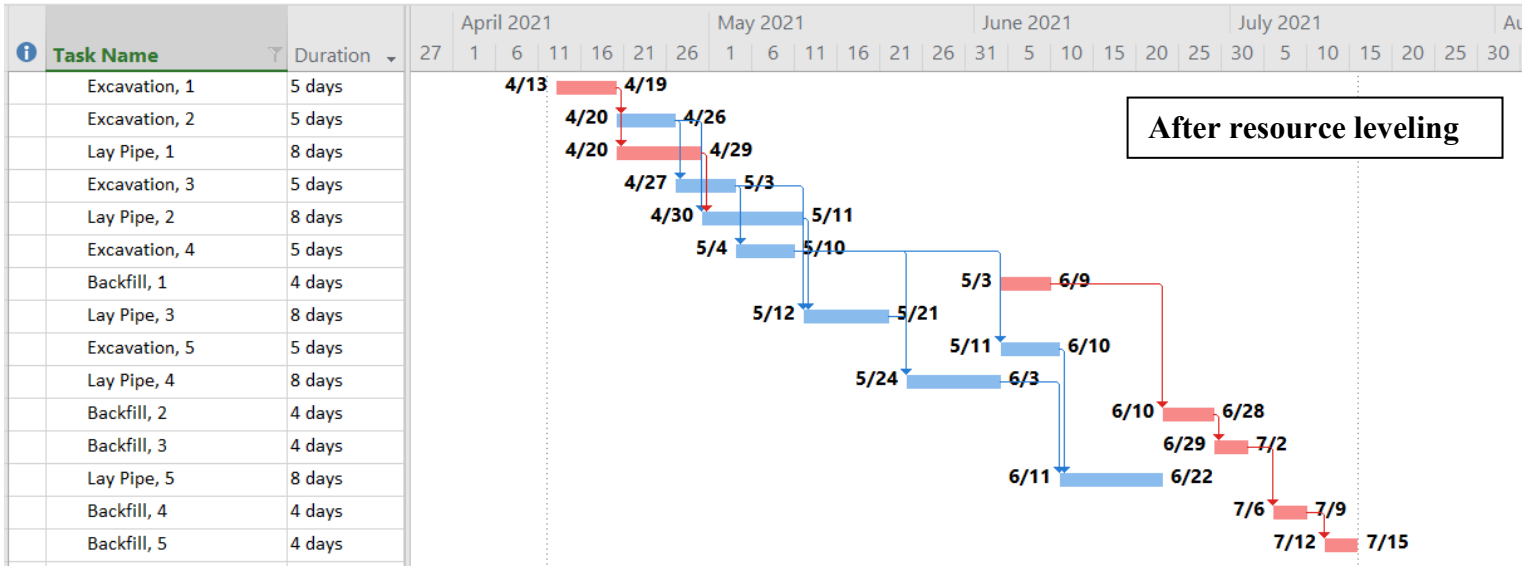


Figure 10: Gannt Charts Before and After Resource Leveling

Before resource leveling, the project was scheduled to finish on 6/22, utilizing 51 workdays. After resource leveling, the project was scheduled to be completed on 7/15, utilizing 67 workdays. The resulting delay is 16 workdays. Given our resource constraints, this delay was caused by several instances of resource constraints. The first delay occurred on 5/3, where backfilling mile 1 was scheduled. This is because laying pipe for mile 2 and excavating mile 4 were already in progress, resulting in 7 laborers occupied out of 8 available. Next, excavation of mile 5 was pushed back from 5/17 to 6/10. This is due to backfilling of mile 2, excavation of mile 5, and laying pipe on mile 3 being scheduled concurrently before resource leveling. This would result in a requirement of 13 laborers. Having to push backfilling to mile 1 of backfilling resulting in requiring the delay of subsequent miles of backfilling. The only activities occurring after 6/22, the original completion date, are backfilling activities that would be completed alongside other activities if the number of laborers wasn't a limiting factor.

4. CONSTRUCTION MANAGEMENT PHASE III

4.1. Project Cost Loading

In order to develop project cash flow, all the resource restraint was lifted, and all resources were inputted as if all the resources are unlimited. Costs were taken from RS Means 2020 data for components of crew teams and O&P cost is included for the cost determination for each resource type. Resources with their costs were defined in the software as following table:

ID	Resource Name	Type	Initials	Group	Max. Units	Std. Rate
1	Laborer	Work	L	Internal	20	$63.25/hr
2	Locating&Clearing Laborer	Work	Loc	Internal	10	$0.00/hr
3	Labor Foreman	Work	Lab. Fore	Internal	10	$66.25/hr
4	Equipment Oper. (loader)	Work	Eq Oper	Internal	10	$84.85/hr
5	Equipment Oper. (crane)	Work	E	Internal	10	$88.50/hr
6	Plumber	Work	Plum	Internal	10	$96.45/hr
7	Plumber Apprentice	Work	Plum Apprentice	Internal	10	$77.15/hr
8	Backhoe Loader	Work	Loader	Internal	10	$31.96/hr
9	Crane	Work	Crane	Internal	10	$58.89/hr
10	Vibrating Plate	Work	Vibrating Plate	Internal	10	$22.74/hr
11	SurveyBoston	Work	S	Subcontractor	10	$0.00/hr
12	GeoTechMass	Work	G	Subcontractor	10	$0.00/hr

Table 9: Project Cost Loading Table

Cost loading graph; in other words, cash flow containing both histogram and cumulative curves are developed as below:

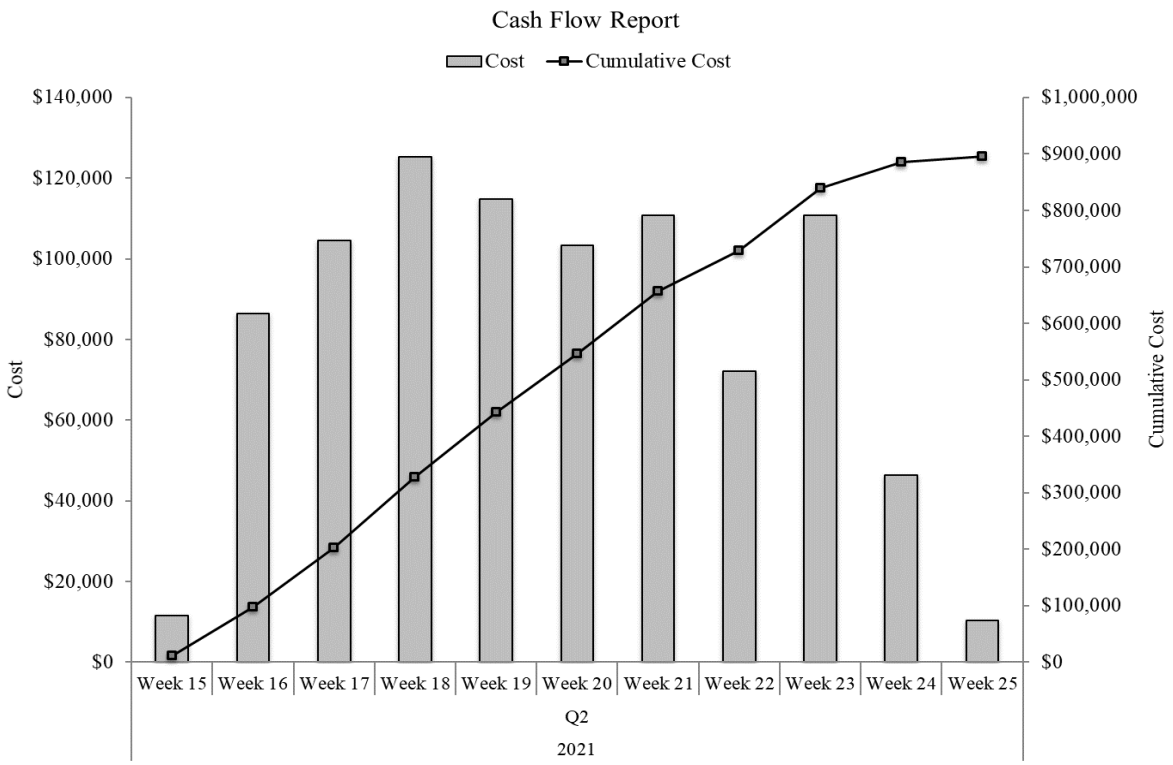


Figure 11: Project Cash Flow Diagram

For this project, each mile of excavation costs $14,000 totaling roughly $3,000 per day, while each mile of laying pipe costs $144,000, totaling $18,000 per day and backfilling costs $21,000, totaling $3,000 per day on average. For the week of 4/12, project expenditures were low at only $12,000. This is because at the start, multiple project activities cannot be completed because there are no preceding tasks completed. During this week, only excavation of mile 1 is completed. During the week of 4/19, the project has more substantial activities running simultaneously, so weekly expenditures increase to $85,000. During this work week, excavation of mile 2 and pipe laying on mile 1 occur for the whole week. The week of 4/26 sees weekly expenditures further increase to $105,000. This is due to the completion of laying pipe on mile 1, in addition to excavating mile 3, starting pipe laying on mile 2. The week of 5/3 sees the highest weekly expenditure of the entire project at $125,000. This is attributed to the continuation of laying pipe on mile 2, in addition to the start of excavation of mile 4 and backfilling of mile 1. The week of 5/10 has high, but not quite as high as $115,000. This is attributed to the laying of pipe along mile 3, in addition to excavating mile 5 and beginning to backfill mile 2.

For the week of 5/17, expenditures are projected to be about $105,000. These expenditures are attributed to laying pipe along mile 3, in addition to backfilling mile 2. The week of 5/24 brings expenditures of $110,000. This is due to laying pipe on mile 4 of the project in addition to backfilling mile 3. The week of 5/31 has weekly expenditures of $70,000. These expenditures are required for the continued pipe laying on mile 4 and 5. There are no other activities occurring during this week, which brings the expenditures down. For the week of 6/7, expenditures decrease to $110,000. This is because pipe laying on mile 5 continues in addition to backfilling mile 4 for 3 days. for the week of 6/14, expenditures are at $50,000. This is attributed to the completion of laying pipe on mile 5, and the start of backfilling mile 5. For the week of 6/21, costs are back down to only $10,000. This is for the completion of backfilling the project.

4.2. Project Schedule Control and Updating

The progress report is given at the end of May 28, 2021 and the data to update the schedule is provided as below:

Activity	Actual Start Date	Actual Finish Date
Locate & clear, mile 1	4/12	4/13
Locate & clear, mile 2	4/14	4/20
Locate & clear, mile 3	4/21	4/21
Locate & clear, mile 4	4/22	4/28
Locate & clear, mile 5	4/29	5/3
Excavate, mile 1	4/20	5/11
Excavate, mile 2	5/12	90% complete
String pipe, mile 1	5/6	5/11
String pipe, mile 2	5/20	5/26
Lay pipe, mile 1	5/24	30% complete

With an assumption of no resource constraint and after updating the schedule with given finished activities, the project finish date is shifted to 7/27/2021 from 6/22/2021 which is about a month. The table below includes the revised early start and early finish dates as well as baseline start and finish dates for the activities. Because of the software nature, even though 90% of completion was entered for excavation mile-2 (starts on 5/12/21) on the project updating date on, 5/28/21, the software wanted to finish the activity in 5-day duration which is already defined in the software. Therefore, for an activity, no matter what the percentage of completion is entered without putting the finish date into the software, the software updates all the activities until the project updating date which is 5/28/21.

The first reason for the delay is the significant delay to start time and the overrun of the excavation of mile 1. The project started 5 workdays late on 4/20 and instead of taking the standard 5 days, the task took 16 days, resulting in an 11-day overrun. This pushed the excavation of mile 2 to 5/12 instead of the scheduled 4/20. This task is 90 percent done as of May 28th, which would lead to further significant delays of the project. Stringing pipe is also taking longer than expected. The project schedule only allowed for stringing pipes to take 2 workdays per mile, but so far the task has taken 4 and 5 days for miles 1 and 2, respectively. There would need to be significant crashing of tasks for this project to be completed on time in its current state.

Name	Baseline Start	Actual Start	Baseline Finish	Actual Finish	Early Start	Early Finish
Locate&Clear, 1	Mon 4/12/21	Mon 4/12/21	Mon 4/12/21	Tue 4/13/21	Mon 4/12/21	Tue 4/13/21
Locate&Clear, 2	Tue 4/13/21	Wed 4/14/21	Tue 4/13/21	Tue 4/20/21	Wed 4/14/21	Tue 4/20/21
Excavation, 1	Tue 4/13/21	Tue 4/20/21	Mon 4/19/21	Tue 5/11/21	Tue 4/20/21	Tue 5/11/21
Locate&Clear, 3	Wed 4/14/21	Wed 4/21/21	Wed 4/14/21	Wed 4/21/21	Wed 4/21/21	Wed 4/21/21
Locate&Clear, 4	Thu 4/15/21	Thu 4/22/21	Thu 4/15/21	Wed 4/28/21	Thu 4/22/21	Wed 4/28/21
Locate&Clear, 5	Fri 4/16/21	Thu 4/29/21	Fri 4/16/21	Mon 5/3/21	Thu 4/29/21	Mon 5/3/21
String Pipe, 1	Tue 4/13/21	Thu 5/6/21	Wed 4/14/21	Tue 5/11/21	Thu 5/6/21	Tue 5/11/21
Excavation, 2	Tue 4/20/21	Wed 5/12/21	Mon 4/26/21	Tue 5/18/21	Wed 5/12/21	Tue 5/18/21
Excavation, 3	Tue 4/27/21	Wed 5/19/21	Mon 5/3/21	Tue 5/25/21	Wed 5/19/21	Tue 5/25/21
String Pipe, 2	Thu 4/15/21	Thu 5/20/21	Fri 4/16/21	Wed 5/26/21	Thu 5/20/21	Wed 5/26/21
Lay Pipe, 1	Tue 4/20/21	Mon 5/24/21	Thu 4/29/21	NA	Mon 5/24/21	Thu 6/3/21
Excavation, 4	Tue 5/4/21	Wed 5/26/21	Mon 5/10/21	NA	Wed 5/26/21	Wed 6/2/21
String Pipe, 3	Mon 4/19/21	Thu 5/27/21	Tue 4/20/21	Fri 5/28/21	Thu 5/27/21	Fri 5/28/21
String Pipe, 4	Wed 4/21/21	NA	Thu 4/22/21	NA	Tue 6/1/21	Wed 6/2/21
Excavation, 5	Tue 5/11/21	NA	Mon 5/17/21	NA	Thu 6/3/21	Wed 6/9/21
String Pipe, 5	Fri 4/23/21	NA	Mon 4/26/21	NA	Thu 6/3/21	Fri 6/4/21
Lay Pipe, 2	Fri 4/30/21	NA	Tue 5/11/21	NA	Fri 6/4/21	Tue 6/15/21
Testing, 1	Fri 4/30/21	NA	Fri 4/30/21	NA	Fri 6/4/21	Fri 6/4/21
Backfill, 1	Mon 5/3/21	NA	Thu 5/6/21	NA	Mon 6/7/21	Thu 6/10/21
Lay Pipe, 3	Wed 5/12/21	NA	Fri 5/21/21	NA	Wed 6/16/21	Fri 6/25/21
Testing, 2	Wed 5/12/21	NA	Wed 5/12/21	NA	Wed 6/16/21	Wed 6/16/21
Backfill, 2	Thu 5/13/21	NA	Tue 5/18/21	NA	Thu 6/17/21	Tue 6/22/21
Lay Pipe, 4	Mon 5/24/21	NA	Thu 6/3/21	NA	Mon 6/28/21	Thu 7/8/21
Testing, 3	Mon 5/24/21	NA	Mon 5/24/21	NA	Mon 6/28/21	Mon 6/28/21
Backfill, 3	Tue 5/25/21	NA	Fri 5/28/21	NA	Tue 6/29/21	Fri 7/2/21
Lay Pipe, 5	Fri 6/4/21	NA	Tue 6/15/21	NA	Fri 7/9/21	Tue 7/20/21
Testing, 4	Fri 6/4/21	NA	Fri 6/4/21	NA	Fri 7/9/21	Fri 7/9/21
Backfill, 4	Mon 6/7/21	NA	Thu 6/10/21	NA	Mon 7/12/21	Thu 7/15/21
Testing, 5	Wed 6/16/21	NA	Wed 6/16/21	NA	Wed 7/21/21	Wed 7/21/21
Backfill, 5	Thu 6/17/21	NA	Tue 6/22/21	NA	Thu 7/22/21	Tue 7/27/21

Table 10: Revised and Baseline Schedule

The Gannt chart below summarizes the baseline schedule as well as revised schedule.

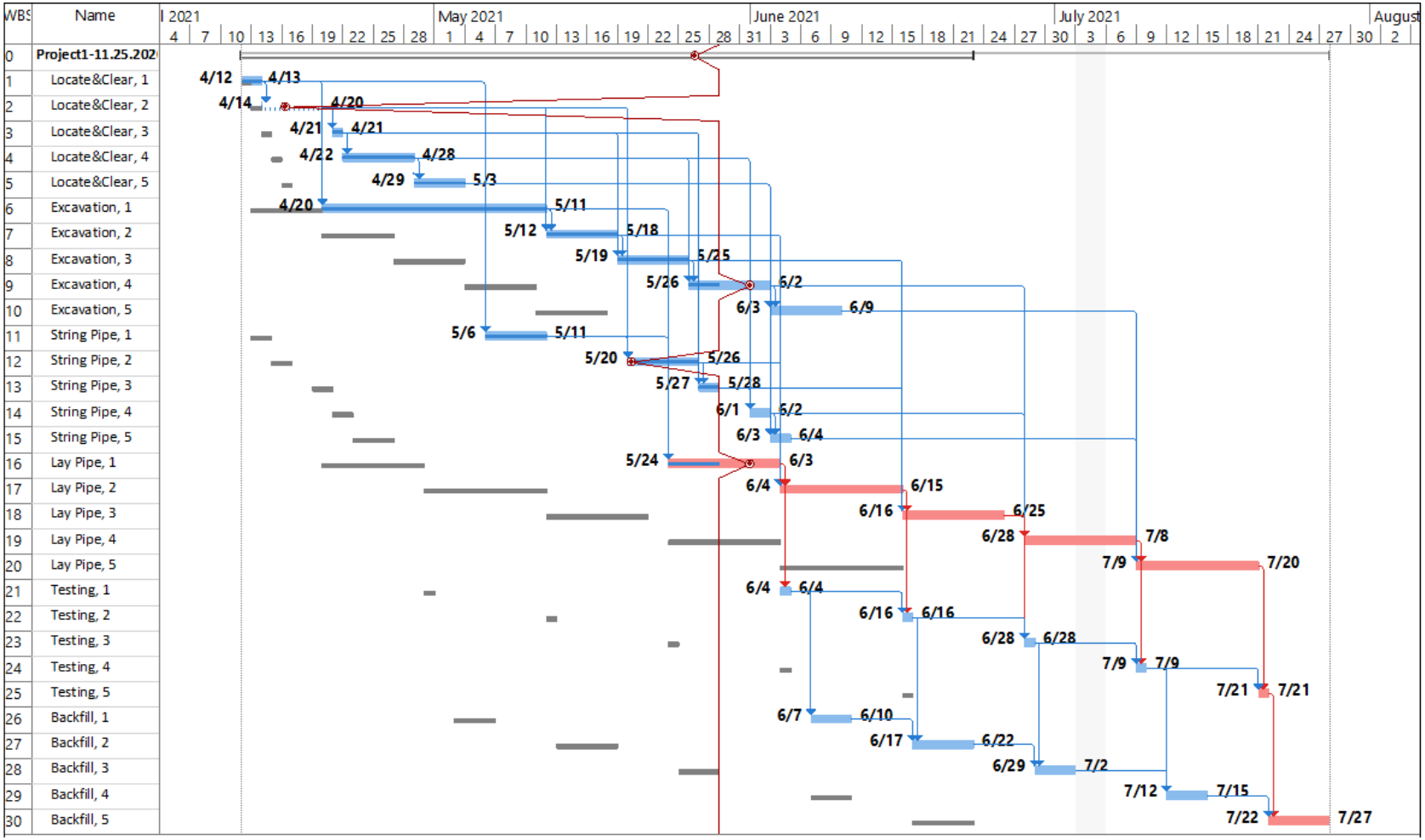


Figure 12: Gannt Chart for Revised and Baseline Schedule