AMERICAN UNIVERSITY OF BEIRUT

ANALYZING CONSTRUCTION WORKFLOW ON BIM BASED OIL AND GAS PROJECTS

By
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AN ABSTRACT OF THE THESIS OF

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Title: ANALYZING CONSTRUCTION WORKFLOW ON BIM BASED OIL AND GAS PROJECTS

Improving construction workflow is an essential step to ensure a proper continuous flow of resources on the project. However, in the O&G industry, this remains a challenge because the current planning practices being used like (CPM) does not visualize or measure flow. Hence, tools like location-based management system (LBMS) provide great visibility for the flow of work in construction sites. In order to analyze issues related to workflow in O&G projects, a gas processing project facility was chosen, data was collected, and the LBMS technique was used to plot flow lines for the design phase, initial plan, and actual construction.

The project was divided into 24 areas that were examined and plotted. A comparison between plan and actual construction workflow were performed, then between design and planned work. Furthermore, multiple areas were presented and discussed together to check the activity flow between different locations. Bottlenecks in construction and design were spotted, in addition to deficiencies in the current planning method used.

The findings identified multiple contributors to schedule delays on the project. These are design changes, out of sequence work, delivery of un-erectable steel items, trade stacking, and parallel work in multiple locations. The importance of this study is in displaying deficiencies in current planning and control practices employed in the O & G industry and showing the power of LBMS methods in visualizing and streamlining workflow during design, initial planning, and construction

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ABBREVIATIONS

CPM	Critical Path Method
GCC	Gulf Cooperation Council (GCC)
AFC	Approved for Construction

CHAPTER I

INTRODUCTION

This chapter serves as a blueprint for the Thesis, highlighting its theoretical direction, significance, research questions, and objectives. First, the chapter presents a brief introduction on Oil and Gas projects complexity, then expands on by explaining the challenges facing the sector and the need to employ the latest construction trends. Finally, it will outline the significance and the research questions and thesis structure.

In the past decade, research has shown that the construction industry, especially the Oil and Gas (O&G) sector, has less productivity in comparison to other industries (Fakhimi et al. 2017). The reason for that can be attributed to the fact that O&G projects are complex, and they involve different stakeholders who need to communicate and interact together to complete the project. This remains a major problem as recent studies have shown that delays are attributed to a lack of collaboration and improper information exchange (Beetz, 2009), which affects construction workflow. As a result, various management research such as lean construction and Building Information Modeling (BIM) have been developed to answer the industry's main challenges. As the complexity of projects increases, the need to implement BIM along with proper planning and control methods becomes a necessity (Fakhimi et al. 2017) particularly in O&G projects which are mega projects with high budgets.

In complex, O&G it is important to share and integrate information efficiently during design and construction to avoid delays and cost overruns. Cost overruns and project delays are a common trend in Oil and Gas projects, according to a detailed report by Deloitte Center of Energy Research. 65 % of major of O&G projects have exceeded their budget by at least 25% and exceeded their schedule by 50% which causes a massive surge in the project's budgets (Deloitte, 2015). Similar findings were reported by EY which found out that 64% of O&G megaprojects are experiencing a cost overrun (EY, 2014).

Applying BIM & latest planning techniques is a necessity to answer the O&G industry's main challenges in terms of collaboration and workflow during various project phases (Fakhimi et al. 2017). Therefore, this thesis studies the planning & control practices being used in the industry and study their impact on design and construction workflow. To achieve the goal of the research, a mega BIM-based O&G project is analyzed.

A. Problem Statement and Significance

Improving construction workflow is an important step to ensure a proper continuous flow of resources on the project. However, in the O&G industry, this remains a challenge because the current planning practices being used like (CPM), does not measure flow. Hence, one cannot improve what one does not measure. Therefore, this thesis will study design, planning, and construction workflows in BIM-based Oil and Gas project. Moreover, it will examine the current weaknesses in planning and control methods being used.

O&G projects have a great impact on countries' economies especially in the Arabian Gulf (Mohammed et al., 2015). Therefore, improving this sector is a necessity to achieve proper economic growth. To suggest improvements, one must understand the nature of the problem in the current practices within the O&G industry. Therefore, this study will investigate workflow between design and construction, and between plan and construction in BIM-based Oil and Gas projects. It will assess the overall planning and control process and highlight benefits and challenges. Hopefully, the results of this research will help in highlighting problems and potential improvements to be used in the design and management of future Oil and Gas projects.

B. Research Questions

The main research questions fueling this research are:

Question 1: How can design and planning workflow affect construction?

Question 2: What are the current deficiencies in the planning and control methods employed in Oil and Gas projects?

C. Scope of Work and Limitations

Objective 1: Understand the effect of design workflow on construction and the planned workflow on actual construction. This objective aims at understanding how the design deliverables affect the flow of construction activities, for example, when delivering the designs and material late to critical areas in the project, and in checking how various construction teams affect downstream activities.

Objective 2: Understand the weaknesses of current planning and control methods used in BIM-based oil and gas projects. This objective aims at identifying the challenges in managing mega complex projects, and to check whether the current planning and control practices need to be revamped especially in the Oil and Gas industry

There are several limitations to the study. First, this study is based on a single project, and therefore the findings cannot be generalized to the whole Oil and Gas industry. Moreover, only start and end date for various project tasks were available, and a complete history of actual progress was not available.

Furthermore, no data related to cost was studied, making schedule performance the only factor that was analyzed.

D. Thesis Structure

The Thesis is divided into six chapters. Chapter 1 presents the research background, significance, objectives and research questions. Chapter 2 reviews the literature related to the topic. Chapter 3 explains the methodology. Chapter 4 explains the research method employed to achieve the research goals. Chapters 5 presents the research results along with a detailed analysis of the findings. Finally, Chapter 6 concludes the study, highlights limitations, and recommendations for future research

CHAPTER II

LITERATURE REVIEW

This chapter examines the research needed for this study. First, BIM is discussed in general, then construction workflow, finally challenges in oil and gas challenges industry.

A. BIM

There exist many definitions for BIM in the literature (Barlish and Sullivan 2012). The commonly used definition is: *"BIM is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle"* (NIBS 2007). According to Building Smart International, BIM performs three different but related functions (Buildingsmart 2016):

1- It is a business process for creating and using generated data during the project life cycle.

2- It is a physical and functional digital representation of the project. It acts as a shared knowledge resource for various project teams.

3- It manages the whole business process by using digital information to control the sharing of information over the project life cycle.

The advancement of the BIM industry sparked the interest of researches to quantify and study its impact on projects. BIM Project Execution Planning Guide by Pennsylvania State University states that there are 25 benefits of using BIM during various project phases as shown in figure 1 (Haron et al. 2010). BIM can improve the whole life cycle of a project since it uses a data enriched 3D model which facilitates collaboration and decision-making during design and construction (Radu 2014). Therefore, BIM is addressing construction industry major challenges in terms of collaboration, planning and site control.

		Project life cycle			
	BIM uses	Plan	Design	Construction	Operation
1	Existing condition modeling	√	√	√	√
2	Cost estimation	√	√	√	√
3	Phase planning	√	√	√	
4	Programming	√	√		
5	Site analysis	√	√		
6	Design reviews	√	√		
7	Design authoring		√		
8	Energy analysis		√		
9	Structural analysis		√		
10	Lighting analysis		√		
11	Mechanical analysis		√		
12	Other Eng. analysis (geotechnical, safety, …)		√		
13	Green building evaluation		√		
14	Code validation		√		
15	3D coordination			√	
16	Site utilization planning			√	
17	Construction system design			√	
18	Digital fabrication			√	
19	3D control and planning			√	
20	Record model			√	√
21	Maintenance scheduling				√
22	Building system analysis				√
23	Asset management				√
24	Space management/tracking				√
25	Disaster planning				√

Figure 1 Benefits of using BIM during Project phases (Haron et al. 2010)

Information flow plays an important role during design and construction because improper communication between different stakeholders will result in delays and cost overruns. Hattab et al. (2013), studied the effect of utilizing BIM on information flow. Results showed that in 2D based projects different participants wait for each other’s design completion and information is gathered in silos before they are shared; thus, rendering them as waste.

In contrast, in BIM based design, information is timely shared, and an integrated model can be created at any time; thus, allowing real time adjustments and clear visualization. Moreover, it reduces idle time, and increases value generation by allowing the owner to access design information when needed. Finally, the BIM based design approach helps in reducing iterative loops, rework, and give the ability for the design teams to improve quality by allowing them to work collaboratively (Hattab et. al,2013).

B. Workflow

Workflow according to Kim and Ballard (2000) is defined as the transfer of material and information through a network of production units, whereby each unit will process them before releasing them to other units downstream. Shingo and Dillon (1989) differentiated between two different types of flow, namely process flow which is the movement of a product on the production line, and operational flow which is the individual activities completed on the product. In construction, the production flow would be the flow between different site locations (Kenley and Seppänen 2010, Sacks 2016). The physical project units like foundations are considered the "products", which will be released from one discipline to another on the same or different locations. Operational flow in construction would follow the movement of different crews from one location to another (Sacks, 2016).

Current techniques used in the industry do not measure the flow. For instance, the critical path method (CPM) focuses on linking different activities logically by identifying critical path only. However, there is no attention to the flow of crews and resources from different locations. In lean construction, percent plan complete (PPC) is a metric used in the Last Planner system. This metric evaluates plan reliability not flow. Therefore, lately a new metric proposed by Sacks et al. (2017) called the Construction flow index promises to help determine whether production flow is improving or deteriorating on a project by providing one single composite number.

Construction workflow can be calculated using the following formula shown in figure 2:

$$CFI(t) = 10 \sum_{i=1}^{7} W_i P_i^{X_i} \quad \text{where } X_i \in [1, 2]$$

Parameter	Description
$P_1 = \prod_{i=1}^{n} RS_i$	Product of all RS_i values, for n trades
$P_2 = \frac{\bar{P}}{\bar{P} + \overline{PSTD}}$	Standard deviation of the duration P normalized using the average of P
$P_3 = 1 - \frac{NB}{TFP}$	Proportion of transfers from location to location for a crew that are continuous (i.e. percentage of the locations after which a crew will not have a break after finishing the location)
$P_4 = \frac{\bar{P}}{\frac{ND}{TFP} + \bar{P}}$	Normalized proportion of average actual working time to total time spent on site for all trades
$P_5 = \frac{NT}{WIP}$	Proportion of locations worked on in a given period to the total number of locations with work in progress over the same period
$P_6 = 1/e^{(10 \times BP/TFP)}$	Indicator of the proportion of work performed out of sequence
$P_7 = \frac{TFP - BF}{TFP}$	Normalized proportion of locations performed out of sequence (a trade crew performing locations out of order or in parallel – not according to the plan)

Figure 2 Construction flow index formula (Sacks et al. 2017))

The formula takes into consideration duration of tasks; work performed out of sequence, continuity of work by a crew from one location to another (no breaks), and average actual time by all trades.

Many people think that BIM can improve the construction workflow in building projects only. However, others argue it can be used to improve the delivery of non-building projects as well (Cheng et al., 2016). A report published by McGraw Hill construction (2012) revealed that the success of BIM in building projects motivated the adoption of BIM in various non-building projects. Yet, the scale of BIM adoption within the O&G industry is not clear.

C. Oil and Gas

Projects are often mega projects with high budgets involving various stakeholders (Mohammed et al., 2015). Due to their complexity, it is important to share and integrate information efficiently during design and construction to avoid delays and cost overruns. Cost overruns and project delays are a common trend in Oil and Gas projects, according to a detailed report by Deloitte Center of Energy Research. 65 % of major of O&G projects have exceeded their budget by at least 25% and exceeded their schedule by 50% which causes a massive surge in the project's budgets (Deloitte, 2015). For example, the Pearl GTL project in Qatar exceeded its 5 Billion USD budget by 300%; another project in Australia, Pluto LNG, exceeded its 9 Billion USD budget by 33% (Deloitte, 2015).

Even though BIM has been used to improve construction workflow in the Buildings industry, yet this is still unclear in O&G projects (Fakhimi et al. 2017). After the review of more than 232 journal articles and conference papers starting from 2010, results have shown that only 3% of the research was related to BIM implementations within O&G Projects (Cheng et al. 2016).The research results are summarized in figure 3

Nonbuilding Type	Road and railroad	Bridge and tunnel	Port and airport	Power plant	Mine	Utility	Waste water	Dam	OGPi	Total
Industrial cases	53	23	6	32	6	6	7	32	6	171
Academic paper	12	39	1	3	—	3	1	1	1	61
Total	65	62	7	35	6	9	8	33	7	232

Figure 3 Non-building uses of BIM research papers (Cheng et al. 2016)

Applying BIM in O&G is a necessity to answer the industry's main challenges in terms of collaboration and workflow during various project phases (Fakhimi et al. 2017). This is due to the fact Oil and Gas sectors suffers from planning methods and techniques that fails to answer the challenges. Therefore this study will analyze the workflow in a gas processing facility using Location Based Management system to analyze issues in workflow and identify weakness in current planning practices.

CHAPTER III

METHODOLOGY

This chapter will explain the methodology applied in the thesis which is summarized in figure 5. It is composed of the following tasks: Literature Review, Data Retrieval, Data cleaning & manipulation, Data Entry, Data Visualization, and Analysis & Conclusion.

The proposed methodology is used to answer the research questions driving the research.

Question 1: How can design and planning workflow affect construction?

Question 2: What are the current deficiencies in the planning and control methods employed in Oil and Gas projects?

A. Literature Review

The literature review study was performed on Oil and Gas projects, highlighting the challenges, planning and BIM implementation within the industry. Various sources have been used including library resources, in addition to resources from major oil and gas companies. Completing this task was challenging due to the limited availability of research papers discussing the planning and construction of O&G projects. This issue was highlighted in a research paper called "Influences of building information modeling (BIM) on oil, gas, and petrochemical firms." By Fakhimi, A.

B. Data Retrieval

Retrieving project data was a time-consuming task spanning over four months. The data was retrieved with the aid of the project's staff. The data included weekly progress reports, material tracking databases and the project's BIM model.

C. Data cleaning & manipulation

After retrieving the data, the process of organizing and cleaning the data started. Some sheets were in PDF format; others were in spreadsheets that had no filenames. The first step was to check and extract useful data and disregard the rest. After that, PDF files were converted to Excel; then the data was cleaned. Afterward, the data was rebuilt in a proper way to extract progress information, including start and end dates of design, planning, and construction phases. Later, the information was used to draw flow lines of the tasks using Microsoft Excel. However, after many trails, Excel could not handle the visuals generated from the data, so we had to resort to another software called VICO control. The only limitation with VICO is that it cannot read data directly from excel. Therefore, the data had to be manually entered one record at a time.

D. Data Entry

As previously mentioned, the data had to be manually entered to VICO to plot the activity flow lines. As a result, the total number of records entered were approximately 1736 records, excluding deleted and corrected records

E. Data Visualization

After entering the data to VICO, the data was ready to be plotted .all project 24 areas were plotted. However, Scaling issue surfaced as shown in figure 4. Viewing all project area on a computer screen, or printed A4 paper was impossible. Therefore, for single area analysis, one area was plotted at a time. For multiple area analysis only, a maximum of ten areas was plotted together on the same graph.

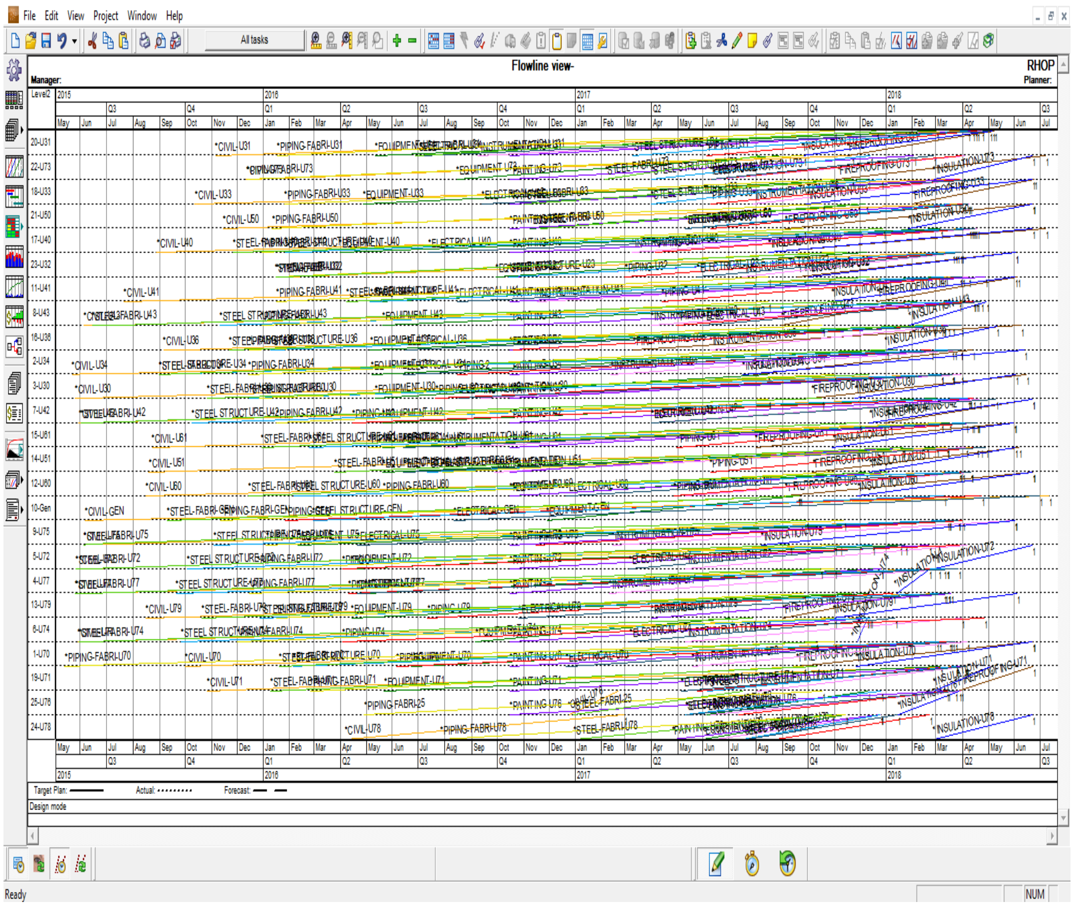

Figure 4 Plotted project areas

Finally, three main curves were generated, design tasks flow lines, planned tasks flow lines and actual construction flow lines.

F. Analysis & Conclusion

After plotting the curves, the analysis process started. Two types of workflow were analyzed, actual design vs. planned work referred to as flow 1 and planned work vs. actual work referred to as flow 2. The first step was studying one single area, whereby different trades were analyzed together to understand bottlenecks in the workflow. The second step was multiple area analysis whereby different trades were examined across areas to identify continuity issues. Finally, conclusions were derived.

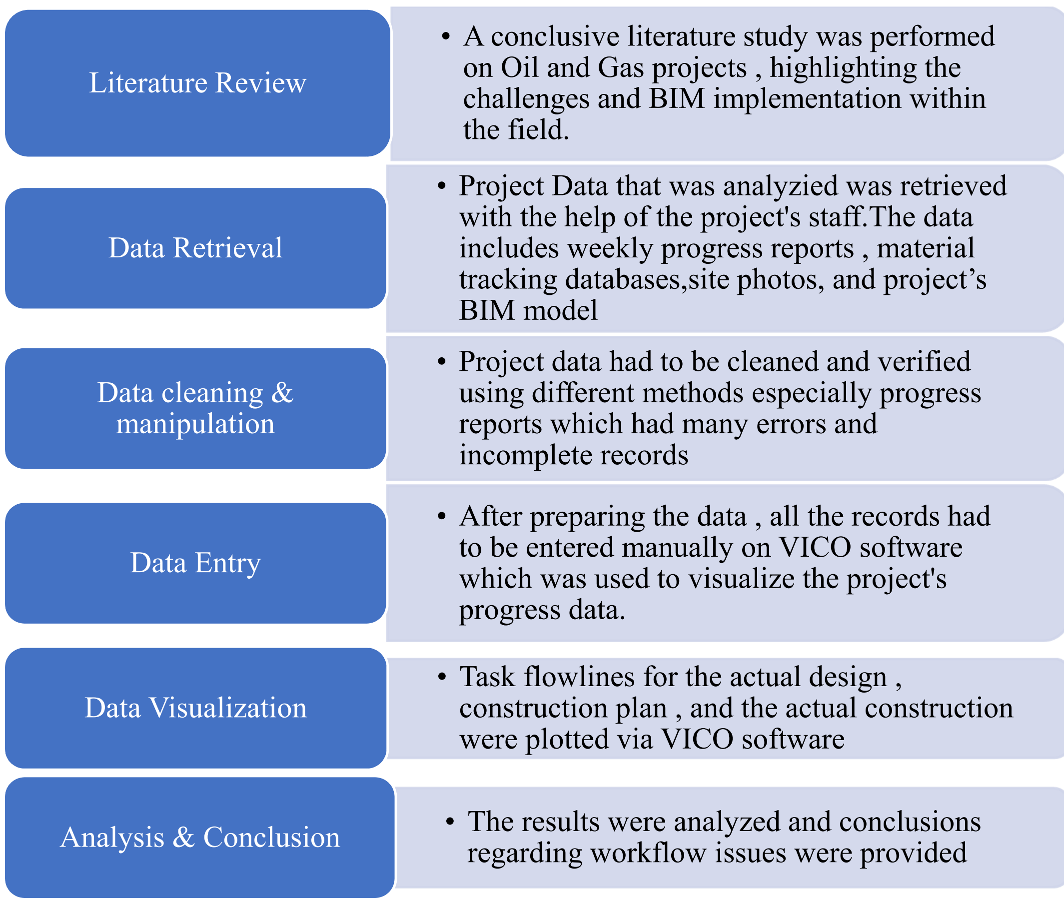

Figure 5 Objective steps

CHAPTER IV

Research Method

After examining research questions, Case study analysis was chosen as the research method, because it is an appropriate method for answering ‘how’ and ‘why’ questions, it uses both quantitative and qualitative methods to clarify a phenomena. Finally, provides qualitative understanding when arriving at conclusions and analyzing results (Meredith, 1998)

A. Case study analysis:

This research will study a Gas processing project from the GCC area. The choice was made based on three main factors:

1. Project size and type

This is a mega O&G project with a total budget of 6.5 Billion USD. This project is the 2nd largest Gas processing facility built in Oman.

2. BIM implementation

The owner forced the project stakeholders to use BIM during design and construction contractually. The project had a BIM implementation plan specification, and Models were delivered by the designer every three months.

3. Availability of data

Planning weekly/monthly reports, and material tracking system databases are available for use in this research.

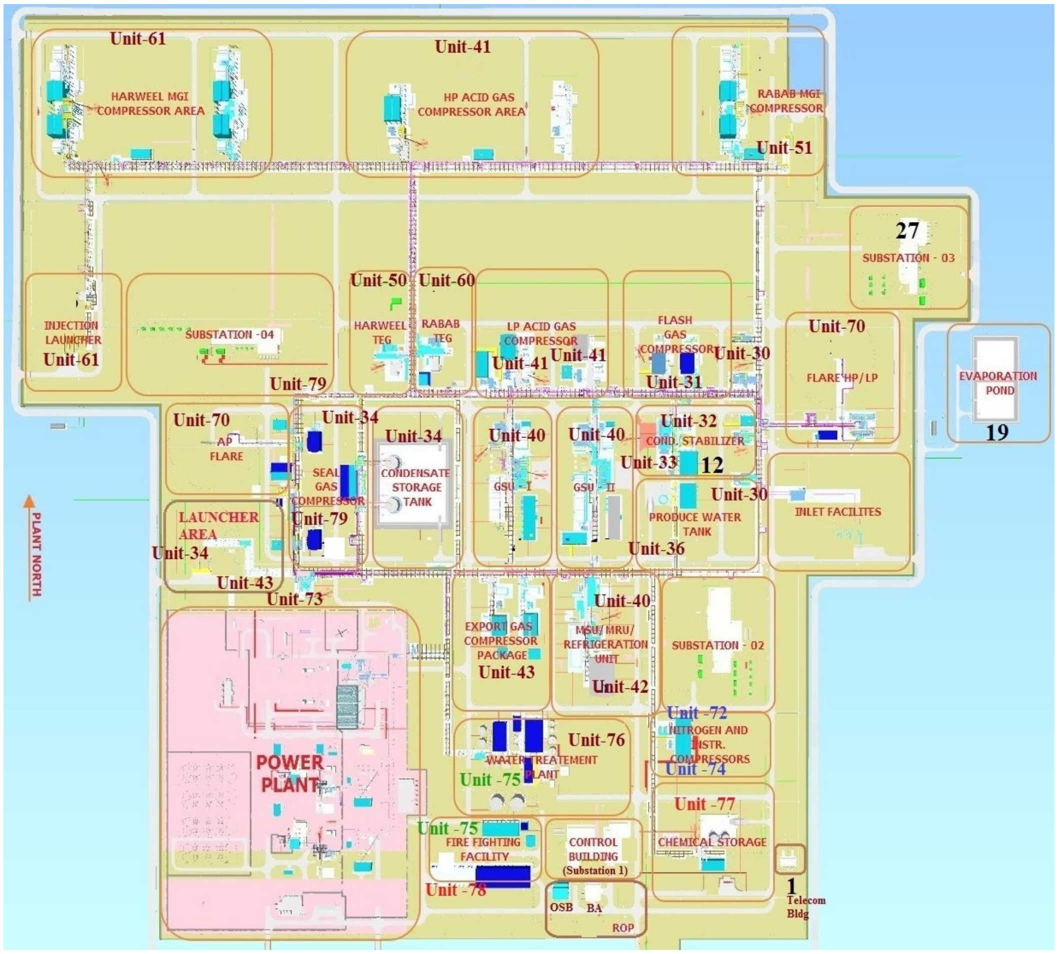

Figure 6 Project’s plot plan

CHAPTER V

RESULTS AND ANALYSIS

This chapter presents the results of the workflow analysis conducted on the project. The data used in the analysis was collected from different sources including weekly reports, the project's BIM model, and material tracking database. Two types of workflow were analyzed, actual design vs. planned work which will be referred to as flow 1, and planned work vs. actual work which will be referred to as flow 2. To achieve that goal, plan and actual dates were plotted using VICO software.

The project was divided into 24 areas that were examined and plotted. This chapter will discuss selected project areas separately. A comparison between plan and actual construction workflow will be performed, then between design and planned work. After that, trade analysis within the same location will be performed to spot clashes. Furthermore, multiple areas will be presented and discussed together to check the activity flow between different locations. Finally, conclusions will be derived related to bottlenecks in construction and design workflows, in addition to deficiencies in the planning method used.

A. Construction activities:

Before plotting the results, it is essential to mention the construction activities in Oil and Gas projects.

Civil activities, which include earthworks, structures/pipe support foundation installation, trenching and paving. Steel activities, which include the fabrication and erection of steel structures including pipe racks, platforms, and technical structures. Piping, the most critical activity, includes fabrication and erection of pipes. Hydro testing, which is a pressure test used to check leakages in pipes. Insulation, which is the process of performing insulation on pipes or equipment for heat conservation or protection. E&I activities, which include cable pulling, the installation of light fixtures, junction boxes, sensors, and earthing. Heat tracing, which is the process of applying electric surface heating system composed of wires on pipes to maintain the temperature of fluids .Moreover, Equipment activities, which include the delivery and erection of equipment. Finally, Fire Proofing, which is the process of applying passive fire protection coatings on steel structures to withstand the effects of fires and lower the possibility of structural collapse.

From an activity sequence point of view, fabrication will directly affect erection. Civil activities will affect piping, steel, equipment, and E&I. Besides, piping will affect insulation works. Steel erection will affect piping erection, and equipment.

B. Single Area analysis- U40

The first area that will be discussed is Unit-40, which is the largest area in the project, it is responsible for gas sweetening, which is the process of removing H2S, CO2, and other Sulphur elements to meet the sales gas pipeline specifications. Some of the main commodities for that area is shown in Table 1. This area holds approximately 20% of the total project scope for piping erection, 25 % for piping fabrication, and 20 % of the above ground cabling.

Table 1 Unit 40 commodities

Unit -40	Concrete	Steel Erection	Piping Fabrication	Piping Erection	A/G Instrument Cabling	U/G Instrument Cabling
%	11.57%	12.89%	24.44%	18.75%	18.34%	12.96%
commodities	11,757 Cu.M	4,987 MT	134,692 inch-Dia	38,419 inch-dia	49,815 LM	154,725 LM

Due to the lack of design data, the planned design vs actual design workflow cannot be plotted. Therefore, the only way to plot the actual design curve was possible by using AFC drawing delivery logs from the project. However, by doing so, the exact duration of the design process cannot be precisely known because when there are two revisions of the same document, only the latest revision will be shown in the log, so the exact start date cannot be known. Moreover, the AFC log does not contain the list per location for all disciplines making it hard to get the dates per unit. According to Table 2, approximately 92 % of the drawings were revised. Nevertheless, the logs will be used in line with other data from sources to fill the missing dates for various areas. After retrieving the dates, the design curve can be finally plotted

Table 2 AFC logs for unit 40

		Revision number								
Unit	**Document Type**	**01**	**02**	**03**	**04**	**05**	**06**	**08**	**09**	**Grand Total**
40	CS - Steel Structures.			317	115					432
	CX - Civil & Structural Other.	17	3	155	43	7	1			226
	IN - Instrumentation.			1					1	2
	Equipment MS - Mechanical - Static.					6				6
	PX - Process AFC			10	6	5	2	6	38	67
	ZV - Vendor	44	36	9	6					95
	Total	**61**	**39**	**492**	**170**	**18**	**3**	**6**	**39**	**828**

4. Flow 1- Unit 40

The first step in flow 1 analysis would be plotting both design and plan flow lines. Second, no-work zones will be highlighted with a blue circle, then trade clashes in a red circle and good areas in a green circle. Note that, clashes between fabrication and construction activities excluding erection activities will not be highlighted, since the fabrication is not executed on site.

Figure 7 illustrates the workflow for design activities in unit 40. The design process started in April 2015 and finished in June 2017. Electrical and the instrumentation teams were working in sync in comparison to other disciplines. Civil design took the longest period at a span of two years. This can be attributed to the large number of revisions which is 92% of the total delivered drawings. Also, it can be inferred that Civil is the main activity driving the design.

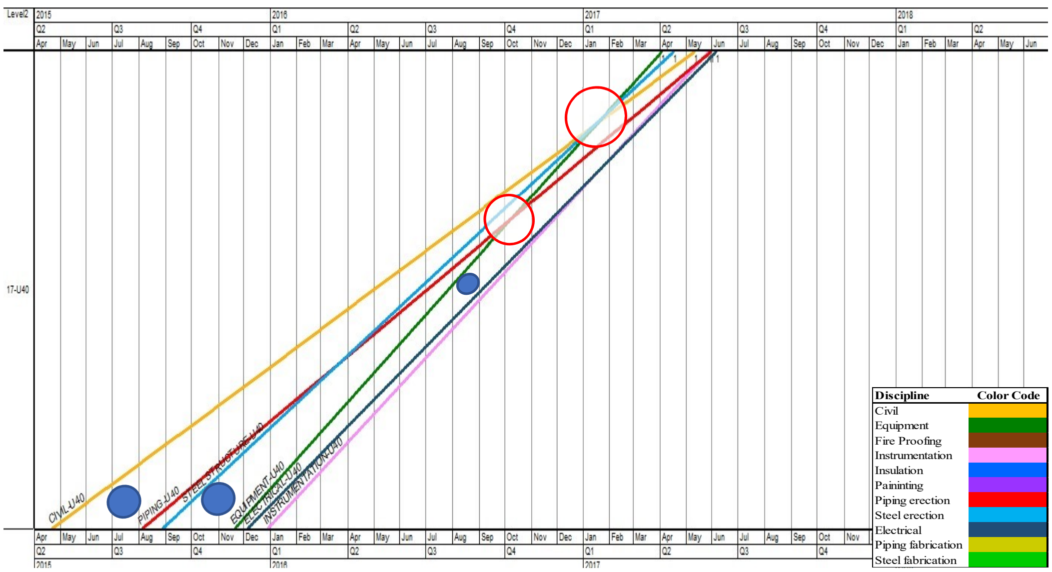

Figure 7 Design flow lines for Unit-40

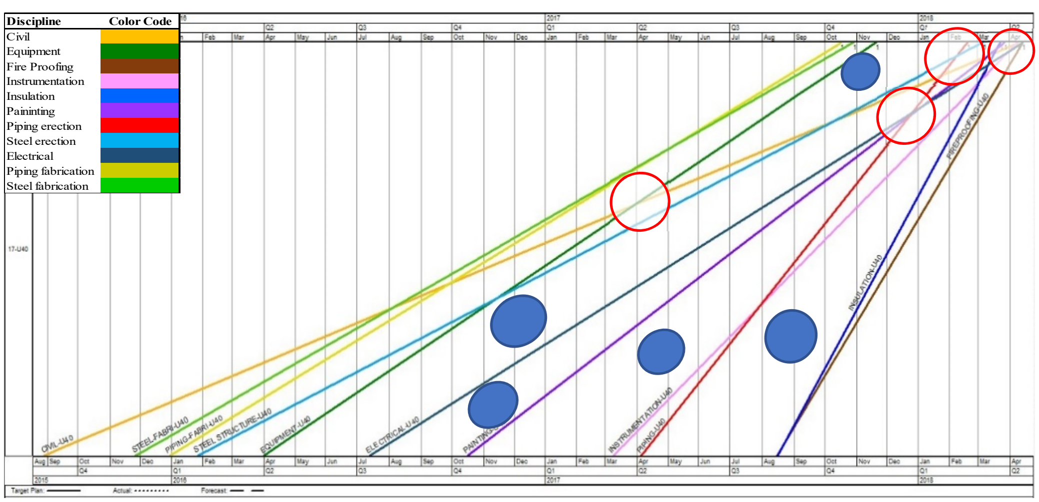

Figure 8 Plan flow line for Unit 40

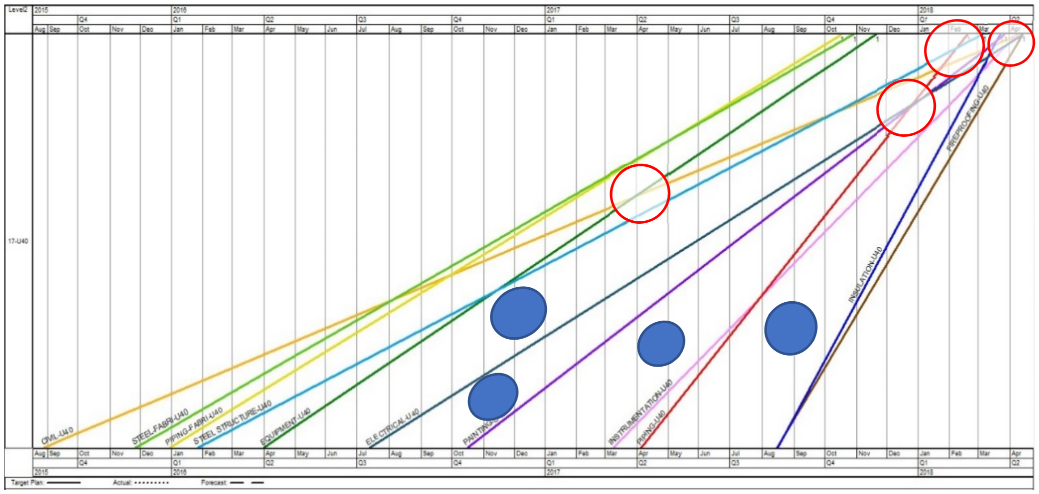

Figure 8 shows the unit's plan flow lines; it displays how various disciplines were planned based on the final date that is set by the revised plan milestone, which is April 2018. There are large no work zones between various activities such as piping and steel, and between piping fabrication and erection. Large buffers are considered waste since it can cause clashes or discontinuity across or within areas. These buffers are expected because the whole plan was built using the CPM method, and these buffers cannot be visualized or spotted.

Comparing the main critical activities together, as shown in Figure 9, there is a large buffer between piping erection and fabrication. A valid argument would be that the design team has done this intentionally to accommodate for steel structure erection since it is a predecessor activity, especially in that area ,where approximately 80% of pipes are mounted on steel structures. However, after viewing only steel and piping activities together as shown in Figure 10, we can see that piping activities will commence after 14 months which is a long duration, and it could have been utilized since it is a critical area. However, the only valid assumption is that this area was not considered an incentive priority area when the plan was set in March 2017. It was until the end of May 2017 when the owner and the commissioning team ordered to have this item as a priority milestone.

Finally, there is one thing to be noted when comparing the design and an actual plan. It can be observed that the planning team has planned activities such as piping fabrication in line with design activities with a minimum buffer as shown in Figure 9.

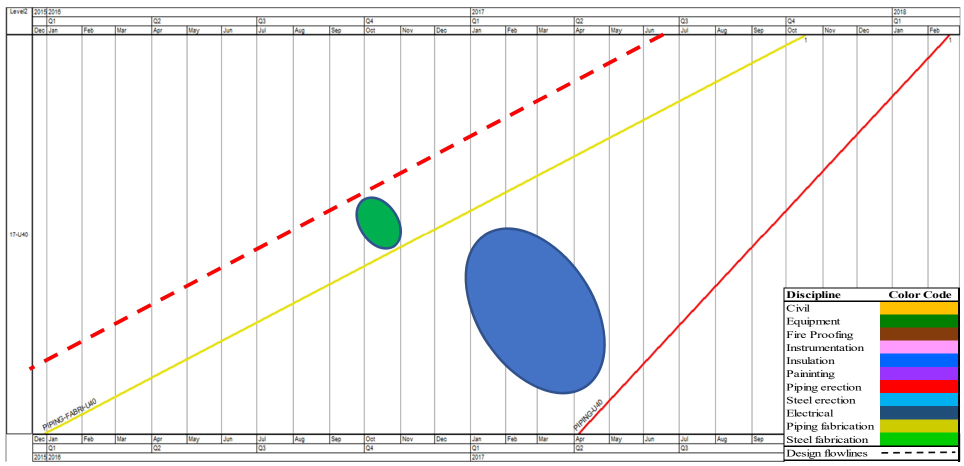

Figure 9 Piping design vs. Plan erection & Fabrication for Unit 40

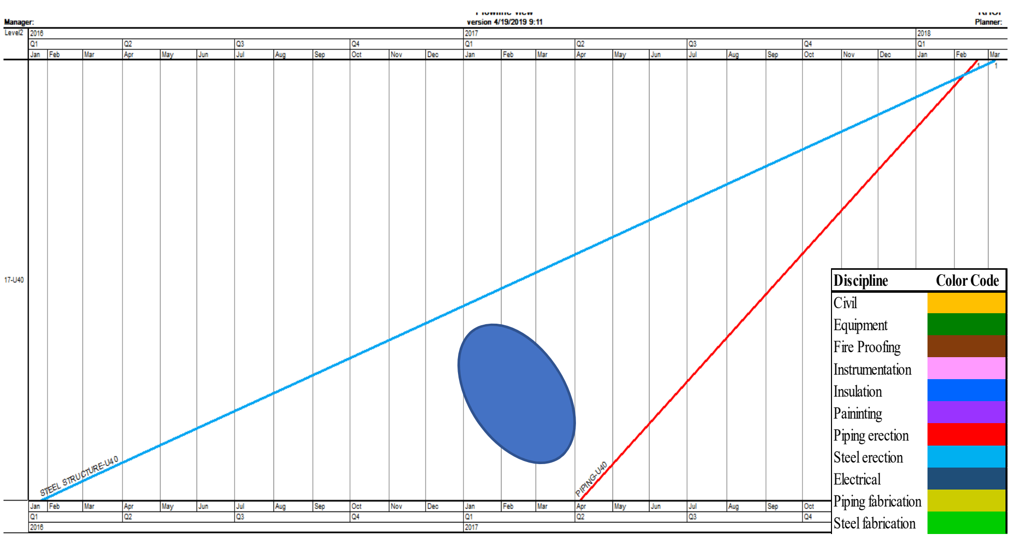

Figure 10 Steel and piping plan for Unit 40

5. Flow 2 – Unit 40:

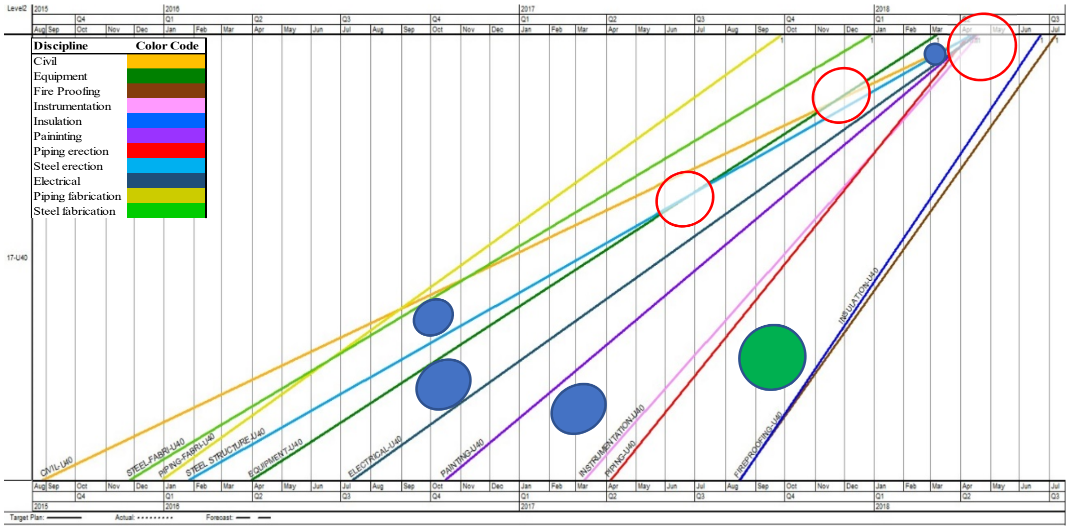

Figure 11 construction activities flow lines for Unit -40

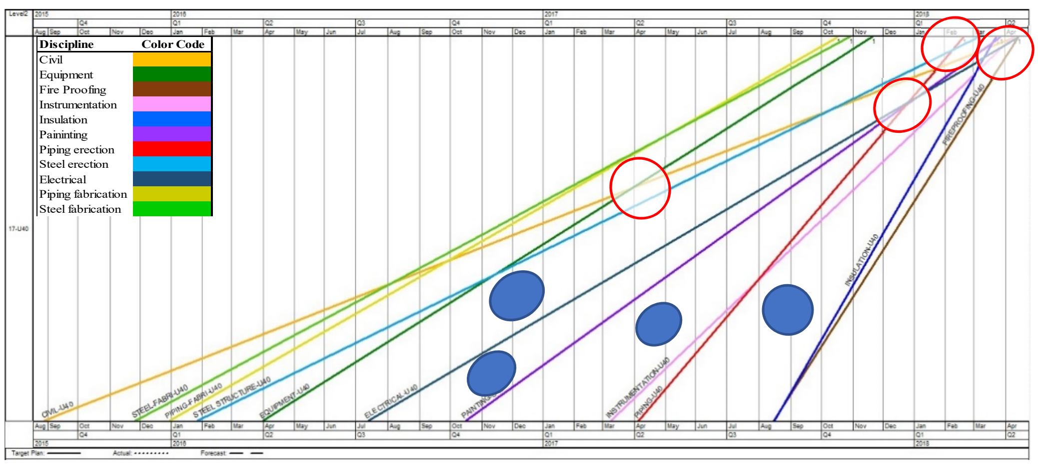

Figure 12 Plan activities flow lines for U-40

Figure 11 presents the actual construction activities flow lines. It shows various buffers and variable production rates. It also shows clashes between disciplines especially in the last 10% of area duration where all disciplines are clashing together, and the different teams working in the same location together and solving sequence clashes on site. Nevertheless, there is a good observation to be noted; piping and insulation production rates are synchronized. This shows that optimization between disciplines is possible if with proper communication and planning.

Now comparing Figure 11 to Figure 12, it can be concluded that the whole area was delayed. Equipment activity which relies on civil and steel was late by three months. Steel fabrication was overdue by two months, steel erection by one month, and piping erection by 1.5 months. Moreover, Insulation and fireproofing were late for three months. Steel fabrication was delayed with all activities downstream steel structures, and, in return, equipment, steel structures, and piping were not erected on time. On the other hand, piping fabrication was the only activity finished early by one month in September 2017.

To investigate the real reason behind steel fabrication delay which was the main activity that caused cascading delay, one should check the AFC log and steel material tracking database.

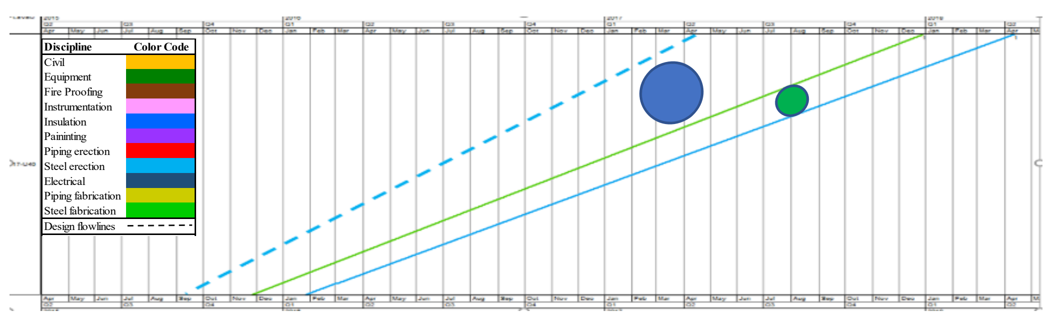

Figure 13 Steel Design vs. Actual Fabrication & Erection

Figure 13 shows completion of steel design activity which was in April 2017 while fabrication was in Dec 2017. However, due to multiple design revisions as shown in table 3, the fabrication process was hampered.

Moreover, as these revisions occurred over time, some of the material used for fabrication was wasted, hence causing a material shortage in fabrication. The design team worked fast to submit the designs, and in doing so, they had to redesign the whole area approximately three times. Moreover, Figure 14 shows a sudden drop in delivery of drawings in the second quarter of 2016, and this can be attributed to the fact that the design team was focused on finishing other areas like Unit 43 and Unit 41 as shown in Figure 10.

Finally, there is a positive observation that can be noted. Figure 8 shows a small buffer between fabrication and erection in comparison to other disciplines and the plan. Moreover, it can be observed that both erection and production rates were approximately the same meaning whatever was sent was erected with no delays.

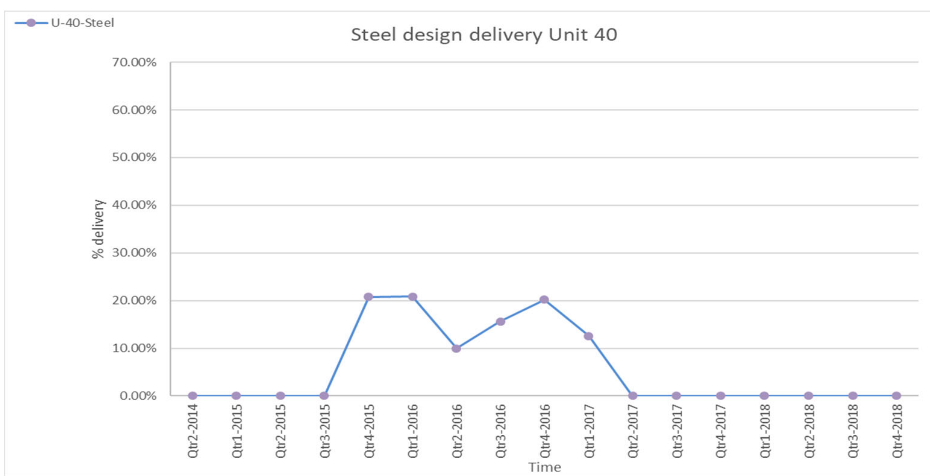

Figure 14 Steel design delivery Unit-40

In conclusion, steel design progress was the main contributor for the workflow disruption, therefore delaying fabrication by two months, and, in return, delaying activities down the chain.

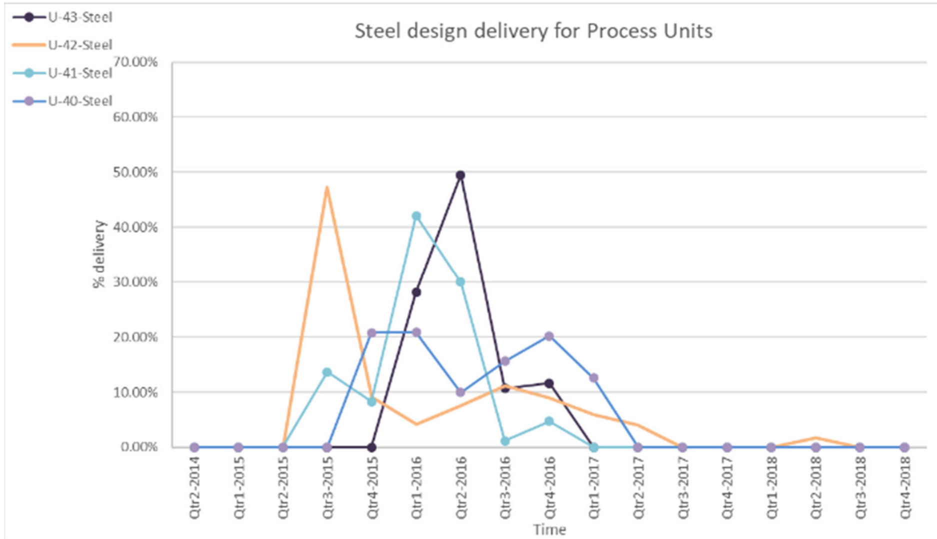

Figure 15 Design delivery for process units

C. Single area analysis - Unit 42:

It is part of the gas processing units, next to Unit 40. This area is small in comparison to Unit 40, with commodities shown in table 3. This area is composed of one large sunshade and a pipe rack attached to it. The construction inside the sunshade is challenging due to the clearance issued between various disciplines.

Table 3 Unit 42 commodities

Unit No	Concrete	Steel Erection	Piping Erection	U/G Electrical Cabling
%	3.17%	2.51%	3.23%	3.60%
commodities	3,216 Cu.M	969 MT	6,612 Inch-dia	48,464 LM

6. Flow 1 – Unit 42:

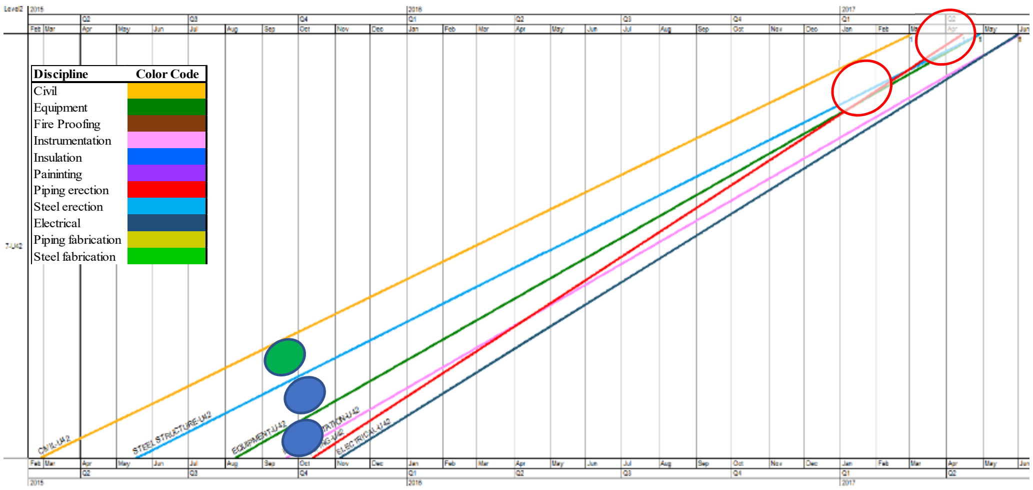

Figure 16 Design flow lines for Unit-42

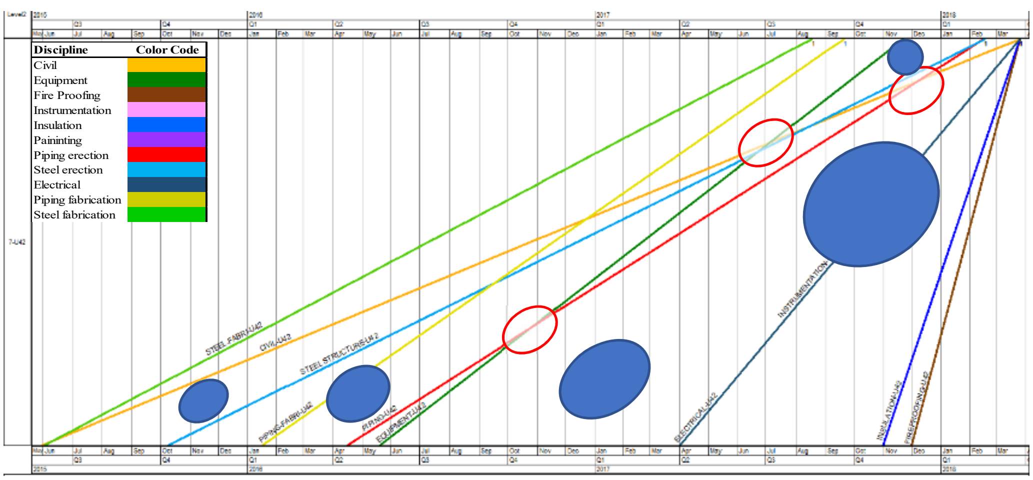

Figure 17 Plan flow lines for Unit-42

Figure 16 illustrates the workflow for design activities in unit 42. The design process started in March 2015 and finished in June 2017. Civil and the steel teams were working in sync in comparison to other disciplines, however, in terms of design changes they had the biggest share as shown in Table 4. Steel drawings were 100% revised and Civil 94% even though this area is small compared to UNIT 40, but this is due to the fact this area is very congested and special attention is required especially for civil. Finally, comparing the design to the plan, we can conclude that the design was more streamlined and organized than construction.

Table 4 AFC delivery log Unit 42

		Revisions								Grand Total
Unit	Drawing type	01	02	03	04	05	06	07	09	
42	CS - Structures.			37	6	62	14	1		120
	CX - Civil & Structural Other.	6	2	34	7	26	17			92
	IN - Instrumentation.			1				1		2
	PX - Process Other.				2	2			7	11
	ZV - Vendor	19	4	1	1					25
Grand Total		**25**	**6**	**73**	**16**	**90**	**31**	**2**	**7**	**250**

To understand the issues and challenges in the design, we had to resort to the BIM model. Figure 18 shows the complexity of this area; many disciplines are located in a limited space, along with different underground trenches making this area the most complex in the process units. Hence a proper construction plan must tackle these challenges especially construction space limitations.

Figure 17 illustrates that the plan had many buffer gaps and discipline clashes. It is true that the plan took into consideration design delivery dates. However, the discipline production rates are not aligned; some trades will start late and finish early while others will start early and finish late.

Figure 18 BIM model view Unit 42

It is unclear why the start date of the electrical and instrument teams was pushed further in the first quarter of 2017 even though the area is filled with electrical and instrument trenches which are required to complete early to start paving works. Paving is important because it is a predecessor for piping steel supports, instrument gauges, and junction boxes. Therefore, not completing these trenches early delay in the whole area, and this is what happened.

7. Flow 2 – Unit 42

Figure 19 displays the actual construction workflow for Unit 42, and when compared to Figure 20, the start dates are the same except for fireproofing and insulation which started late by one month. However, the whole area is delayed. Moreover, there are two clashes happening at the end of the construction duration between various disciplines in Dec 2017 and April 2018. Also, it can be noticed that the disciplines do not have a well-synchronized production rate, significant no work zones at the start of activities and trade clashes at the end.

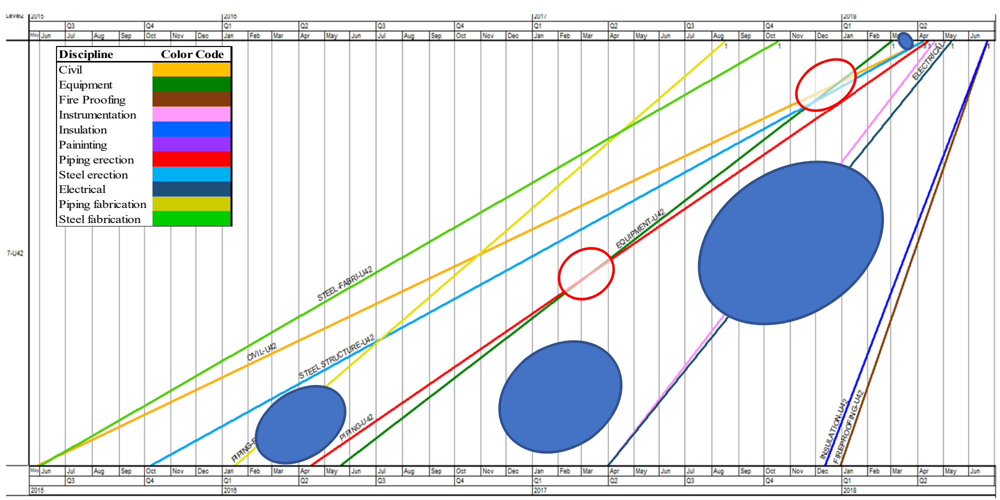

Figure 19 Actual construction Unit-42

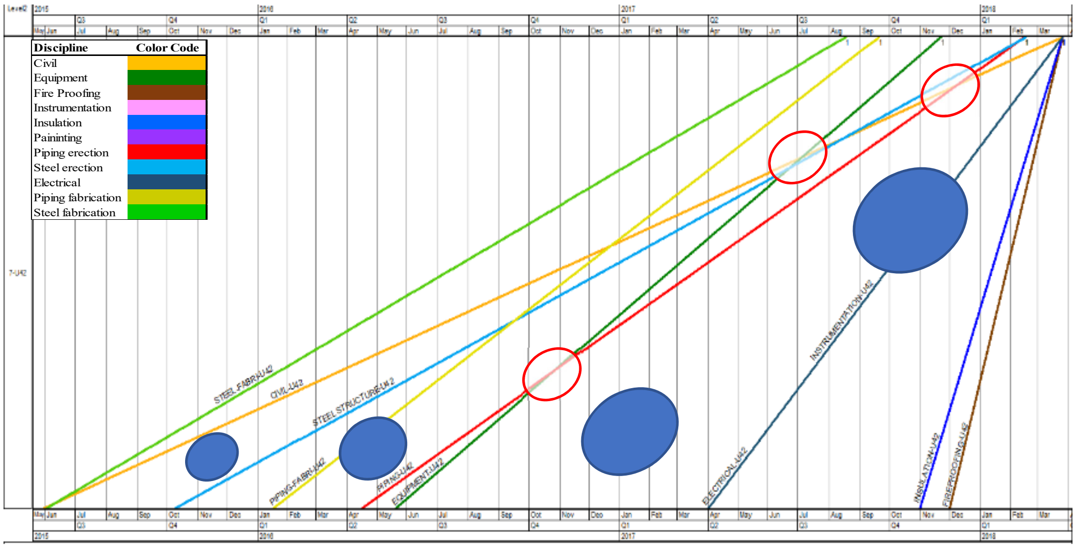

Figure 20 Plan flowlines Unit-42

Table 5 shows the total delays per discipline in Unit 42. In the table, the delayed disciplines are ordered from largest to smallest and equipment had the largest delay, in contrast to piping fabrication which finished early by 36 days.

Table 5 Summary of delays unit 42

Discipline	**Delay (Days)**
Equipment	101
Steel Fabrication	61
Fireproofing	59
Piping Erection	57
Steel Erection	50
Insulation	47
Electrical	45
CIVIL	27
Instrumentation	26
Piping Fabrication	-36

To investigate the root causes of the delay, site photos were taken. These photos showed Unit 42 condition when the discipline clash happened in December 2017 as shown in Figure 19. Figure 21 and Figure 22 illustrate the situation at the site, the steel structure is partially erected without the roof, some equipment is erected, electrical, and instrument trenches are empty, and there is a small number of pipes erected inside the shelter. However, area progress was 80%.

Figure 21 Trenches surrounding Unit 42 sunshade (Dec 2017)

This can be attributed to the fact that the piping progress attained is for the high bore pipes lying on the Pipe rack and some attached to equipment skids. However, for the remaining small-bore pipes that will be on the ground, none are erected due to the situation inside the shelters.

Figure 22 Trenches inside unit 42 (Dec 2017)

The civil team focused on gaining progress by installing foundations, and opening trenches. However, the electrical team started their work by installing junction boxes and light poles and left cable pulling activities for a later stage causing a delay to paving works and to the remaining successor activities such as ground piping.

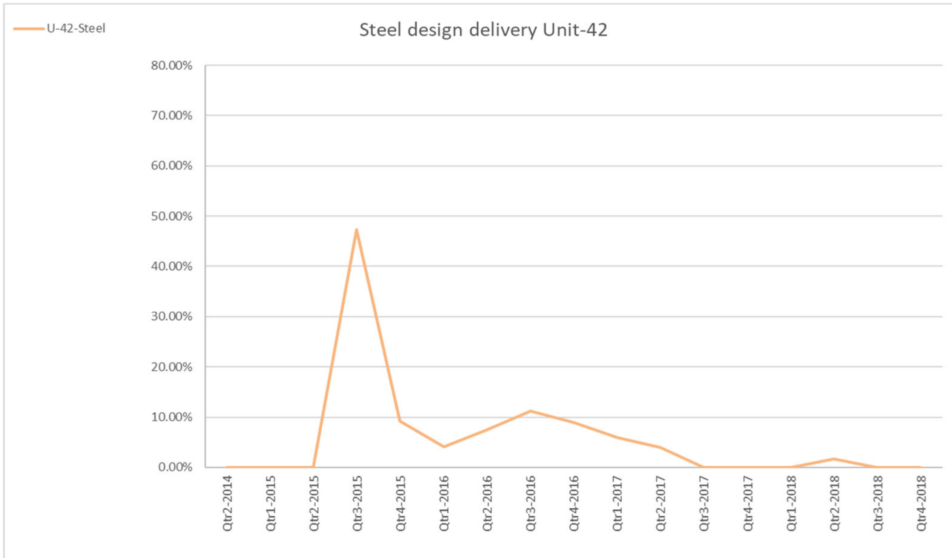

Figure 23 Steel design delivery for Unit-42

To analyze the delay in steel fabrication, there is a need to check the steel design. Table 4 demonstrates that all steel drawings were revised, and approximately 62% were revised more than five times. This is because this area is a very congested area, and the possibility of design clashes is very high. Figure 23 illustrates that 48% was delivered in the 3rd quarter of 2015. However, the remaining was delivered at a long span disrupting the fabrication process and, as a result, disrupting steel erection.

Moreover, another issue related to delivering un-erectable steel elements surfaced. Meaning, the fabricator delivered one column in one month, and then three beams the next month, however, to erect these elements you need a complete set of four beams and four columns. This issue was reported in the weekly reports and verified using the BIM model. This issue frequently occurred due to terms of the contract which did not force the fabricator to deliver erectable items; it only defined a monthly tonnage target.

In conclusion, there are multiple factors that contributed to the delay in Unit 42, these can be summed up in the improper sequencing activities, executing any work available to gain progress disregarding the outcomes which were the case of the Civil team when excavating trenches that cannot be completed, and finally design changes and steel item delivery which affected the steel fabrication and erection process.

D. Example of good workflow:

Even though the previous examples have discussed areas with disrupted workflow, there exist some areas that had a good workflow even though they were delayed.

Figure 24 presents Unit 50 construction flow; it can be observed that piping and steel had a synchronized production rate, which means whenever steal released a section, piping took over and started the work at the same pace as steel.

Even though this area finished late in comparison to the baseline, however, there was a good potential to finish early if civil production rate was optimized to be in parallel with piping and steel. This would have pulled equipment activity and in return pulling piping and steel. This is another example to illustrate that optimizing production rates among different trades is possible with proper planning and coordination between various teams

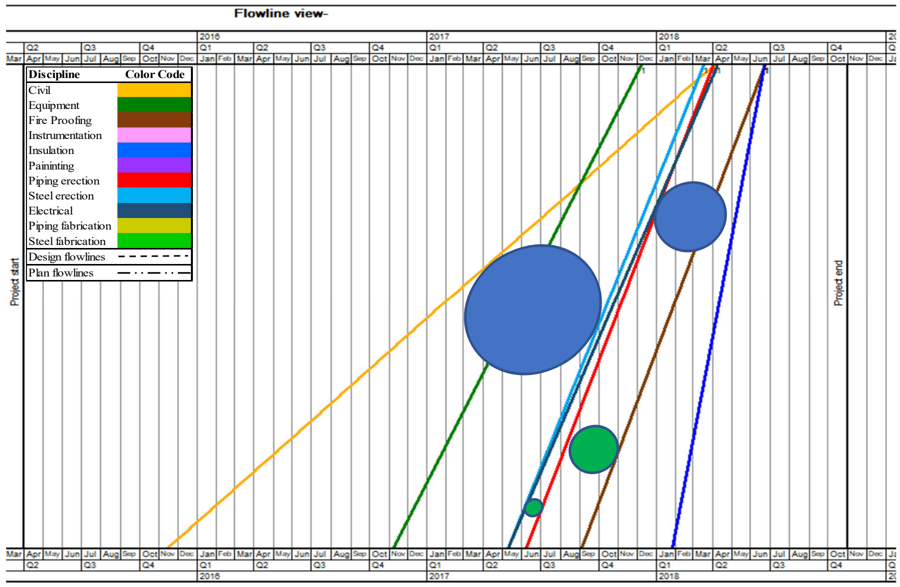

Figure 24 Unit-50 construction workflow

E. Multiple area analysis:

After discussing single areas, it is time to study multiple areas together. The aim is to examine the operation flow between locations that are located geographically next to each other. The Units that will be discussed are 77, 72 and 74.

Figure 25 shows that crews were working in the three areas at the same time; there is no optimization between trades within a single area and between different areas. However, there is one activity that is synchronized between areas. It can be observed that the insulation works commenced at Unit 74, then at Unit 77 and finally at Unit 72. There was a small gap of 20 days between 74 and 77, but no gaps between 77 and 72. Unit 74 had the highest production rate, and 72 the slowest. It is unclear why this was the case even though, as shown in Table 6, Units 72 and 74 had the same piping insulation scope. If unit 74 and 72 had the same production rate, the insulation rate would have completed the area early.

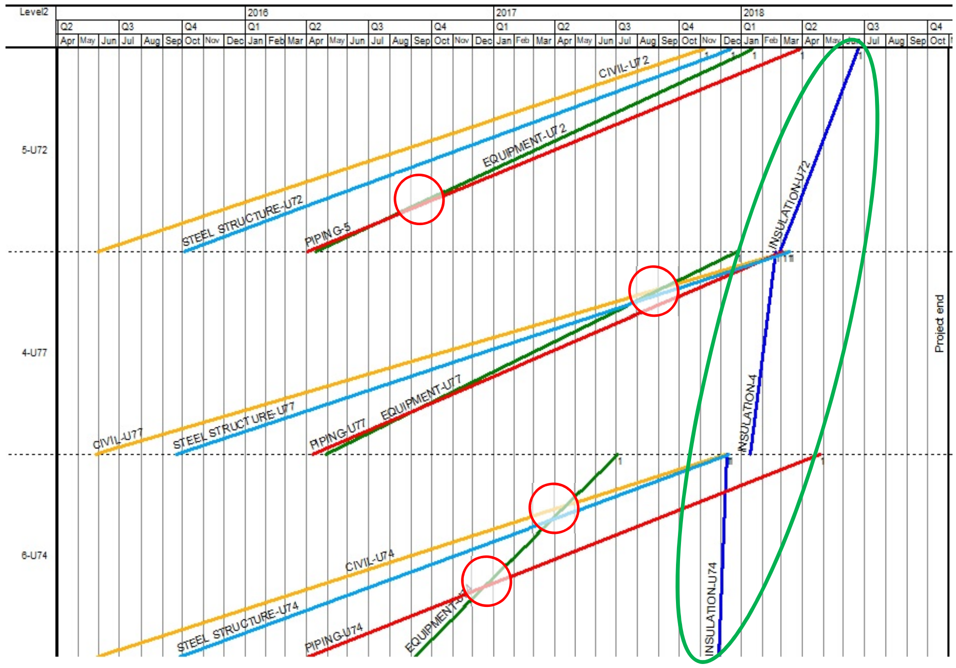

Figure 25 Unit-77, 72, 74 construction workflow

This area demonstrated a real scenario when location-based management approach is followed, even though it was unintentional, yet it can be implemented with different disciplines.

Table 6 piping quantities Units 77,72,74

Unit No	Piping Insulation (m.sq)
74	150
72	150
77	550

F. Single Trade analysis between areas:

Finally, single trade analysis will be performed to check whether there is continuity of work between areas during construction. Areas located in the process and utility areas will be selected and studied. Figure 26 shows piping erection and fabrication across multiple areas. We can see that piping fabrication and erection started in different locations at the same time. Meaning all of these locations are working in parallel.Even though from the contractor point of view it is suitable, but from a production control point of view, this is suboptimal. Having different areas working at the same time will create workflow issues especially in congested areas as mentioned previously like Unit-40. Congestion usually leads to low productivity. Moreover, there is a great chance that crews were moving from one location to another due to work front availability and this was demonstrated in Unit-42 discussion.

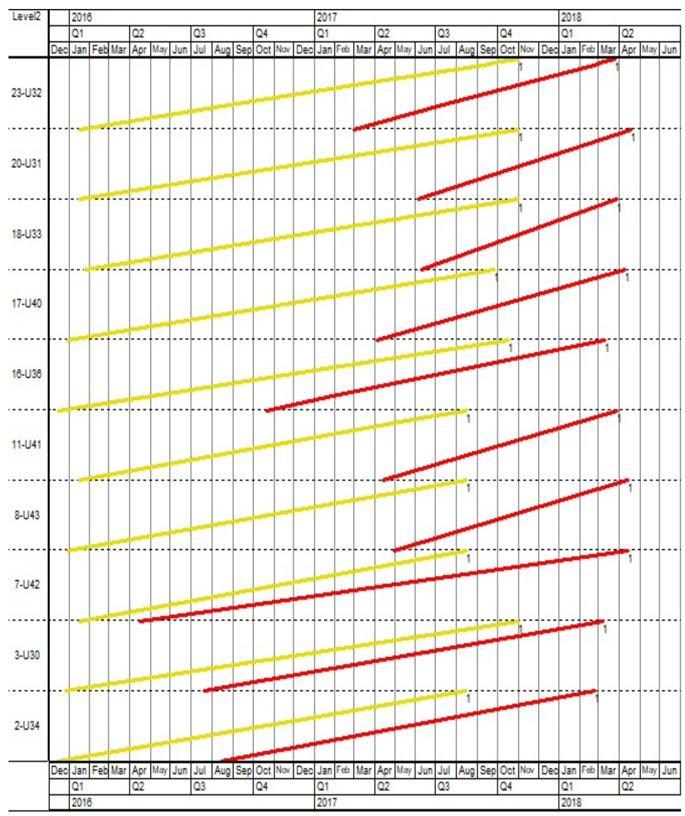

Figure 26 piping fabrication and erection across different areas

To summarize the findings, this chapter analyzed three different areas varying in size and complexity. Then a comprehensive analysis of the root causes of the delay was performed. Also, multiple area analysis was achieved to study the movement of trades between different areas located in the same geographic location.

Unit 40 which is the largest in the project, suffered from design issues related to steel structures. Thus, delaying fabrication and all activities down the chain.

Unit 42 is a small area compared to Unit 40. However, it is very congested and complex. There were multiple contributors to the delay in that area. First, issues related to steel design, un-erectable steel elements, in addition to trades performing tasks that cannot be completed, and finally improper planning of activities.

Example of a good area was provided, Unit 50. Even though this area was delayed, however, a good observation related to synchronized production between steel and piping was illustrated. It showed a real example of how synchronized production can be achieved between disciplines, and it is possible if the conditions allow it.

Finally, trade analysis between areas was performed, and as expected, the planners did not take into consideration the continuity of work between areas or discipline clashes which LBMS technique have spotted.

As displayed, all the areas were working on parallel; however, all of them were delayed. The fact that civil activities were spanning over two years in all areas regardless of the size of the unit was alarming. This proves that the planning did not take into consideration the complexity of these areas, and dates were set either by meeting with different discipline leads or by incentive milestone dates.

In conclusion, the above analysis shows the power of the location-based management planning method. One can wonder what the construction team would have done differently if this tool was used on the project.

CHAPTER VI

CONCLUSION AND FUTURE WORK

Improving construction workflow is an essential step to ensure a proper continuous flow of resources on the project. However, in the O&G industry, this remains a challenge because the current planning practices being used like (CPM) does not visualize or measure flow. Hence, tools like LBMS provide great visibility for the flows of work in construction sites. In order to analyze issues related to workflow in O&G projects, a gas processing project facility was chosen, data was collected, and LBMS technique was used to plot flow lines from design, plan, and actual construction.

The project was divided into 24 areas that were examined and plotted. A comparison between plan and actual construction workflow were performed, then between design and planned work. Furthermore, multiple areas were presented and discussed together to check the activity flow between different locations. Bottlenecks in construction and design were spotted, in addition to deficiencies in the current planning method used. The findings identified multiple contributors to the delay in the project. These are design changes, out of sequence work, delivery of un-erectable steel items, and parallel work in multiple locations

This chapter draws conclusions based on the results and findings obtained from the study. The chapter then presents suggestions and recommendations for future work.

A. Observations, Conclusions, and Recommendations

1. Observations

- During the last 10 % of the progress, the complexity of work increased because multiple trades were working together in the same locations, these observations were highlighted in flow line diagrams. The work locations are often small and congested such as pipe racks, sunshades. Congestion in limited space has a negative effect on productivity (Kenley et al., 2010). As a result, various teams faced difficulties in completing activities on time.

- All areas were working in parallel according to the defined plan, on the hope to have open fronts in all areas and ensure continuity, however even though the flowline charts were showing progress drops, but site photos and reports showed the opposite.
- "Perform any task available" mentality is present; all teams were committed for achieving progress disregarding the effects of such actions on other activities. In doing so they performed out of sequence of work which caused an area delay. Example: excavating trenches and leaving them open.
- The planning team left the start date for some trades late even though they were critical for the completion of some areas. In addition, the planning used CPM method and did not implement the LBMS technique even though there was a strong potential.
- Issues related to the design, and delivery of AFC drawings, caused disturbances to upstream activities such as fabrication and in return, causing a cascading delay effect.
- Matching problems related to delivery of un-erectable steel elements caused by contract terms that gave the fabricator the freedom to deliver material ton wise, and not structure wise.

- Different locations working in parallel did not offer a better construction workflow; the graphs illustrated a chaotic workflow across different areas, regardless of the area size.
- Variability of workflow in different locations disrupted overall project performance. All project areas did not meet the planned targets.

2. Conclusions

- The current planning method employed fails to answer to the complexity of Oil and gas project since it is using the CPM method only.
- Overloading resources by working in different project areas in parallel had a negative effect on workflow.
- Improper design delivery can lead to disruptions to the overall project cycle.

3. Recommendations

- Planners should use LBMS alongside CPM to create a well-defined proper plan that takes into consideration the proper distribution of resources between areas.
- Planning and Construction team should utilize the latest tools including BIM to identify sequence issues in the plan, and improve construction workflow.
- The Construction team should abide by the last planner system philosophy; the teams should not start tasks that they should not or cannot complete. They should only pledge to complete tasks that are appropriately defined, sound, sequenced and sized (Tommelein, and Ballard ,1997)
- Various Teams should increase coordination between each other, to synchronize their production rates to ensure a better workflow.

- Contract terms with fabricators should take into consideration other criteria in addition to tonnage to avoid material matching problems that may arise.
- Plan in greater details as tasks approach their execution, the longer the forecast the more wrong it is. (Tommelein and Ballard, 1997).
- The plan variability witnessed in the project can be alleviated by using the last planner system, which is composed of four different planning stages, Master Schedule, Phase schedule, Look planning and Commitment planning (Ballard, 2000; Elezi et al. 2014; Tommelein and Ballard, 1997; Hamzeh , 2009). These stages can be described as follows :
  1- In Master Schedule, main tasks that should be done are summarized, and project milestones are set.
  2- In Phase Scheduling, project's phases are identified; information regarding what will be executed will be provided.
  3- Lookahead Planning spans over this course of 6-8 weeks. Phases defined in the phase scheduling are broken into operations while identifying and removing their constraints. As a result, these operations are turned into tasks made ready; therefore, reliable commitments can be made in the weekly plan. Lookahead planning is the connection between the weekly plan, and the phase schedule.
  4- Weekly Work plan is the detailed planning stage, based on weekly deliverable tasks. The completed tasks are checked and the reasons for incomplete tasks are studied. Therefore, creating a feedback loop that allows continuous improvement.

B. Future Work

This research studied the effect of the design, and plan on construction workflow to recognizing current deficiencies in the planning and control methods employed in the Oil and Gas industry. Hence, the following is recommended for future research:

- This study was based on a single O&G construction project, even though various data was collected. However, progress data per location was incomplete. Future research should be performed on projects with proper updated progress data.

- The research analysis focused on the construction part and disregarding pre-commissioning which is a very critical phase O&G projects.

- The study used the schedule as a measure of project performance. Further studies should provide include more data including the actual productivity, cost, and other data if possible

APPENDIX A

PROJECT GRAPHS

Unit 70:

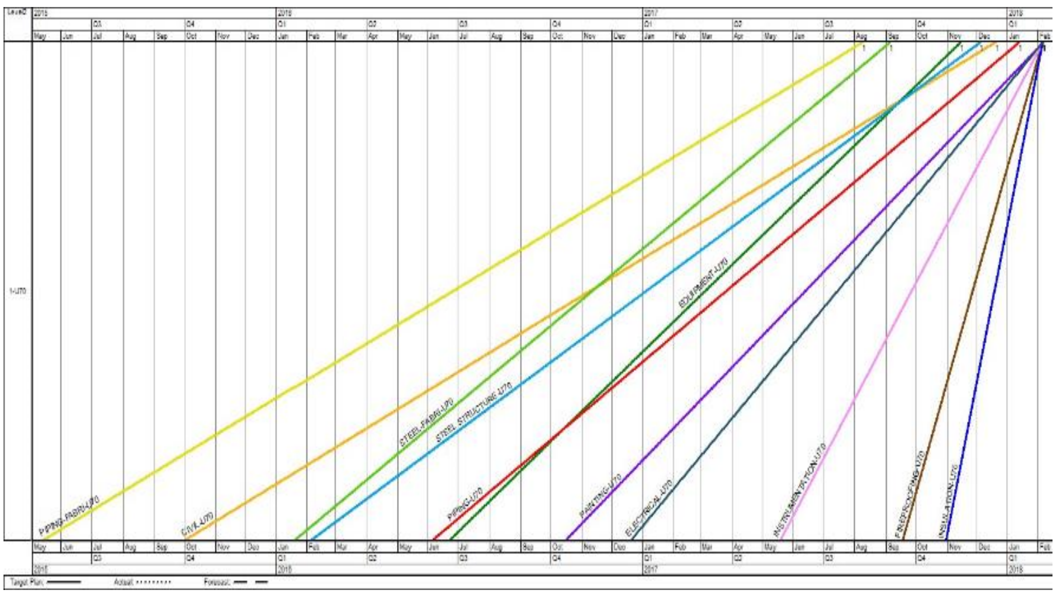

Figure 27 Planned tasks flowlines Unit 70

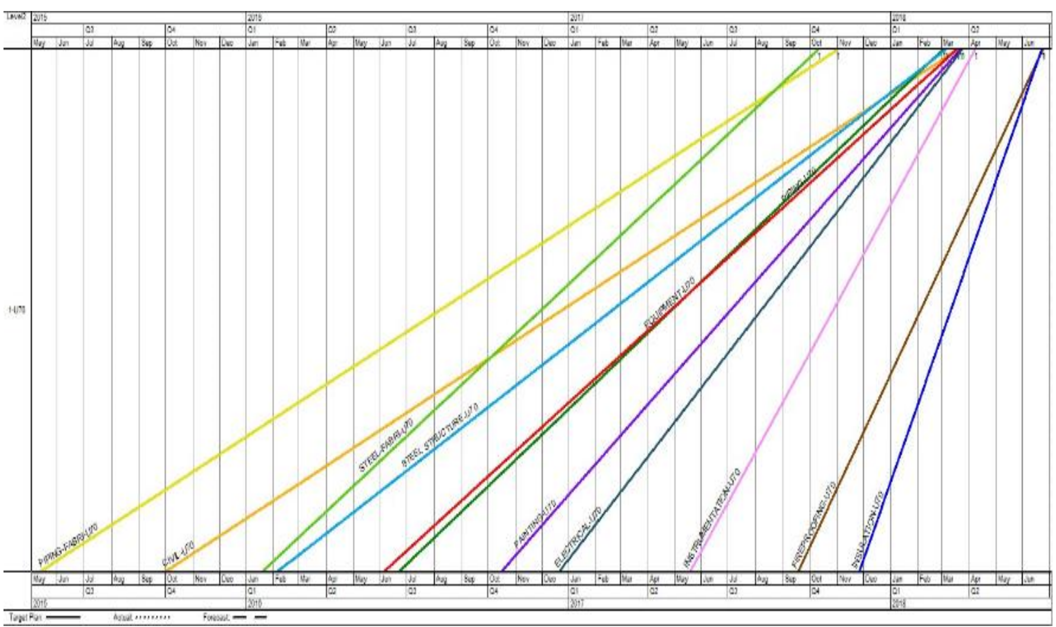

Figure 28 Construction tasks flowlines Unit 70

Unit 34:

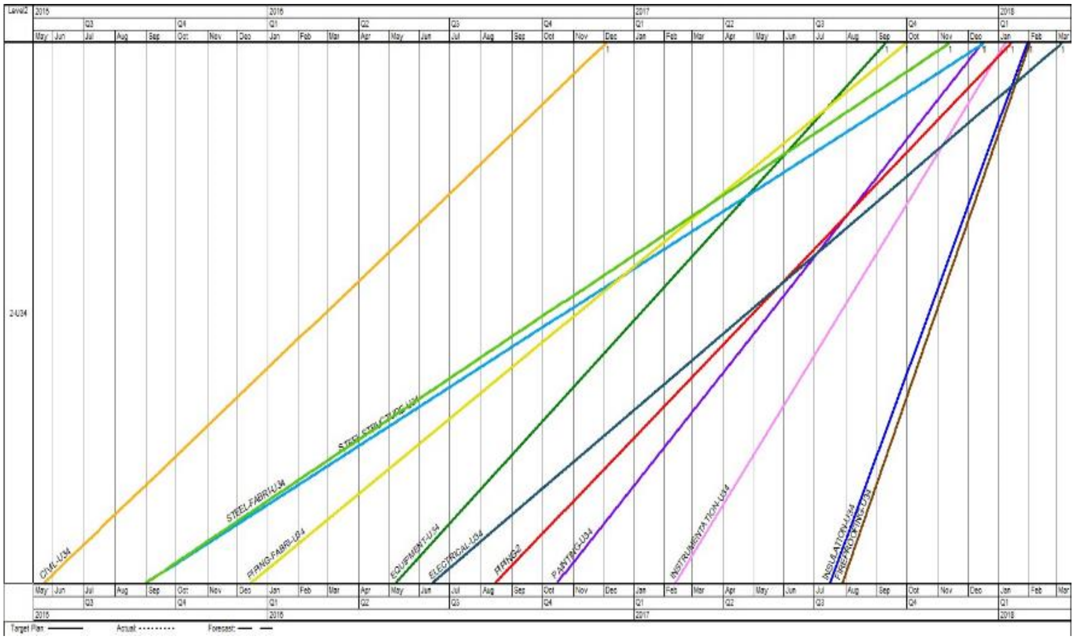

Figure 29 Planned tasks flowlines Unit 34

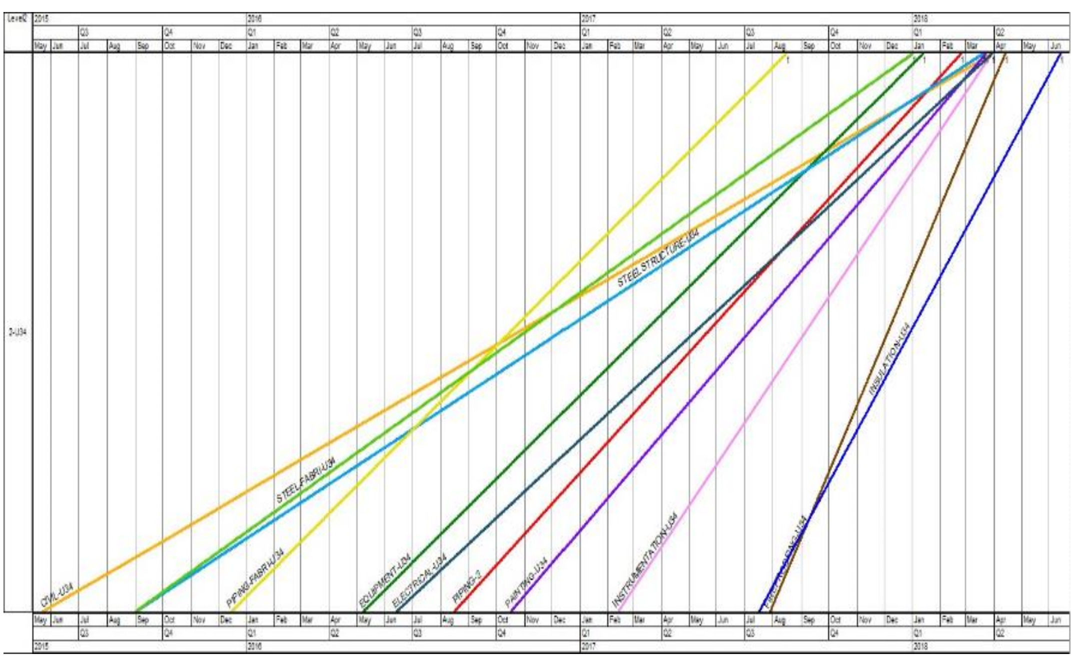

Figure 30 Construction tasks flowlines Unit 34

<u>Unit 30:</u>

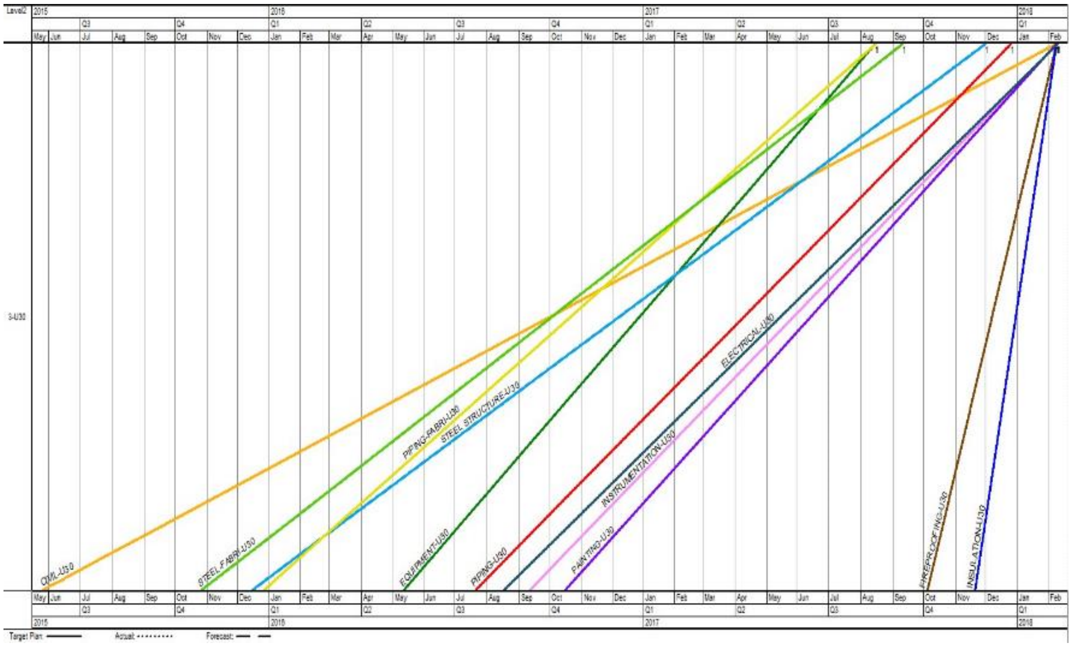

Figure 31 Planned tasks flowlines Unit 30

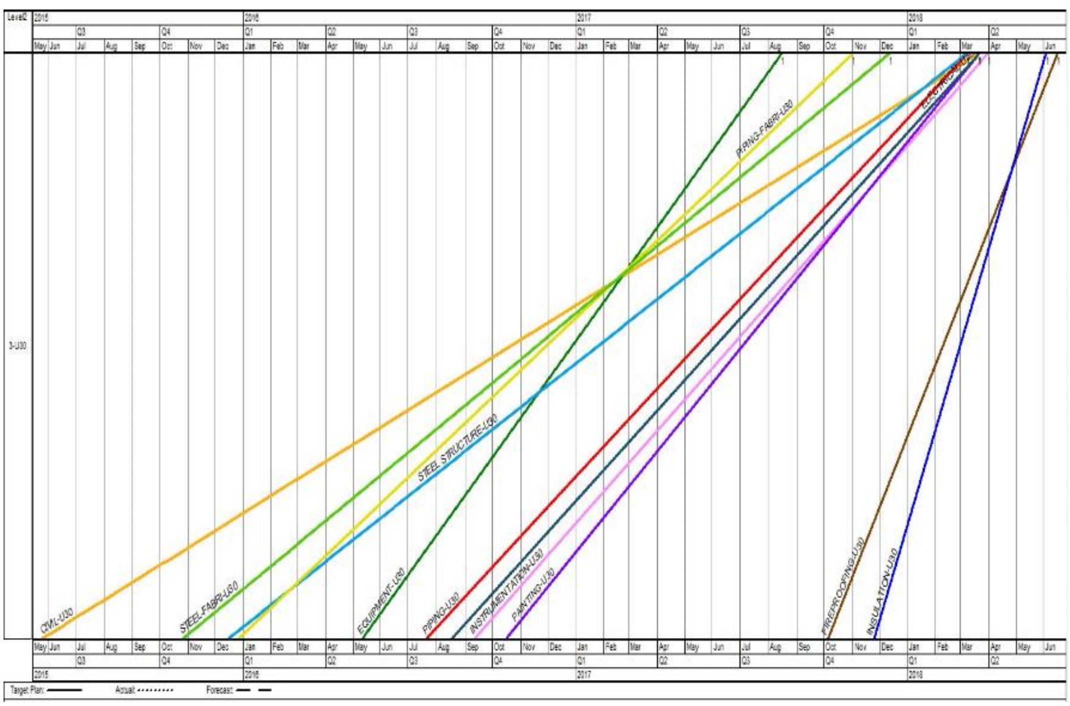

Figure 32 Construction tasks flowlines Unit 30

Unit 77:

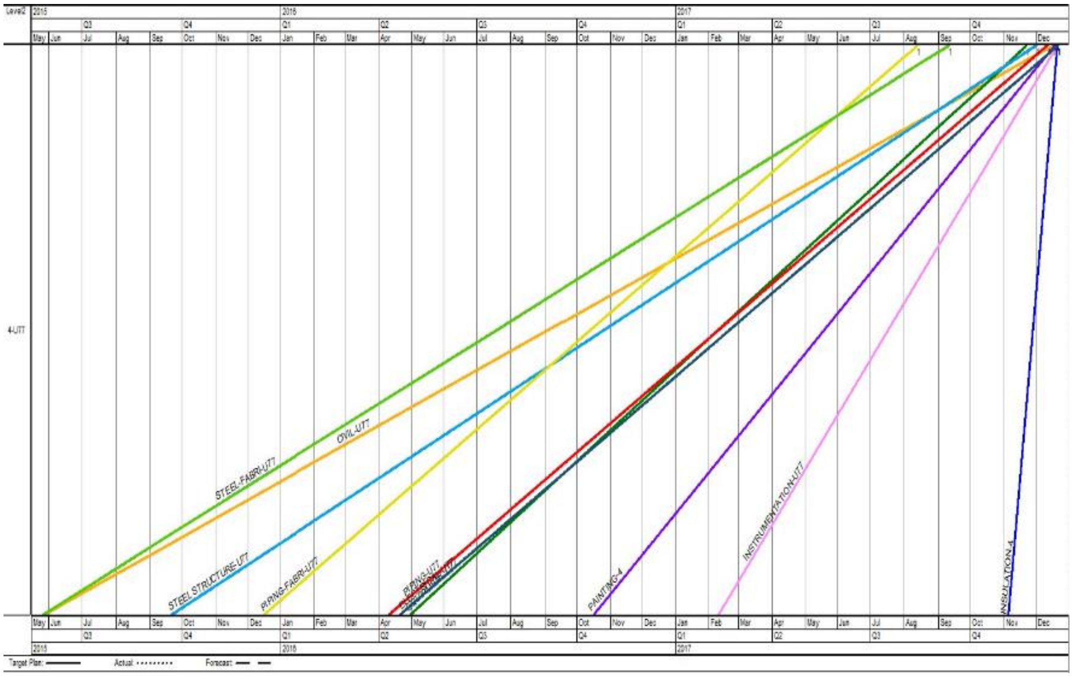

Figure 33 Planned tasks flowlines Unit 77

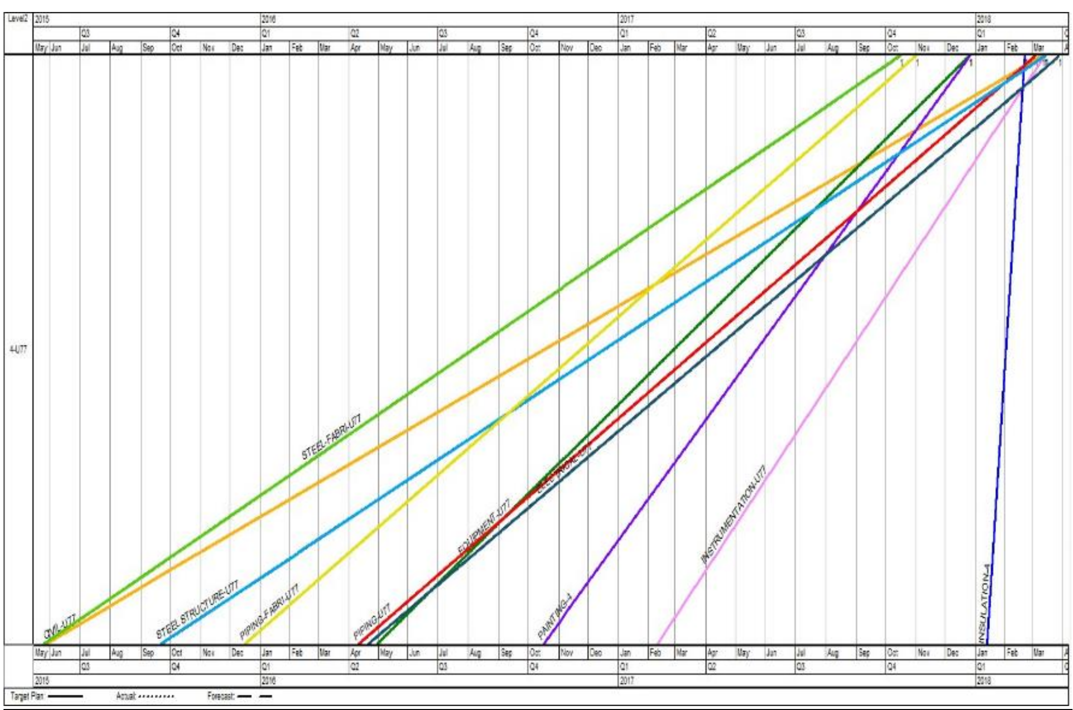

Figure 34 Construction tasks flowlines Unit 77

Unit 72:

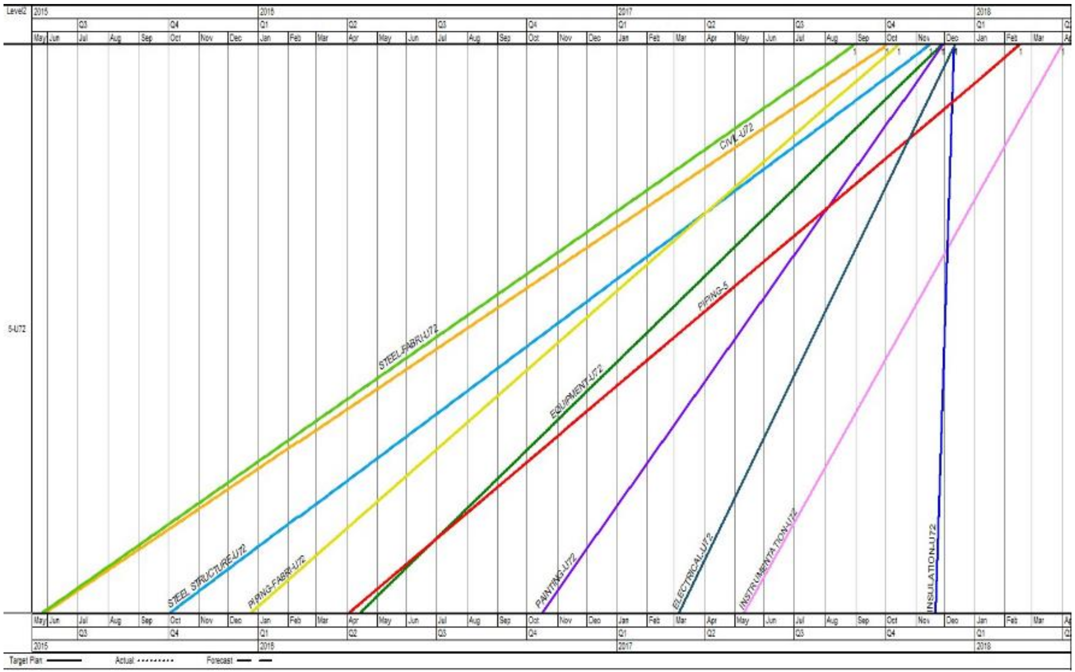

Figure 35 Planned tasks flowlines Unit 72

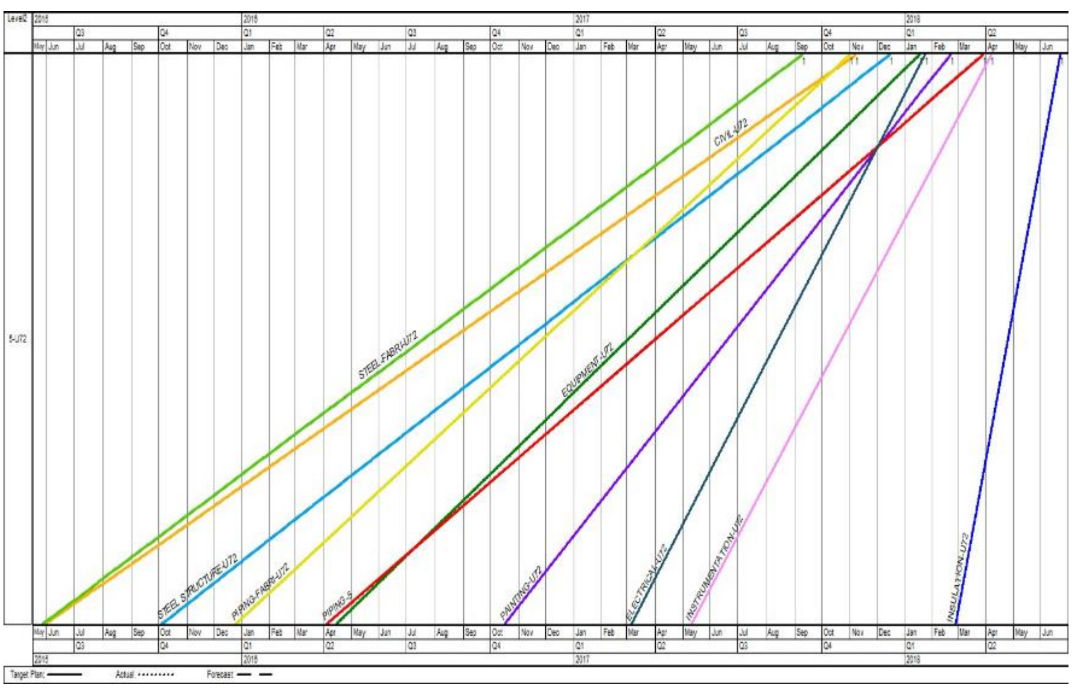

Figure 36 Construction tasks flowlines Unit 72

Unit 74:

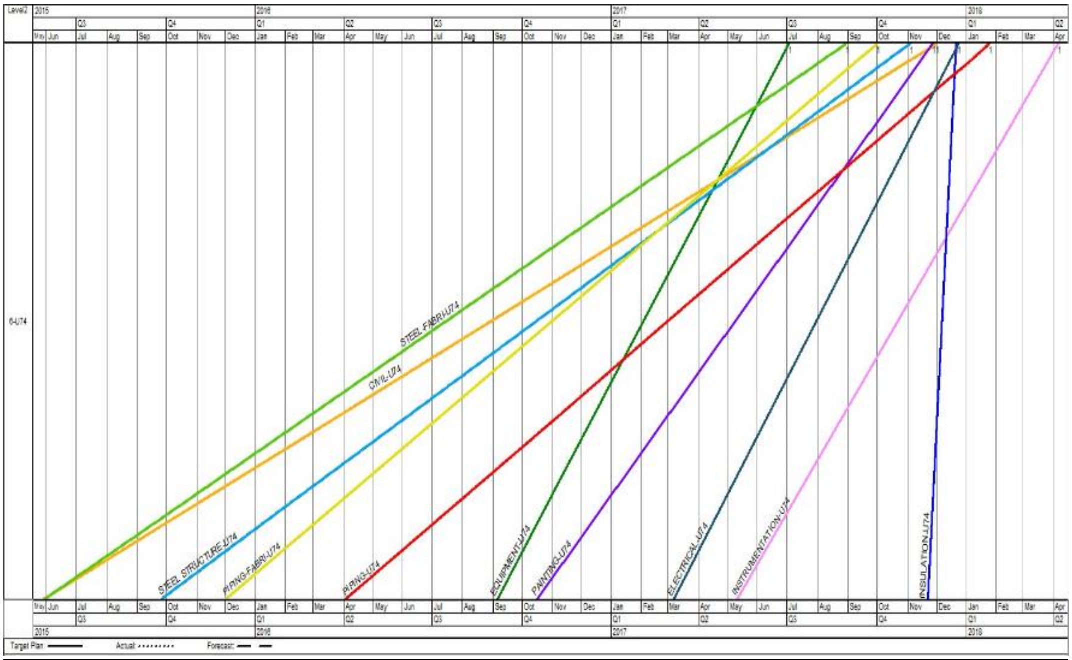

Figure 37 Planned tasks flowlines Unit 74

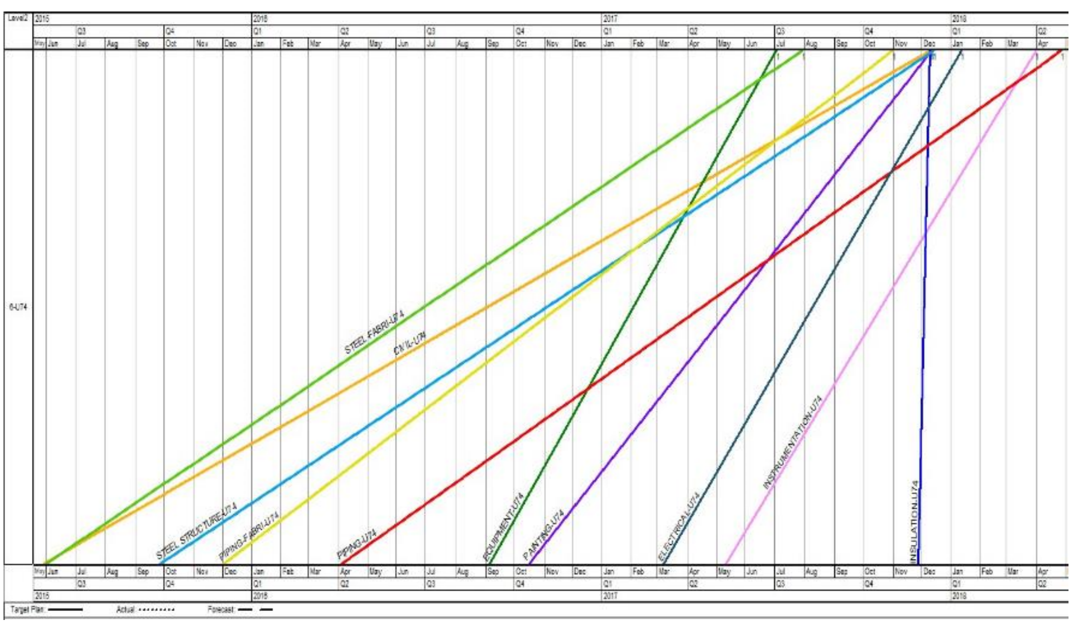

Figure 38 Construction tasks flowlines Unit 74

Unit-42

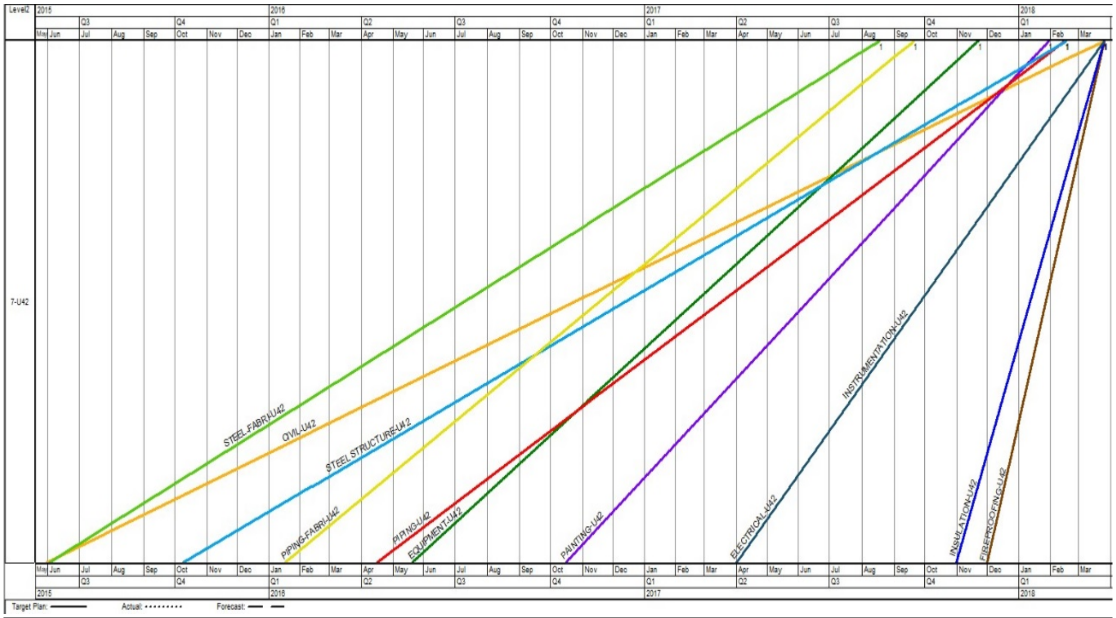

Figure 39 Planned tasks flowlines Unit 42

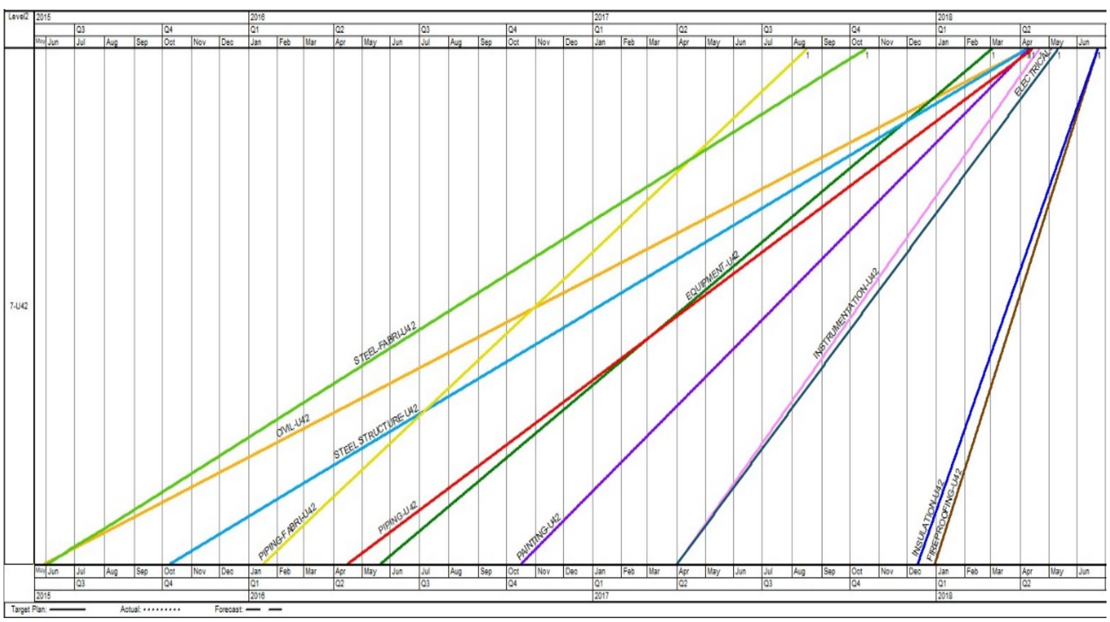

Figure 40 Construction tasks flowlines Unit 42

Unit-43

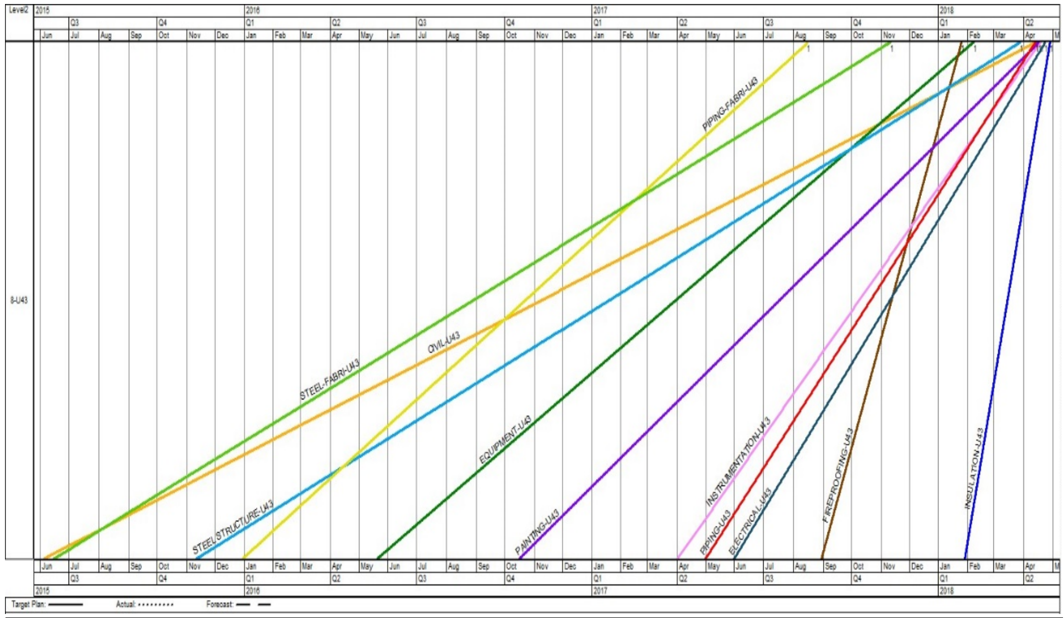

Figure 41 Planned tasks flowlines Unit 43

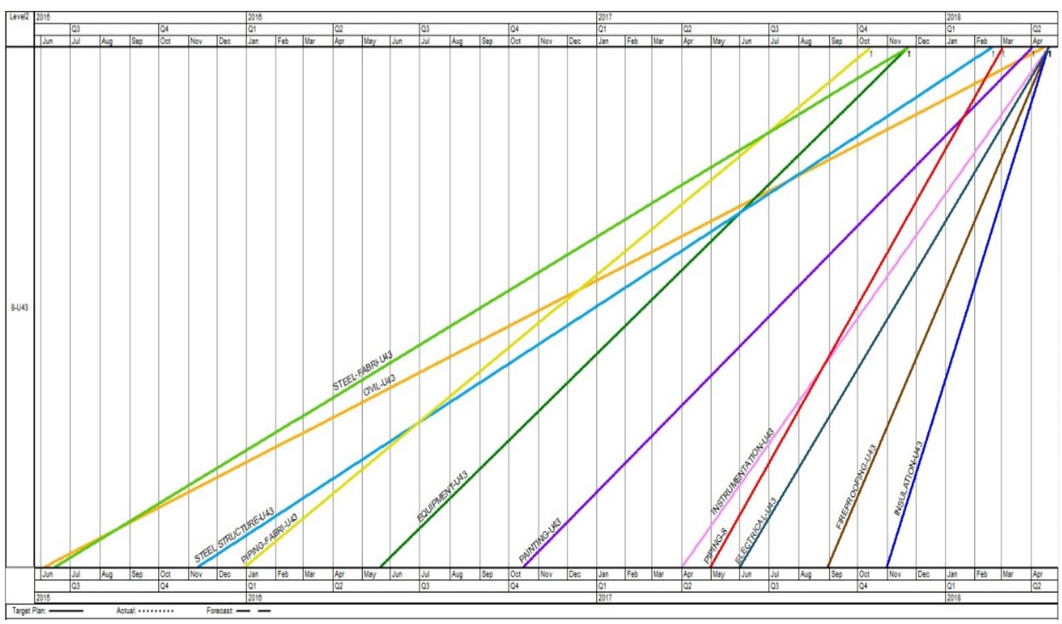

Figure 42 Construction tasks flowlines Unit 43

<u>Unit-75</u>

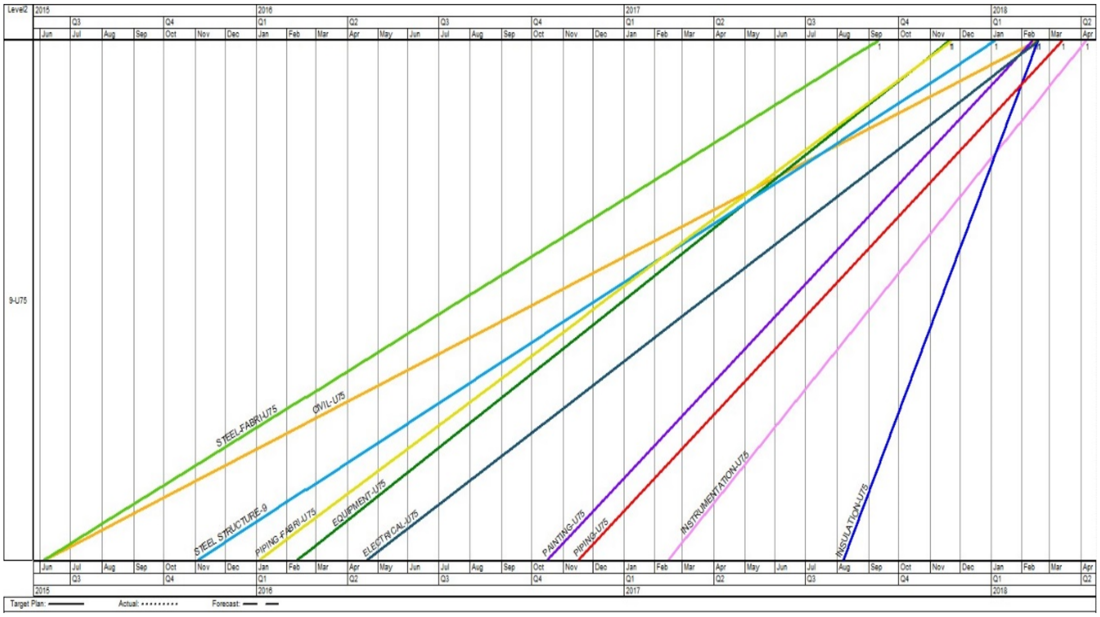

Figure 43 Planned tasks flowlines Unit 75

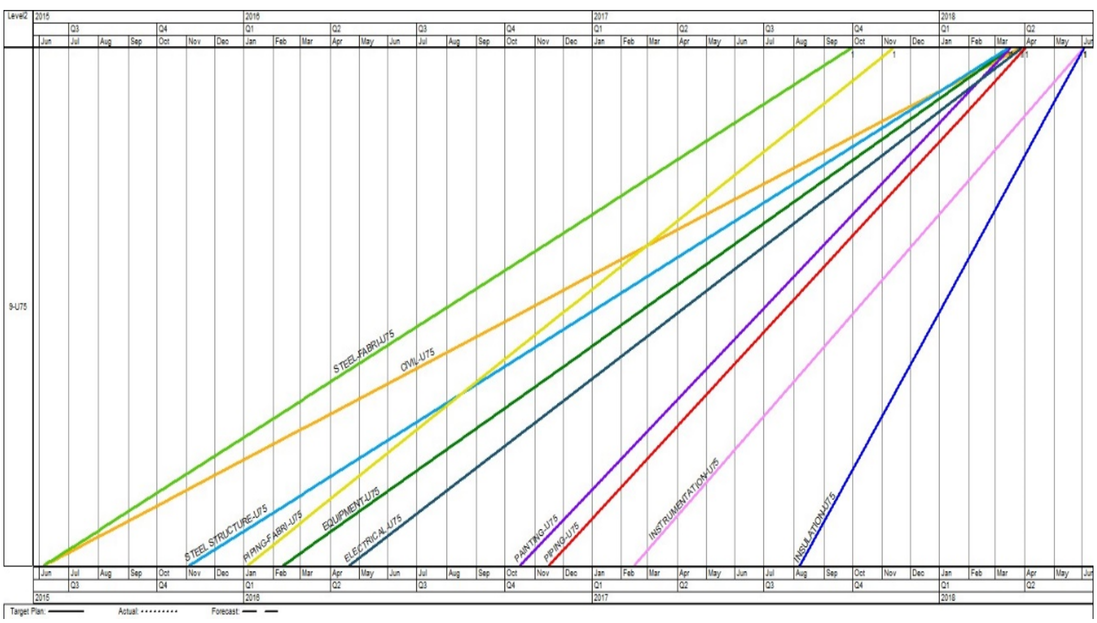

Figure 44 Construction tasks flowlines Unit 75

Gen

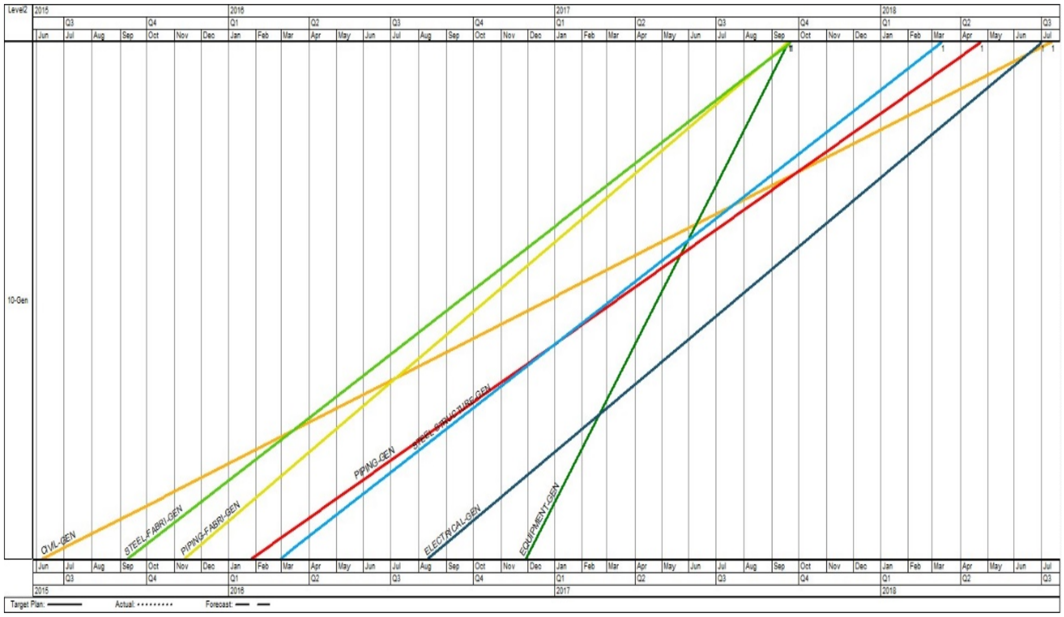

Figure 45 Planned tasks flowlines Gen

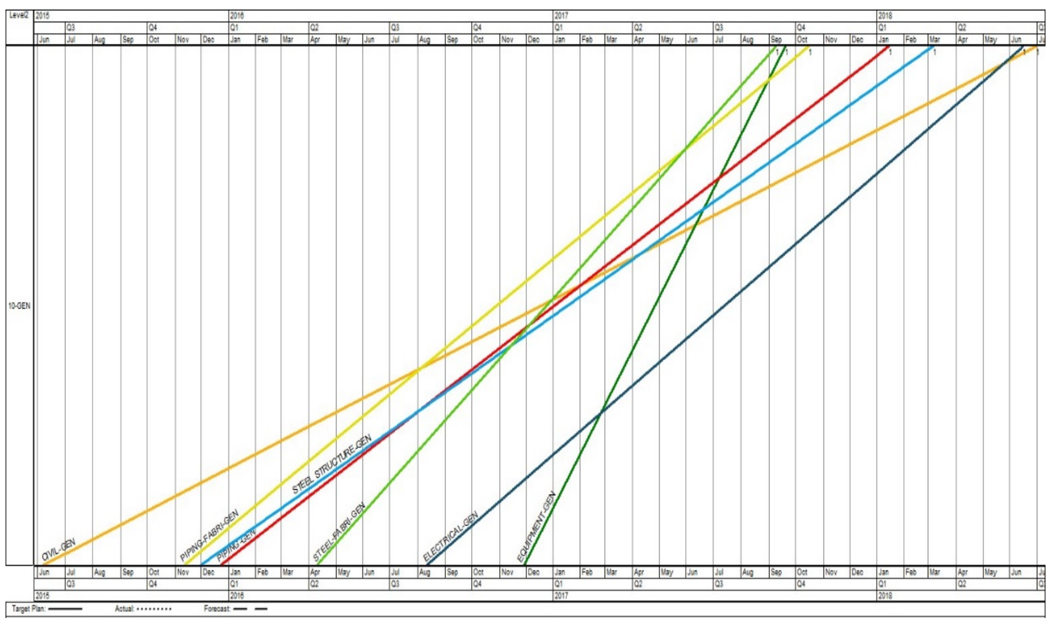

Figure 46 Construction tasks flowlines Gen

Unit 41:

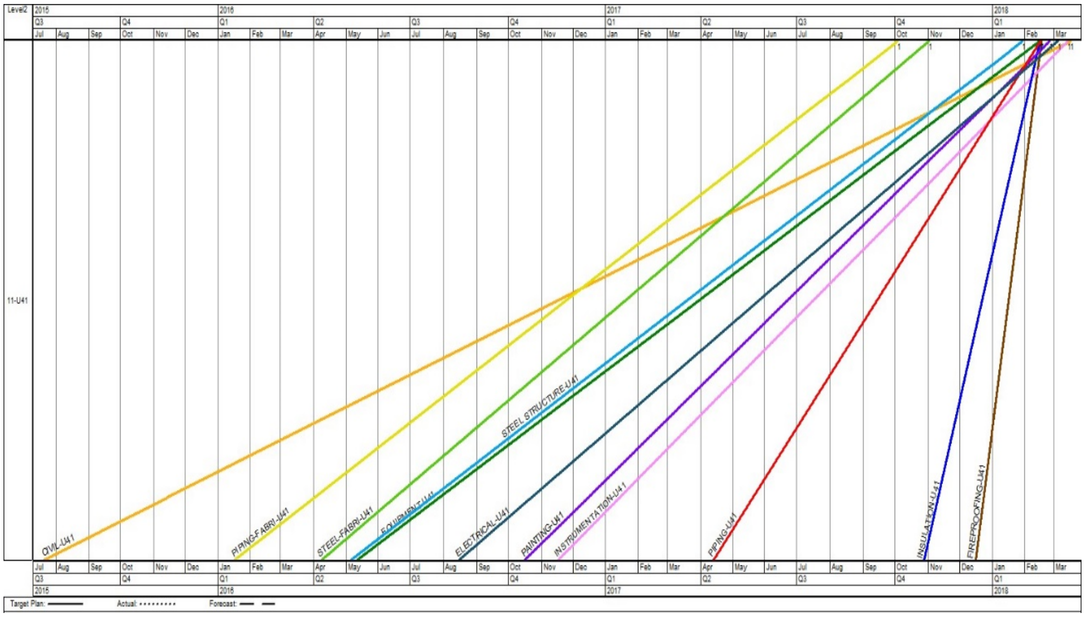

Figure 47 Planned tasks flowlines Unit 41

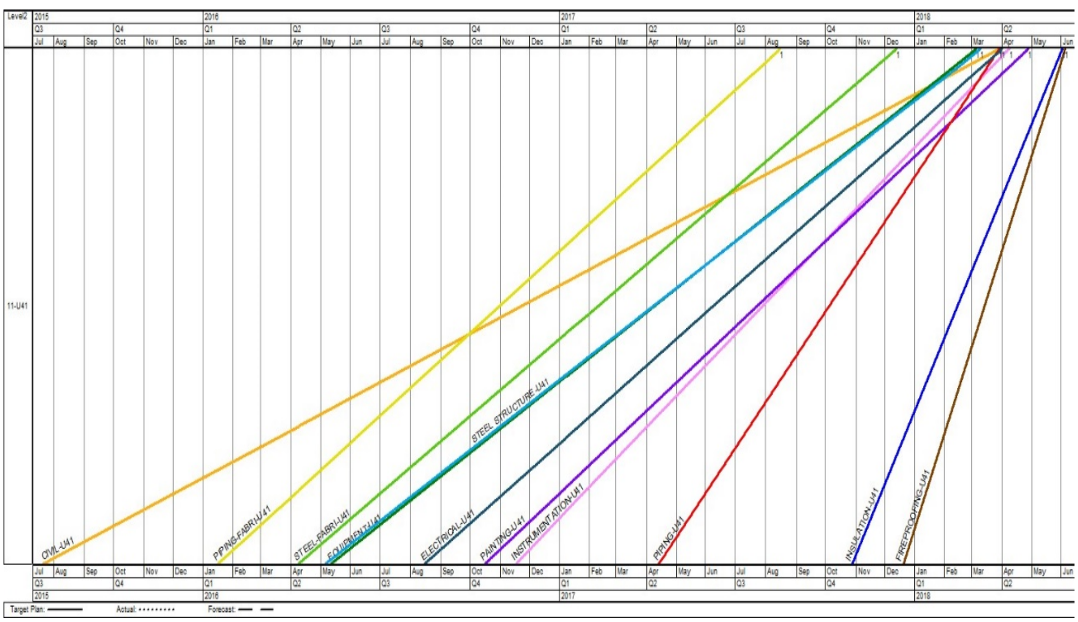

Figure 48 Construction tasks flowlines Unit 41

Unit 60:

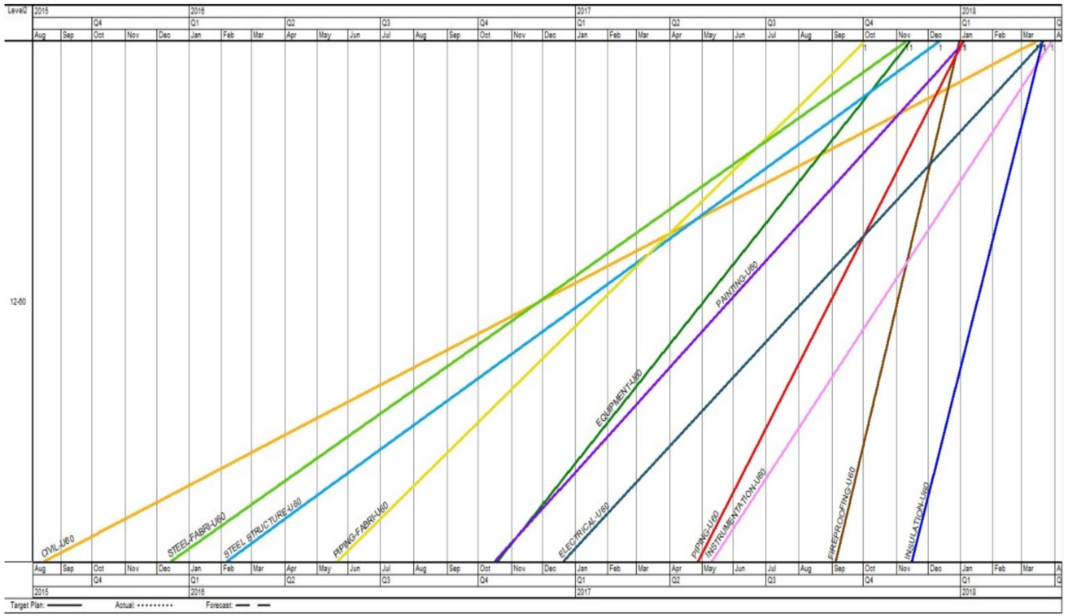

Figure 49 Planned tasks flowlines Unit 60

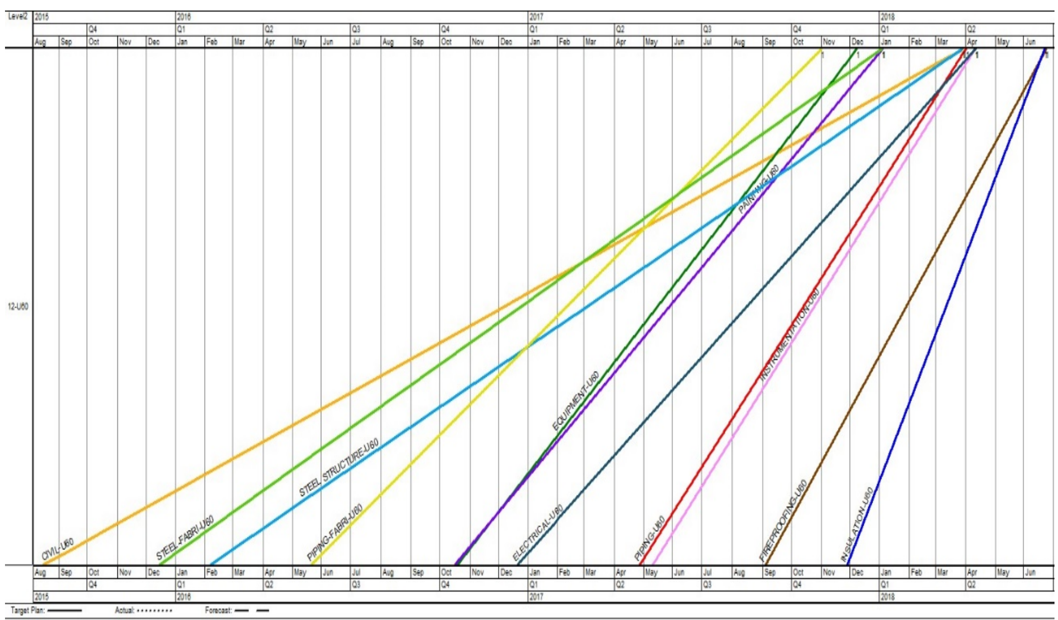

Figure 50Construction tasks flowlines Unit 60

Unit 79:

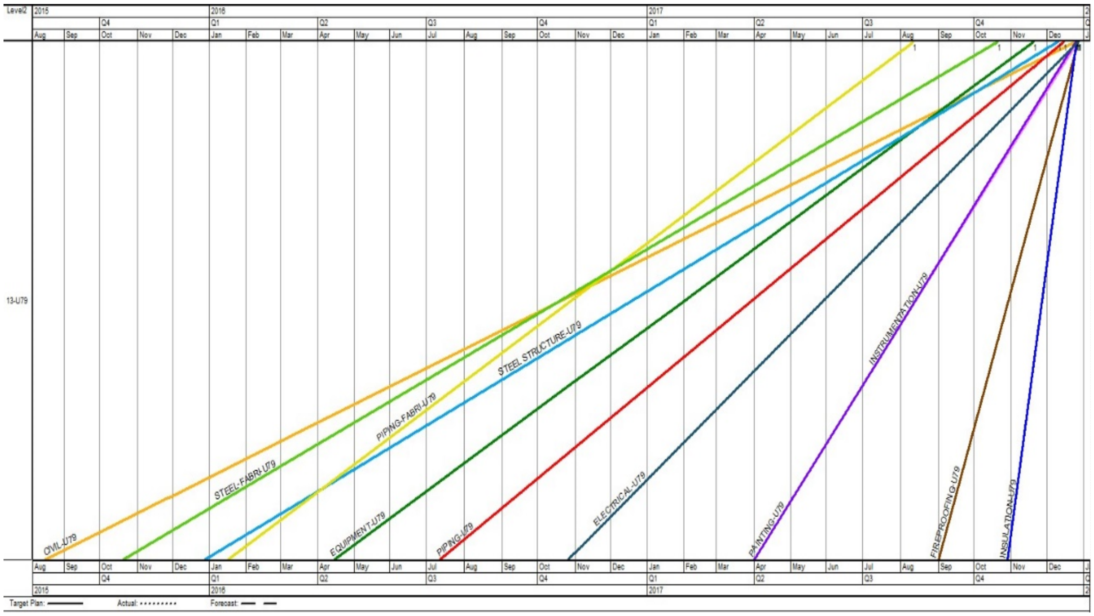

Figure 51 Planned tasks flowlines Unit 79

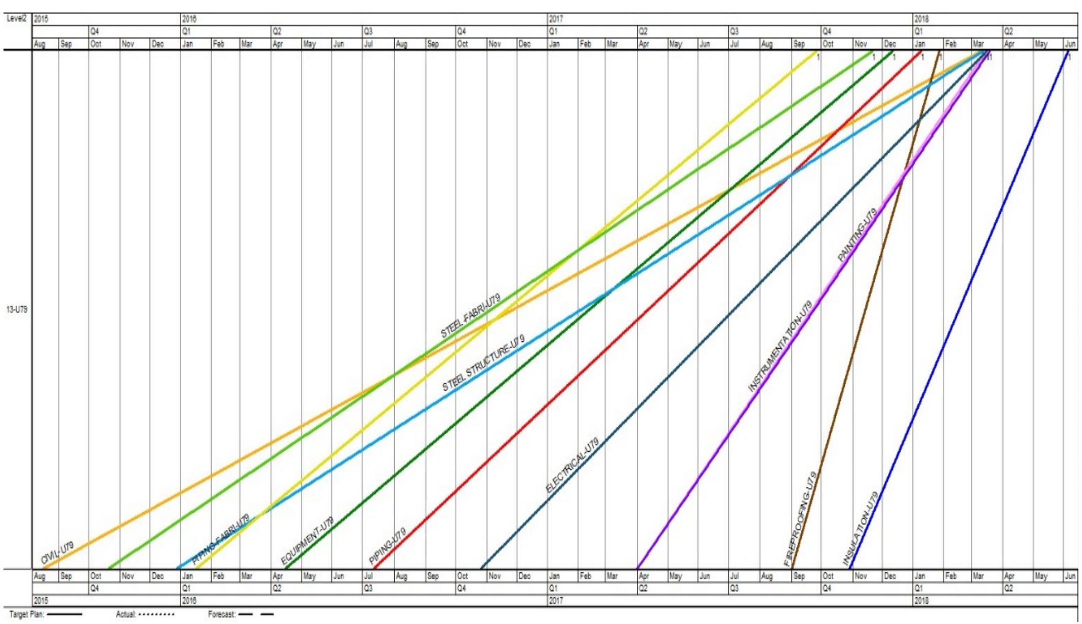

Figure 52 Construction tasks flowlines Unit 79

Unit 51:

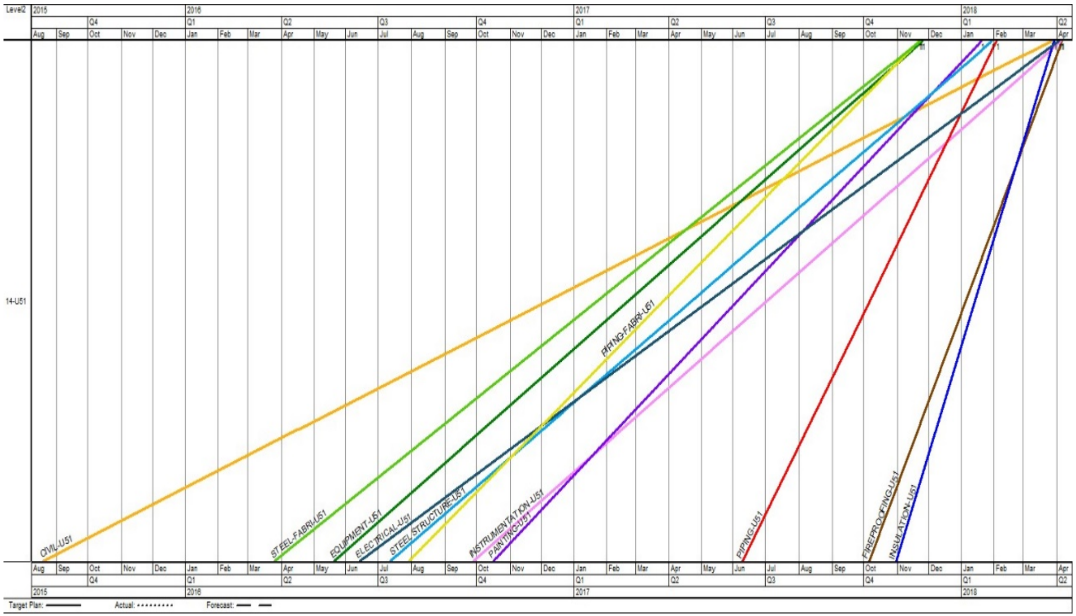

Figure 53 Planned tasks flowlines Unit 51

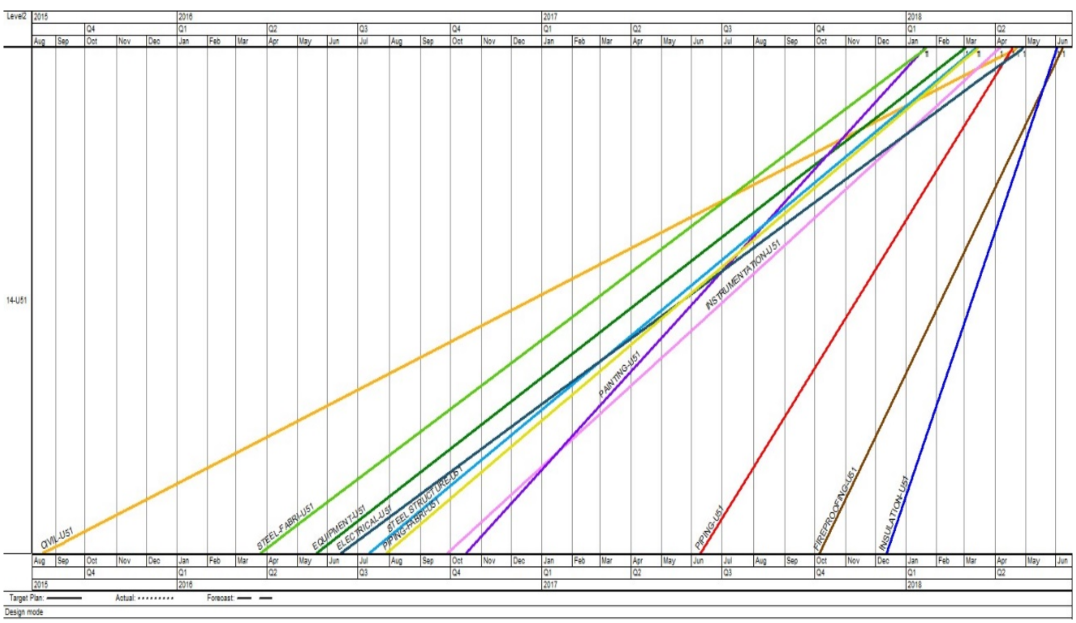

Figure 54 Construction tasks flowlines Unit 51

Unit 61:

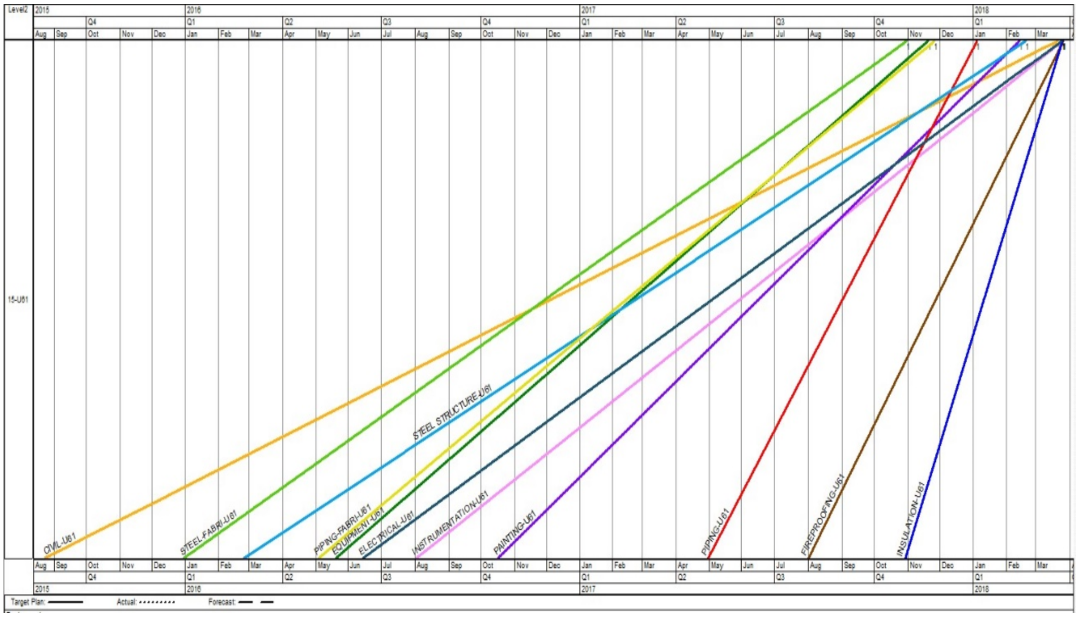

Figure 55 Planned tasks flowlines Unit 61

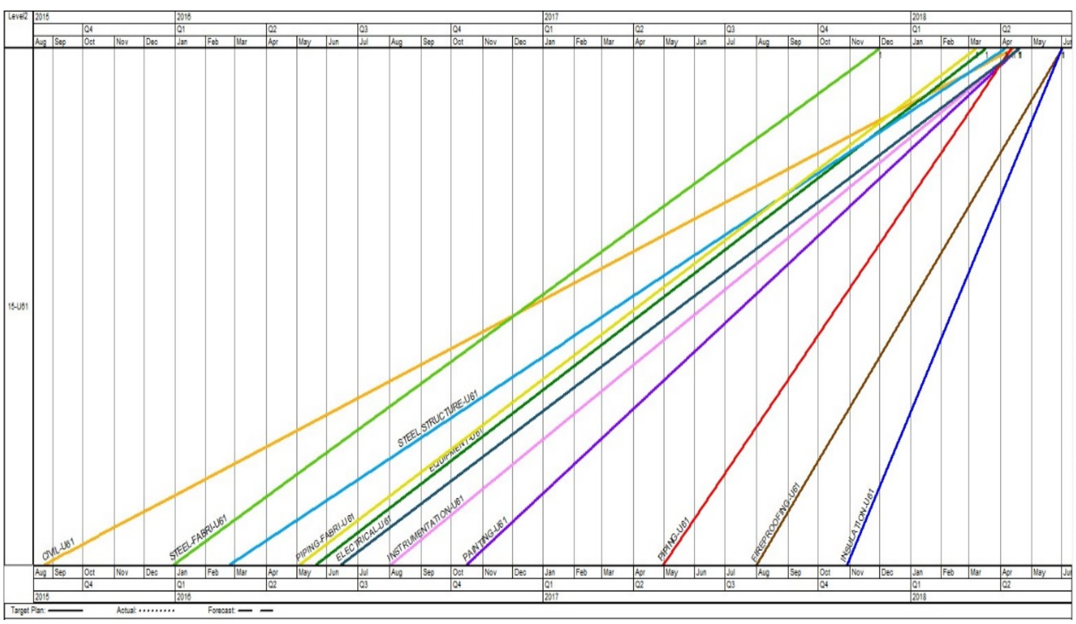

Figure 56 Construction tasks flowlines Unit 61

Unit 36:

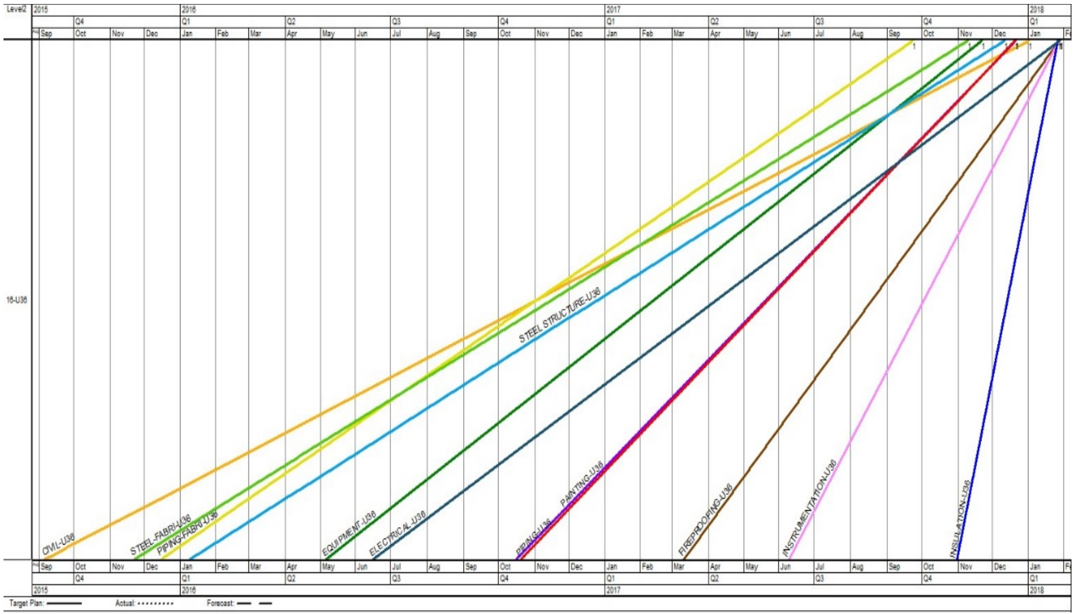

Figure 57 Planned tasks flowlines Unit 36

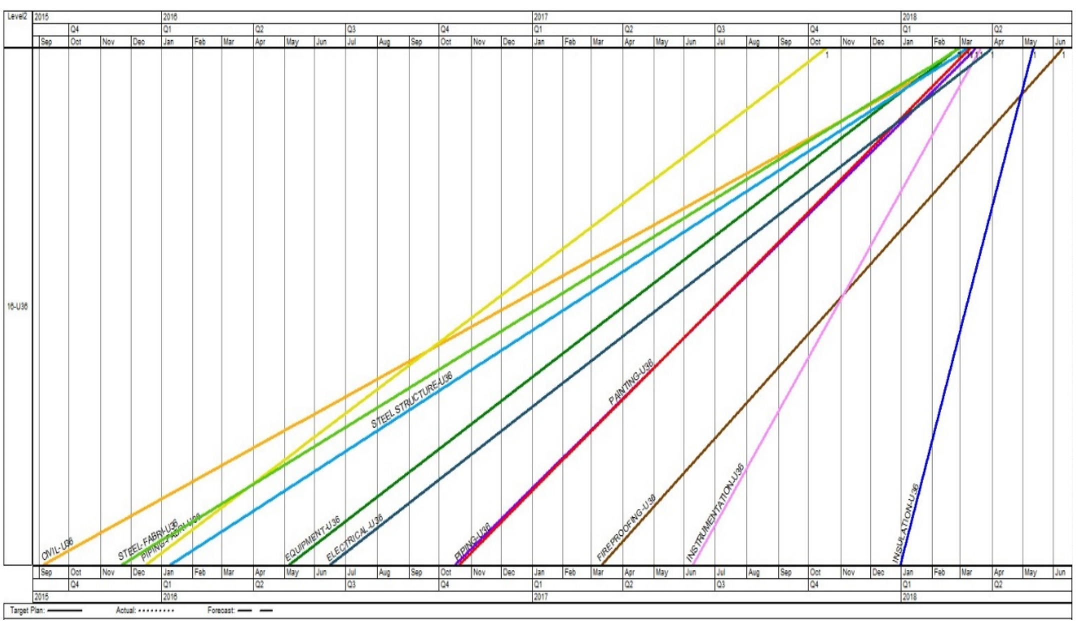

Figure 58Construction tasks flowlines Unit 36

Unit 40:

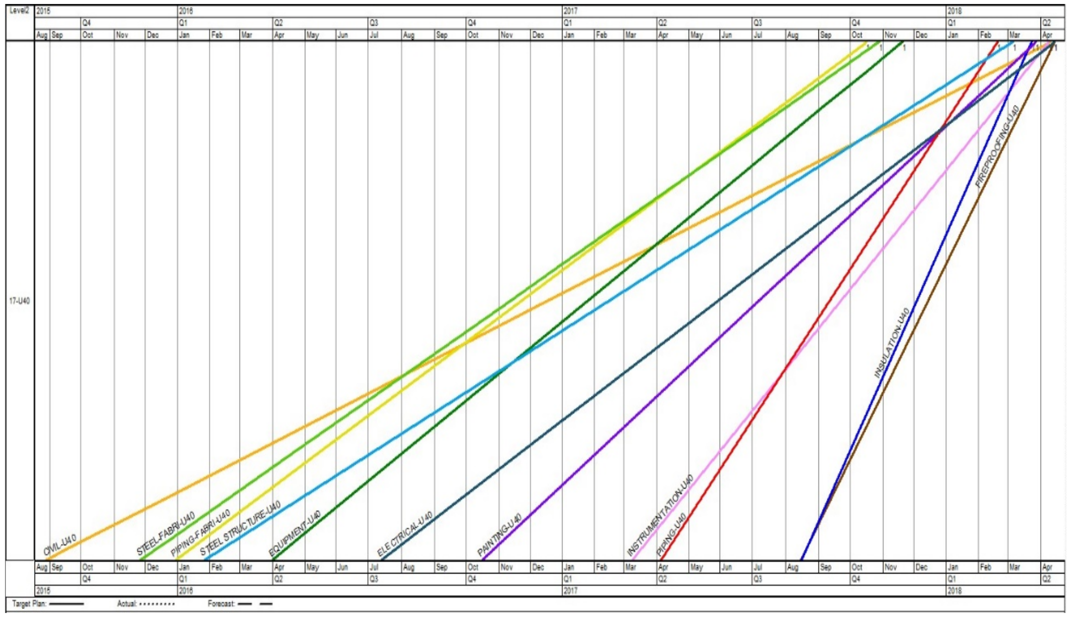

Figure 59 Planned tasks flowlines Unit 40

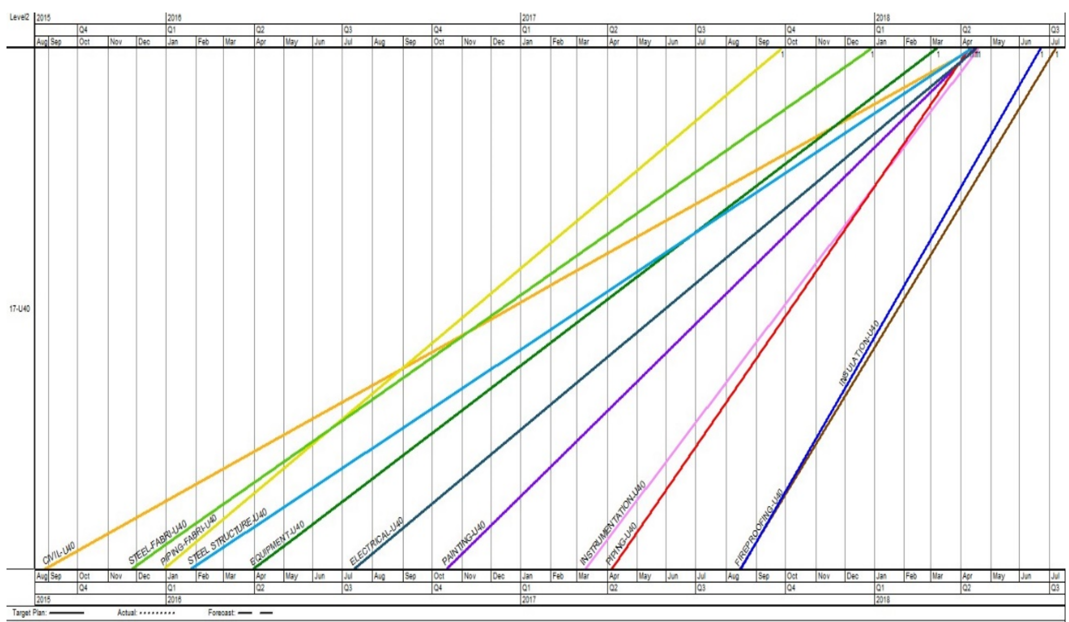

Figure 60 Construction tasks flowlines Unit 40

Unit 33:

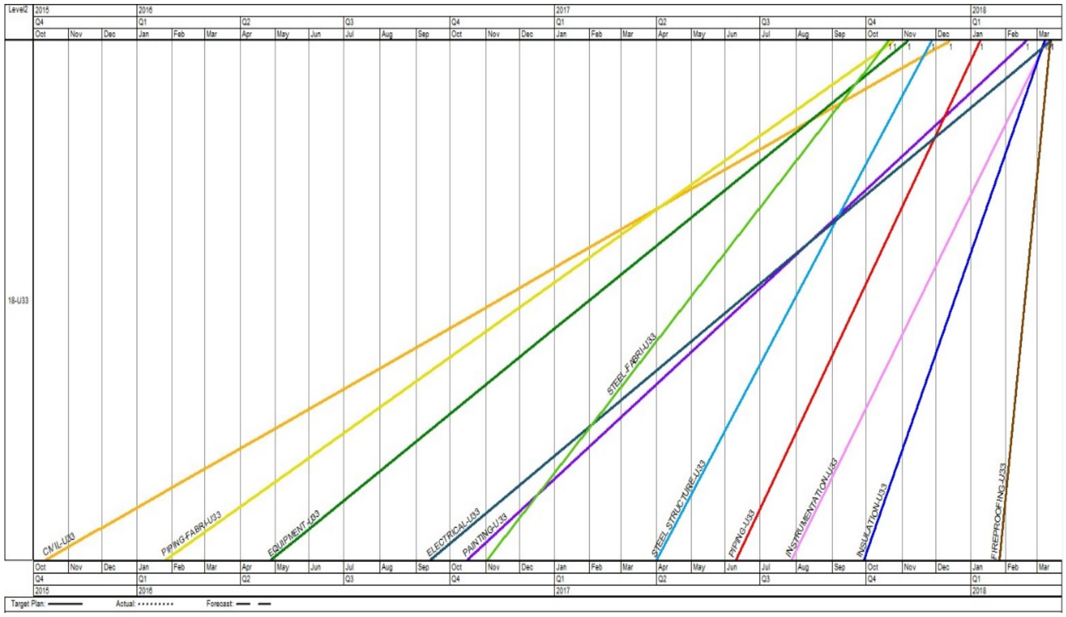

Figure 61Planned tasks flowlines Unit 33

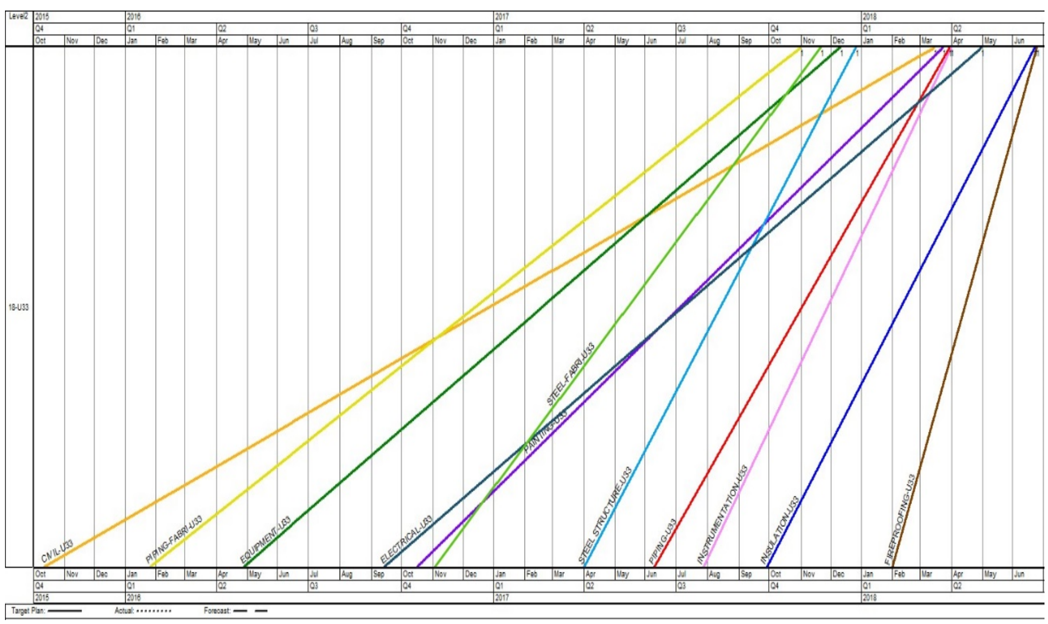

Figure 62Construction tasks flowlines Unit 33

Unit 71:

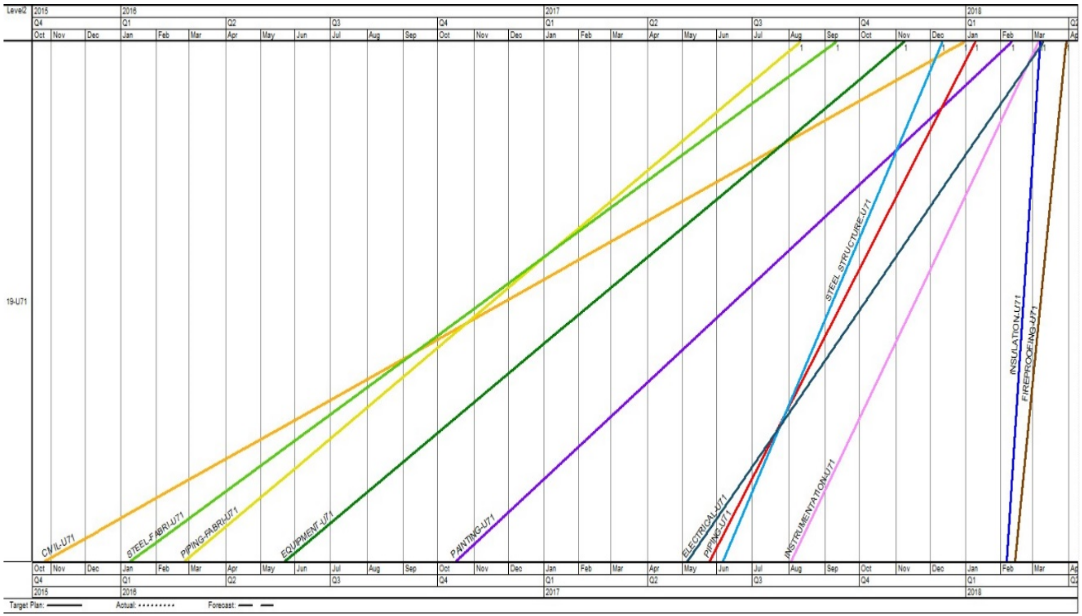

Figure 63 Planned tasks flowlines Unit 71

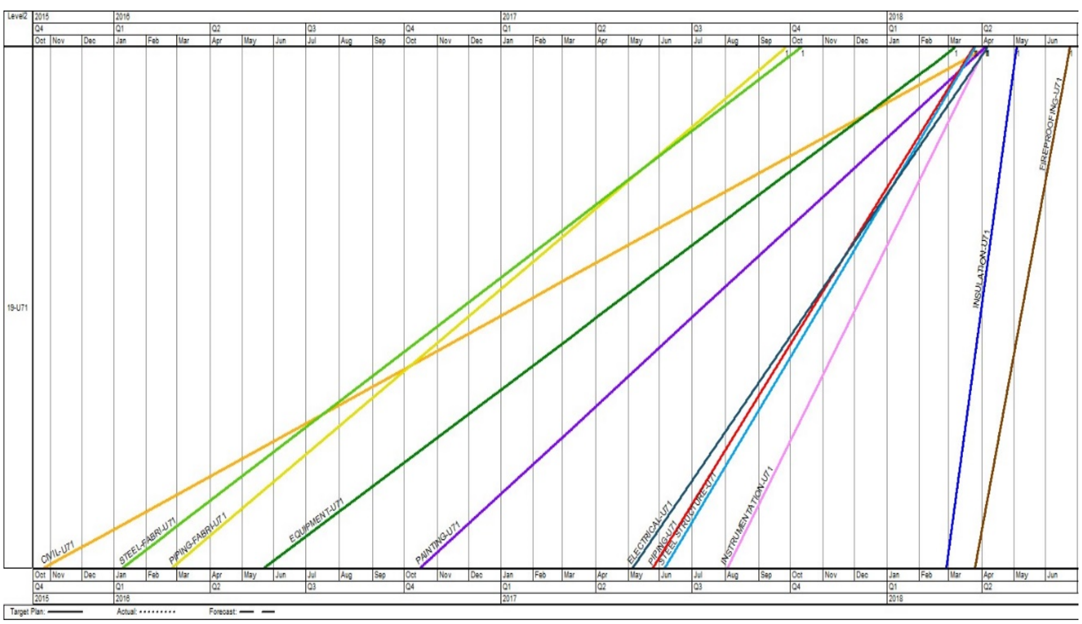

Figure 64 Construction tasks flowlines Unit 71

Unit 31:

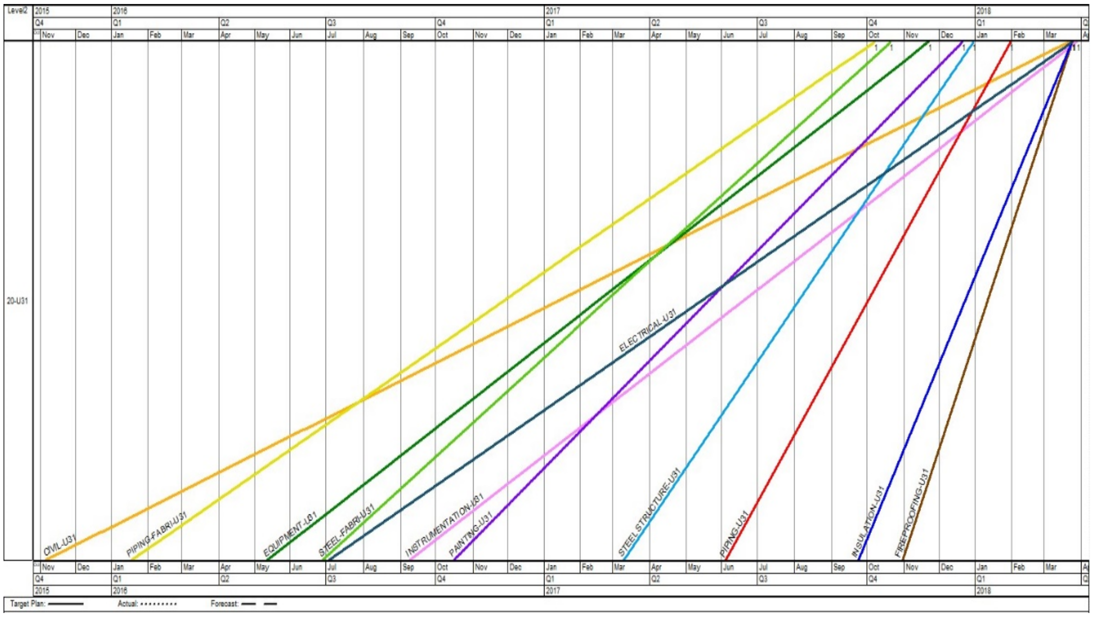

Figure 65 Planned tasks flowlines Unit 31

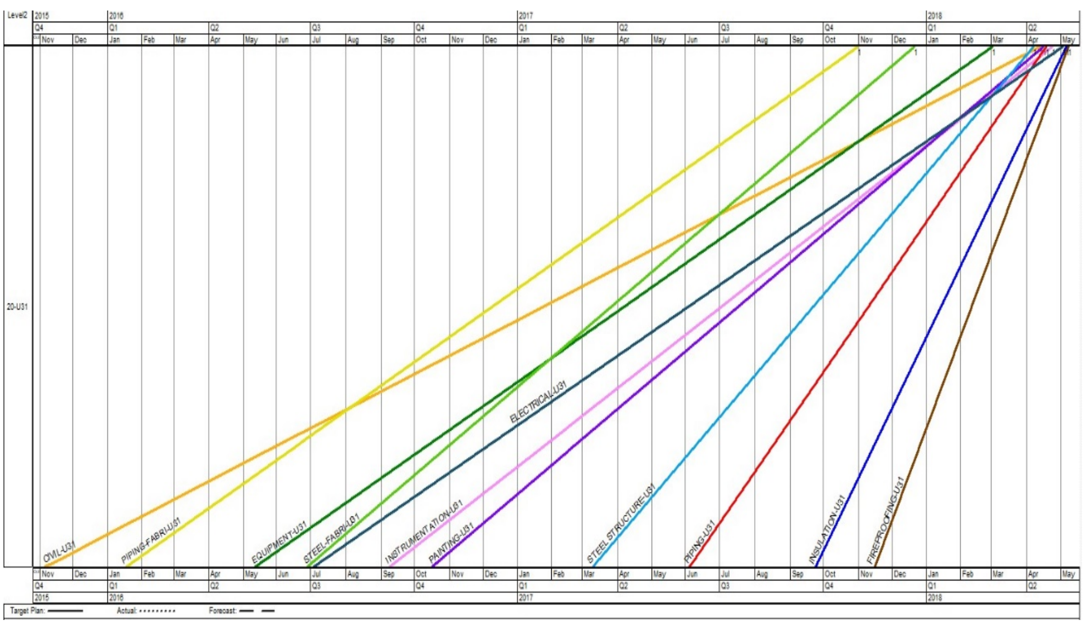

Figure 66 Construction tasks flowlines Unit 31

Unit 50:

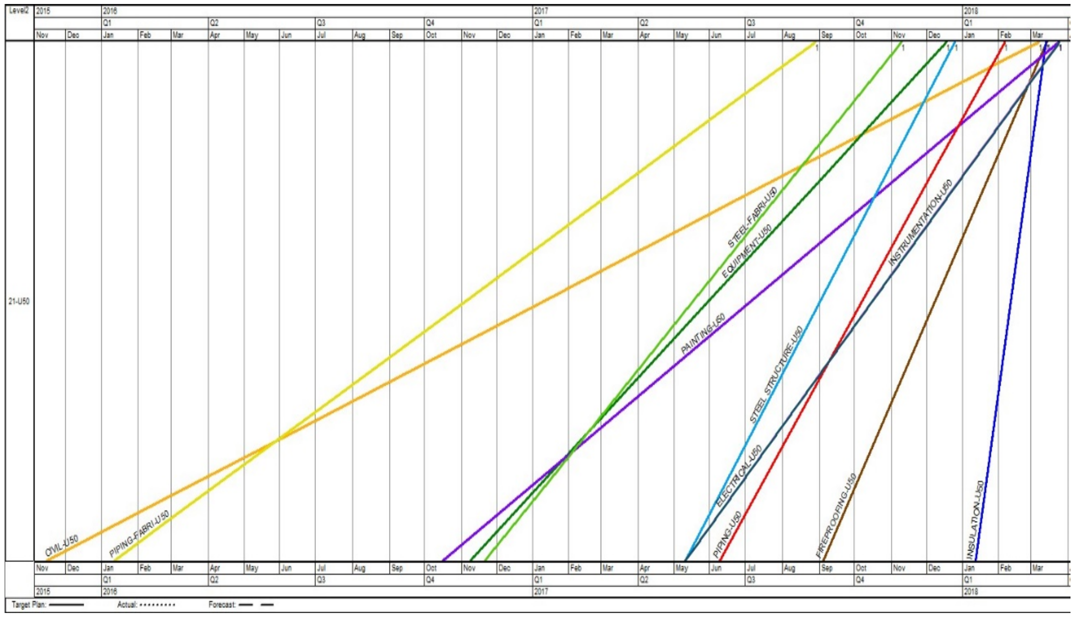

Figure 67 Planned tasks flowlines Unit 50

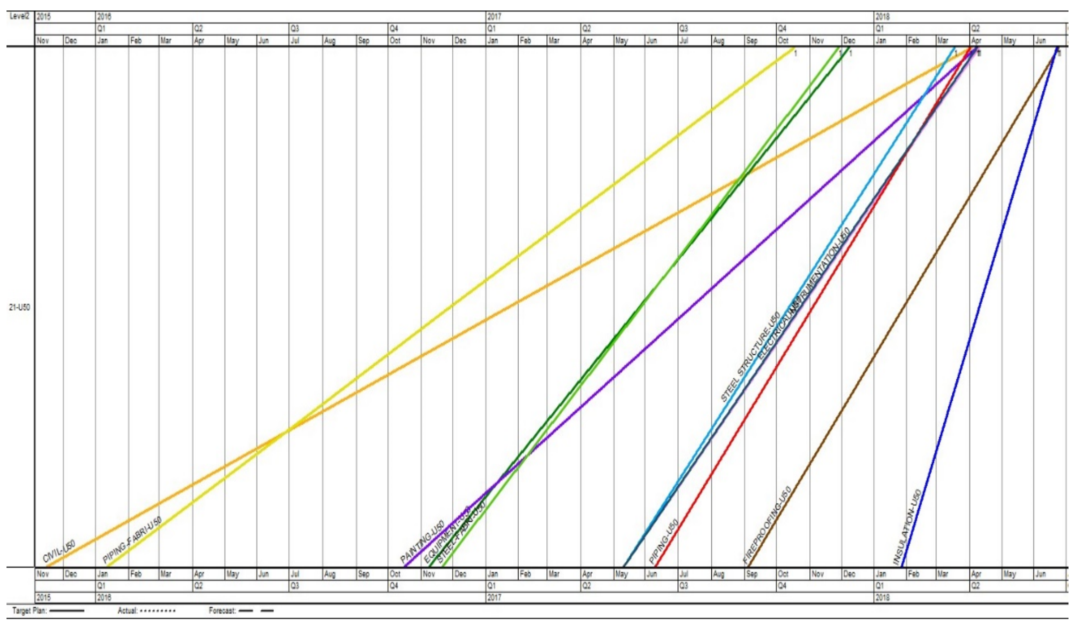

Figure 68 Construction tasks flowlines Unit 50

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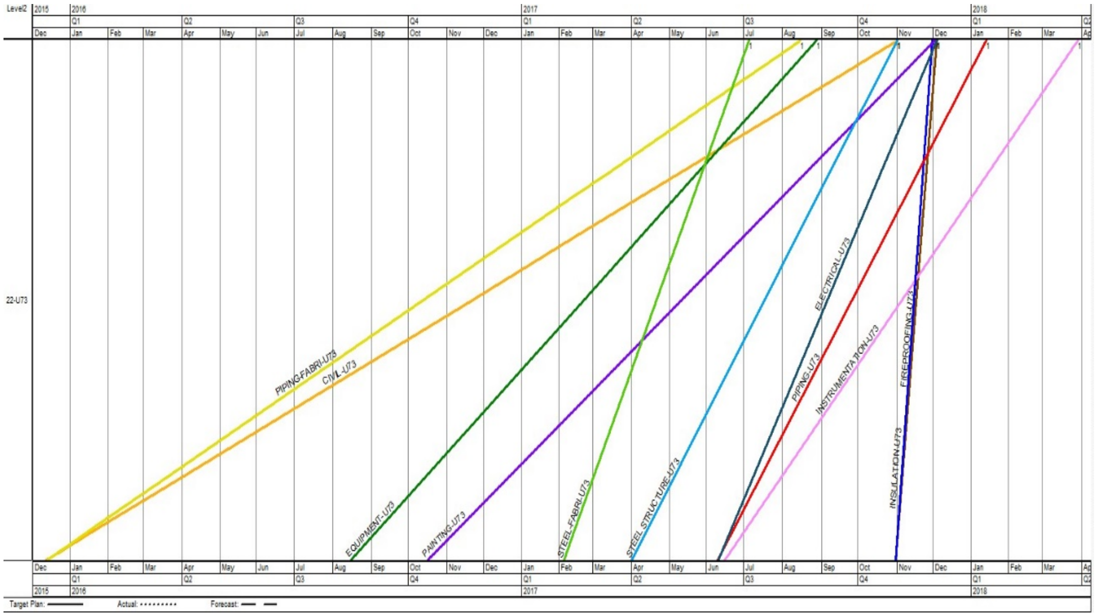


Figure 69 Planned tasks flowlines Unit 73

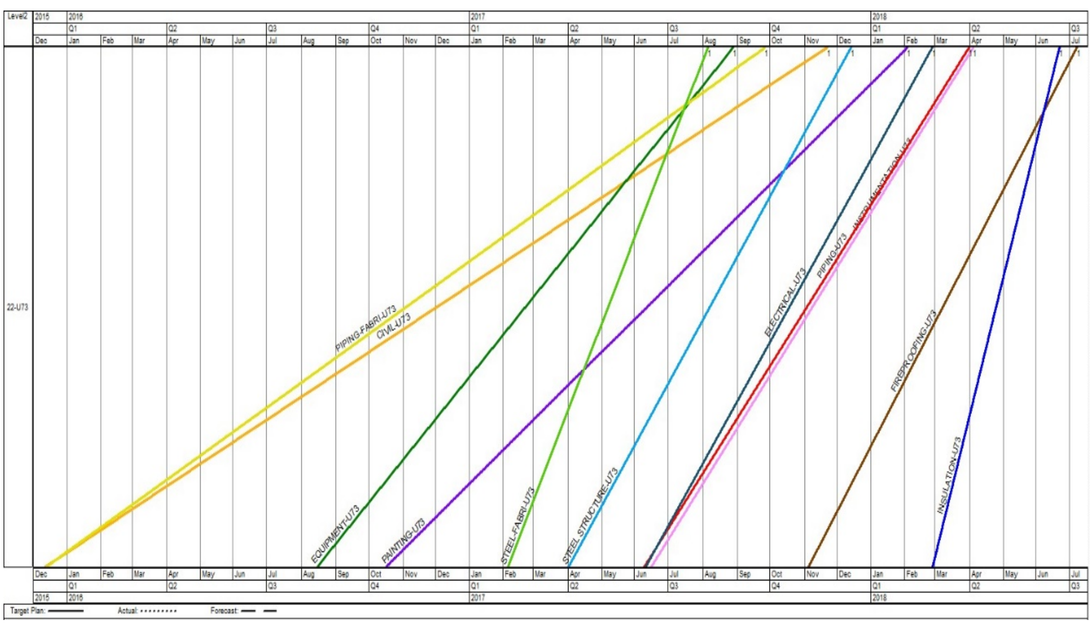
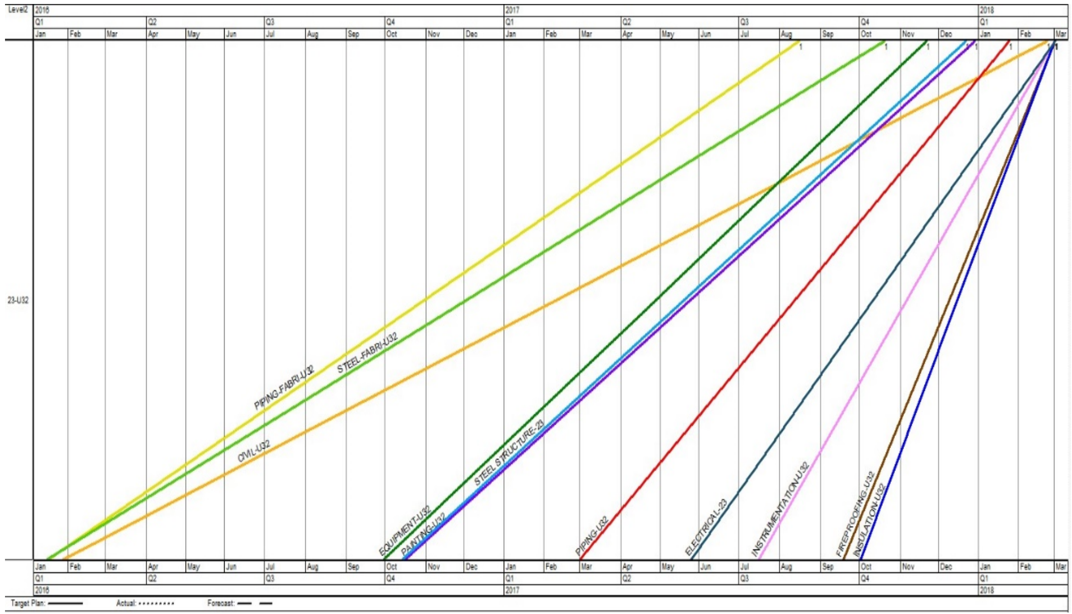


Figure 70 Construction tasks flowlines Unit 73

Unit 32:



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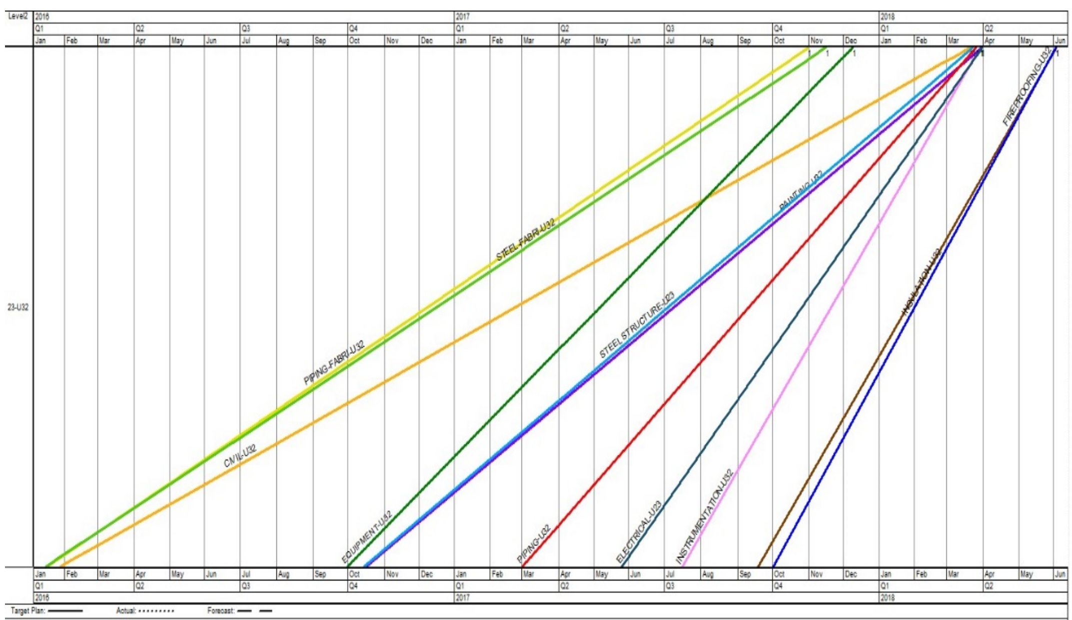

Figure 72Construction tasks flowlines Unit 32

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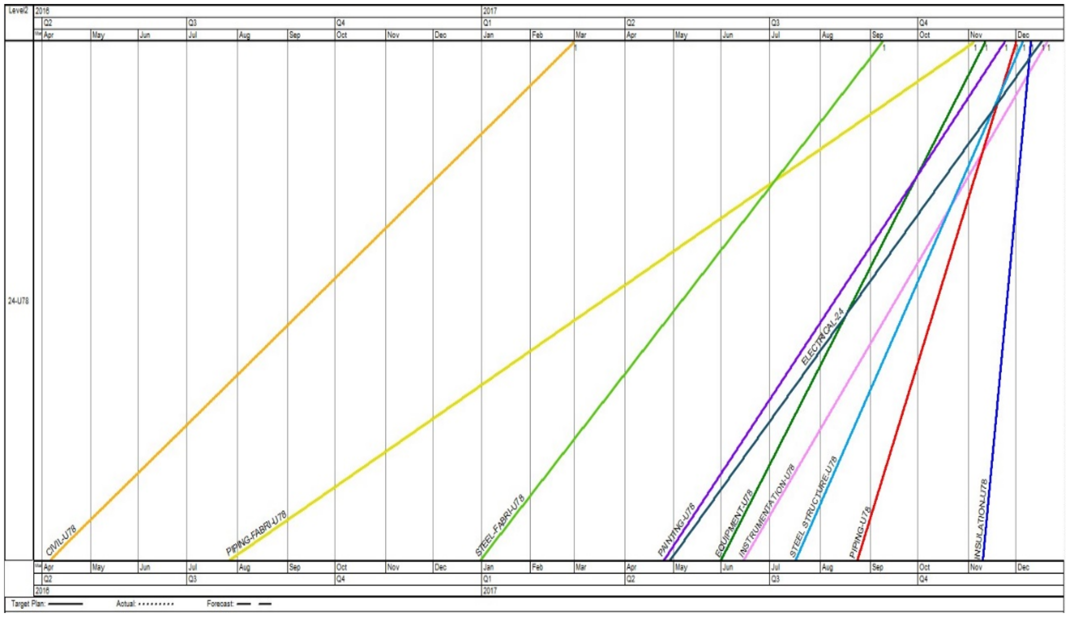

Figure 73 Planned tasks flowlines Unit 78

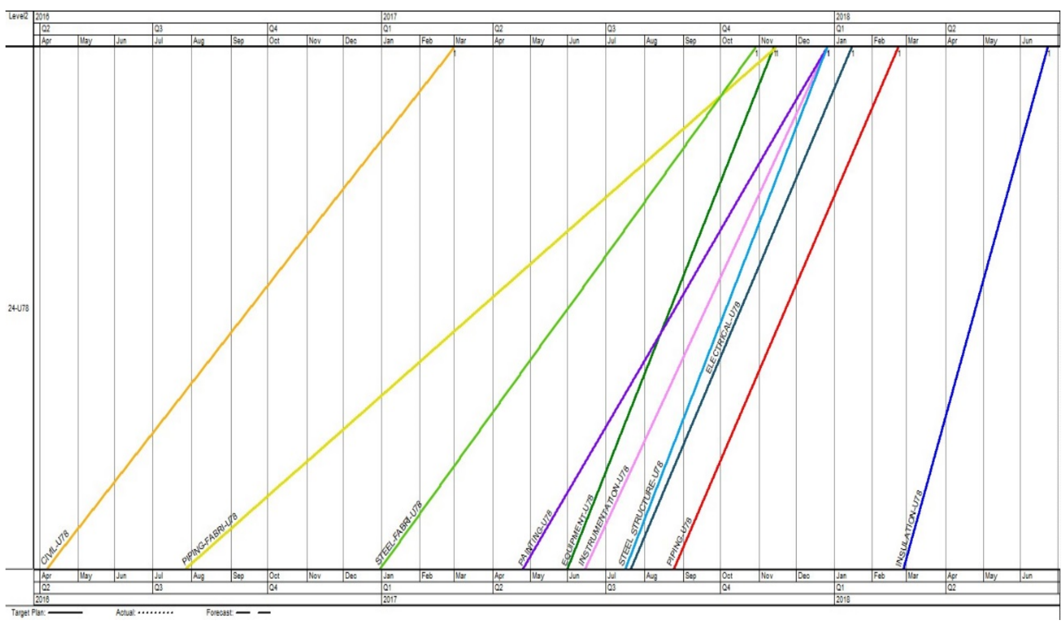

Figure 74 Construction tasks flowlines Unit 78

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