MODIFIED LINEAR SCHEDULING IN SCHEDULING MULTIPLE UTILITY LINE CONSTRUCTION PROJECT

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ABSTRACT

Although popular scheduling methods, such as Gantt chart and its variation (linked Gantt chart) and Critical Path Method (CPM) are really beneficial to the construction industry, these methods are still criticized while applied to scheduling linear construction projects. Linear scheduling method (LSM) and its variations are beneficial to linear construction in its presentation on productivity and project progress corresponding to true location. However, the current LSM and its variations have not studied the scheduling problems on several utility lines which happen often in the utility construction company. These utility lines intersect with each other at some locations as designed. Each line at the intersected location has its own elevation. Crews are assigned to work on each different line. These crews may arrive in the intersected location simultaneously which cause work space conflicts. The current LSM and its variation do not indicate the interference locations; predict the interference time, and how to avoid the work space conflicts to keep the crew work continuously. This study develops the modified LSM which uses a group of linear equations to identify the construction interference locations of utility lines, estimate the interference time based on the historical production rate, and adjust the construction schedule to satisfy the construction constraints. It helps to avoid the construction interruption, keep the continuity of crew work, and avoid the delay of construction and cost overruns.

KEY WORDS

Linear Scheduling Method, Multiple Utility Line Construction Project, Construction Constraints, Work Space Conflicts, Modified Linear Scheduling Method

INTRODUCTION

HCC is one of the largest utility contractors in the North Florida area. It was founded in 1974. Most of the company's work comes from either private developers or public-funded municipal projects. In the private sector, the company performs underground utilities services for buildings, plants, subdivisions and other facilities. Land developers award contracts to

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HCC for street construction and utility installation. Public projects include work like installing new utilities and replacing old utilities in existing cities or developments. HCC performs a variety of infrastructure projects in the public sector, including the construction and maintenance of sewer systems, storm water systems, water distribution systems, gas systems and power conduit systems. The company's participation in both the public and private sectors and its diverse mix of project types and sizes have contributed to the Company's revenue growth and profitability in changing economic environments. In 2002, the company reported revenues of $22 million. The annual revenue rose to $30 million in 2003, a 36% growth in gross revenues. The business expanding brings challenges of construction management to HCC, especially in planning and scheduling stage.

The main challenge is how to avoid work space conflicts among several utility lines to maintain work continuity, reduce rework incurred from work space conflicts, improve productivity, and maximize its profit. Utility projects have their own features. For the underground utility project, the layouts of several utility lines are diverged. But on some locations, these utility lines intersect with each other, one over another. The construction of each utility line must be sequenced in this situation to avoid workspace conflicts, or lines with lower elevation are constructed ahead of the ones with higher elevation, and to provide work continuity for crews or resources.

The company applies several currently popular planning and scheduling methods to solve the challenges from scheduling. These methods include Gantt Chart and Linear Scheduling Method (LSM). The following sections would review the popular methods' advantages and disadvantages in scheduling linear construction projects, and present a methodology of solving the challenges faced by HCC. The developed method uses a group of linear equations to identify the construction interference locations of utility lines, estimate the interference time based on the historical production rate, and adjust the construction schedule to satisfy the construction constraints. The method is applied to Florence path and the application shows avoiding the construction interruption, keeping the continuity of crew work, and avoiding the delay of construction and cost overruns.

CURRENT SCHEDULING METHODS IN CONSTRUCTION INDUSTRY

The most common scheduling method used in the construction industry is the Gantt chart (Bar chart) and the Critical Path Method (CPM). The Gantt chart (Bar chart) has gained wide acceptance and popularity because of its simplicity and ease of preparation and understanding. No "theory" or complicated calculations are involved. The CPM network can show the logical dependencies of activities, and estimate and predict the completion date of a project based on mathematical calculations. But both the Gantt chart and CPM are unable to accurately model the repetitive nature of linear construction. This includes the inability of CPM to provide work continuity for crews or resources, to plan the large number of activities necessary to represent a repetitive or linear project (Harris, 1996), and the inability of Gantt chart (Bar chart) and CPM to indicate rates of progress, and to accurately reflect actual conditions (Mattila and Abraham, 1998). The consequence of this is that there have been many attempts to find an effective scheduling technique for linear construction. These include, but are not limited to, the Line of Balance (LOB), the vertical production method

(VPM), the repetitive project modeling (RPM), the linear scheduling method (LSM), and the repetitive scheduling method (RSM) (Mattila and Abraham,1998). All of these concepts and methods are the variations of linear scheduling method. The following describes the inability of Gantt chart and current linear scheduling method in solving the construction interferences of two or more utility lines.

LINKED BAR CHART: A MINGLE OF CPM AND BAR CHART

Linked Bar Chart is currently popular in the construction industry for its easily understood presentation. It is time-based diagram. The bar charts are linked based on their logical relationships. Critical relationships are highlighted through CPM computation (Figure 1). It even shows the project progress on the bar charts.

However, there is no indication of production rates in linked bar chart, this situation could not be anticipated by the scheduler during the development of the linked bar chart. It has no capability that would ensure a smooth procession of crews from unit to unit with no conflict and no idle time for workers and equipment. This leads to hiring and procurement problems in the flow of labor and material during construction (Arditi, Sikangwan, and Tokdemir, 2002).

Another problem of the linked bar chart is when scheduling repetitive projects such as pipe line is the enormous size of the network. In a pipe line project of n sections, the bar chart prepared for one section has to be repeated n times and linked to the others; this results in a huge linked bar chart that is difficult to manage and cause difficulties in communication among the members of the construction management team.

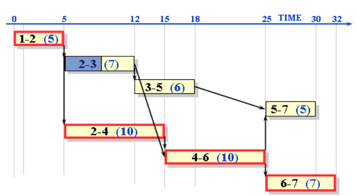

Figure 1: Time-Scaled Logic Diagram (Flood, 2005)

LINEAR SCHEDULING METHOD (LSM)

A characteristic of LSM technique and its variations is the typical unit network. Representative construction projects that fit into this category are a repetitive housing project or a high-rise building. (Lutz and Hijazi, 1993) Typical process production or flow line curves are depicted in Figure 2 and Figure 3. Figures 2 and 3 show the balanced and unbalanced production flow lines for a high rise building.

Linear construction projects often consist of repetitive processes which have different production rates. This phenomenon of production rate imbalance has the potential for negatively impacting project performance by causing work stoppages, inefficient utilization of allocated resources, and excessive costs. Production rate imbalance occurs when the production curves of leading processes intersect the curves of following process because of different production rates and insufficient lag between start times of processes.

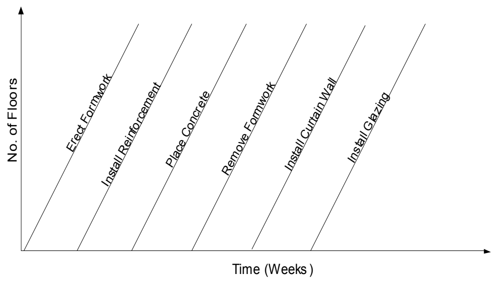

Figure 2 Balanced Production Curves for Repetitive Processes (Source: Lutz and Hijazi,1993)

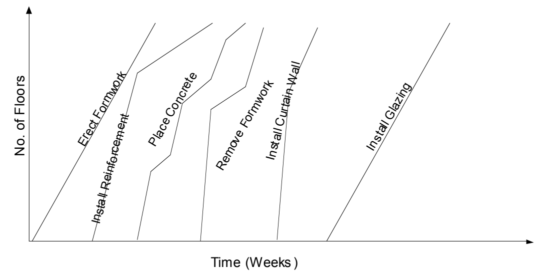

Figure 3 Non-balanced Production Curves for Repetitive Processes (Source: Lutz and Hijazi, 1993)

The major benefit of the LSM is that it provides production rate and duration information in the form of an easily interpreted graphical format. LSM plots for a linear construction project can be easily constructed, it can show at a glance what is wrong with the progress of project, and it allows for the detection of potential future bottlenecks.

Although the LSM can be used to aid in the planning and control of any type of project it is better suited for application to repetitive projects as opposed to non-repetitive projects. A limitation of this method is that it assumes that production rates are linear. Due to the stochastic nature of construction processes, the assumption that production rates of construction projects and processes are linear may be erroneous.

The above has reviewed scheduling methods in construction, such as the Gantt chart and CPM. Gantt chart is the most popular scheduling method in the construction industry for its overwhelming advantages over other scheduling methods. However the applications of Gantt chart do have problems in scheduling linear construction projects. The LSM and its variations are beneficial to linear construction. However, their application in construction industry has been limited. Table 1 shows a comparison of Gantt chart and LSM in scheduling repetitive projects. From the comparison, it obviously shows that LSM has more benefits than the linked bar chart method in scheduling linear and repetitive construction project. However, the existing LSM method and its variations have not solved the location interference problems in the underground utility project.

Table 1 Comparison of Linked Bar Chart and Linear Scheduling Method

	Linked Bar Chart	Linear Schedule Method
Time-based chart	√	√
Space-based chart	-	√
Time buffer	-	√
Space buffer	-	√
Identification of project progress	Sort of. Without identifying the exact location	√
Production rate	-	√
Flow of Labor	-	Different production rates indicate the flow of labor
Space Conflicts	-	-

RESEARCH OBJECTIVES

An underground utility construction company usually undertakes construction of several utility lines of a project, such as storm drainage line, sanitary sewer line, potable water line, gas line, etc. These utility lines may intersect with each other at some locations as design. Each line at the intersected location has its own elevation. Crews are assigned to work on each line. These crews may arrive in the intersected location simultaneously which cause work space conflicts. The current LSM and its variation do not indicate the interference location; predict the interference time, and how to avoid the work space conflicts to keep the crew work continuously. The objectives of this study are to explore a method:

- to indicate the interference locations for projects with two or more utility lines
- to predict the interference time of these utility lines
- to avoid the work space conflicts

The next section will introduce a method for sequencing the construction process in order to avoid interference between crews working on the same utility project.

PROPOSED METHOD ─ MODIFIED LINEAR SCHEDULING METHOD

The objective of this method is to overcome the main challenges in scheduling construction of two or more utility lines with different line layouts; identify construction interference locations, predict the interference time, and adjust schedule. The methodology depicts two utility lines with interferences. Suppose there are two utility lines, line 1 and line 2. Line 1 and line 2 intersect at one location. The engineering drawings require the elevation of line 2 is below the elevation of line 1 at the intersected point. This requires the construction of line 2 at the intersected point must be two days ahead of the construction of line 1. The following steps describe the modified linear scheduling method:

- Extract surveying data of each utility line from the engineering drawings. List the linear equation of each utility line and compute the intersected points. For example two groups of survey data are extracted from drawing respectively for line 1 and line 2, they are listed in Table 2. The items under "Line 1" column head are the stations of line 1. Two stations of line 1 are listed -- L1-1 and L1-2. And their surveying data are respectively (500,-5.00) and (2800, 5.00). It is similar to the Line 2. The linear equations about the two lines can be figured out by applying these two groups of data:

  $$y^1 = 0.0061x^1 - 8.0435 \qquad \text{(Equation 1)}$$

  $$y^2 = 0.0139x^2 - 23.333 \qquad \text{(Equation 2)}$$

  The intersected location can be identified accurately by solving these two linear equations. It is (1960.19, 3.91). Figure 4 displays the intersected location of two utility lines.

Table 2 Surveying Data from Engineering Drawing

Line 1	x	y	Line 2	x	y
L1-1	500	-5.00	L2-1	600	-15.00
L1-2	2800	9.00	L2-2	2400	10.00

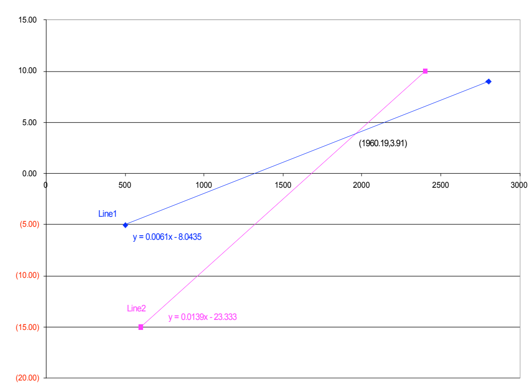

Figure 4:Linear Equations for Line 1 and Line 2

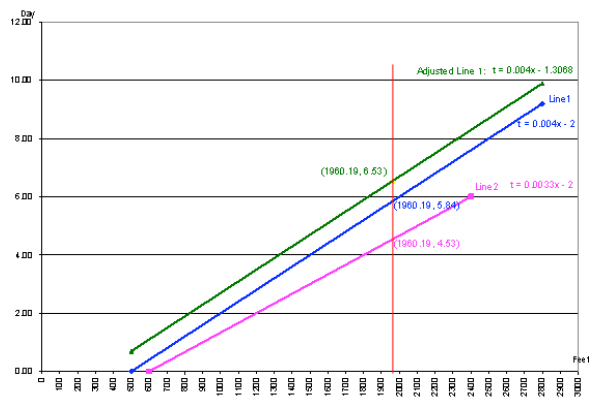

Figure 5: Interference Location and Time of Line 1 and Line 2

- Estimate the interference time of these two lines. Table 3 lists the production rate and length for each line. The construction duration of each line can be computed by dividing line length by production rate. The linear equations for drafting the LOB diagrams of these two lines are:

$$t^1 = 0.004x^1 - 2 \qquad \text{(Equation 3)}$$

$$t^2 = 0.0033x^2 - 2 \qquad \text{(Equation 4)}$$

Figure 5 depicts the LOB scheduling for line 1 and line 2. The blue line and pink line represent the planned schedule for line 1 and line 2. At the location x = 1960.19 L.F., the corresponding time for line 1 is 5.84 day and for line 2 is 4.53. Since the elevation of line 2 at the intersected location is lower than the elevation of line 1, this requires the construction of line 2 must be two days ahead of line 1. However, the time buffer between these lines at this point only 1.33 day (5.84 - 4.53 = 1.33 day). This requires the management personnel to adjust the schedule.

Table 3 Estimated Construction Duration

Line 1	L.F.	Productivity (L.F./Day)	Duration (Days)	Line 2	L.F.	Productivity (L.F./Day)	Duration (Days)
L1-1	0	250	0	L2-1	0	300	0
L1-2	2300	250	9.2	L2-2	1800	300	6

- Adjust the original schedule. In order to satisfy the construction constraints, line 1 must delay its construction at the intersected point. That means the construction time at the intersected point for line 1 is 6.53 days (2 + 4.53 = 6.53 days). In addition, the construction companies usually wants to keep the crew work continuously which keep the production rate constantly and avoid the setup time and learning time.

Therefore displacing the line 1 along the time axis to make the line 1 through point (1960.19, 6.53) with production rate 250 L.F./Day. The adjusted LOB linear equation for line 1 is:

$$t_a^2 = 0.004x_a^2 - 1.3068 \qquad \text{(Equation 5).}$$

APPLICATION OF THE MODIFIED LINEAR SCHEDULE METHOD ON FLORENCE PATH

INTRODUCTION OF FLORENCE PATH

The Villages is a huge residence community project located in Ocala, Florida. It is developed by HCC. It includes many units, such as Unit 97, Unit 98, and Unit 99, etc. Each Unit is composed of several hundred housing lots. The Villages Unit 97 is a typical project that HCC usually work on. HCC undertakes the construction of the underground utilities of the Unit 97. The utility lines include: Storm Drainage, Sanitary Sewer, Fire/Irrigation Water, and Potable Water. Florence path is one of streets in the Unit 97 community. The plan and profile of this street is shown in Figure 6. The storm drainage and the sanitary sewer lines are laid in the middle of the street, the irrigation line and the water line are laid on the each side of the street. As shown in Figure 6, the storm drainage line and sanitary sewer line intersect with each other at several locations. HCC assigns two crews to individually construct the storm drainage and sanitary sewer lines. The problem faced by these two crews is that of how to avoid the construction conflicts at the intersection locations in order to assure the work continuity of each crew. To solve this problem, several issues must be addressed:

- Exactly identify location of the intersection points
- Original linear scheduling for the utility lines
- Linear scheduling adjustment

The following describes the steps to solve this problem.

IDENTIFY INTERSECTION LOCATION

In order to accurately locate these intersection points, the coordinates, as shown in Table 4, of the storm drainage and the sanitary sewer stations on a plane are used. There are six storm drainage stations and identified as D97-27, D97-26, D97-25, D97-24, D97-23, and D97-22. The distances and displacement on y axis of these stations from referenced station 40+00.00 are listed in Table 4. The coordinates of the sanitary sewer line are also similarly listed. The data listed in Table 4 is shown in Figure 7. The x-axis represents the distance and the y-axis represents the displacement. The x-y relationship equation for each section of the storm drainage and the sanitary sewer lines are located along the line section.

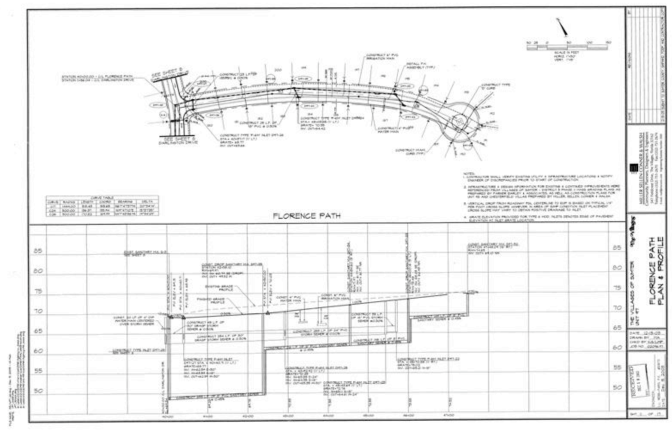

Figure 6: Florence Path Plan and Profile

Table 4 Coordinates of Storm Drainage Stations and Sanitary Sewer Stations (Note: LT (+): left turn, assumed as positive, RT (-) right turn, assumed as negative).

STREET	Storm Drainage Stations	Station #	Displacement LT(+), RT(-)	Sanitary Sewer Stations	Station #	Displacement LT(+), RT(-)
FLORENCE PATH	D97-28			Exist S-3		
	D97-27	4040.71	11.00	S97-35	4238.1	0.00
	D97-26	4037.17	-11.00	S97-34	4454.6	-5.00
	D97-25	4292.92	11.00	S97-33	4600.16	5.00
	D97-24	4303.45	-11.00	S97-32	4748.09	-16.00
	D97-23	4543.69	11.00			
	D97-22	4570.38	-11.00			

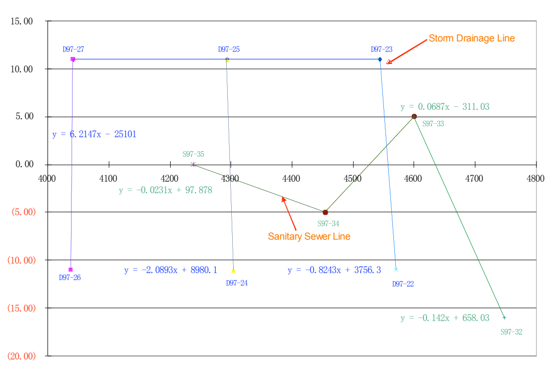

Figure 7: Storm Drainage Line and Sanitary Sewer Line in X-Y Coordinate System

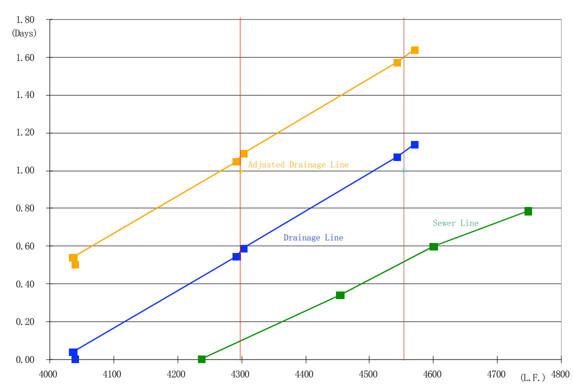

Figure 8: Linear Scheduling and Adjusted Linear Scheduling for Storm Drainage Line and Sanitary Sewer Line

The two intersection points are located for the drainage and sanitary sewer lines as follows:

$$y = -2.0893x + 8980.1$$
$$y = -0.0231x + 97.878 \qquad \text{(Equation 6)}$$

and

$$y = -0.8243x + 3756.3$$
$$y = 0.0687x - 311.03 \qquad \text{(Equation 7)}$$

The two intersection locations are (4298.82, -1.42) and (4554.68, 1.88).

LINEAR SCHEDULING ON FLORENCE PATH

Table 5 shows the information about each section of storm drainage line on the Florence Path: the length between two stations, average depth of section, pipe size of that section, and production rate and construction duration. Table 6 shows the information about the sanitary sewer line. Figure 8 shows the linear scheduling of these two lines constructed by two separate crews. The x-axis shows the location of utility line. The y-axis is the time axis. Both crews start working on the same day. Storm drainage line crew starts at location 4040.71 at day 0. Sanitary sewer line starts at location 4238.1 at day 0. Since the average depths of storm drainage line between two stations are various, the production rates between two stations vary. Therefore, the production rate line of storm drainage line in Figure 8 is several connected straight line instead of one straight line. Similarly it applies to drainage line. The two parallel vertical lines in Figure 8 indicate the two intersection locations which are (4298.82, -1.42) and (4554.68, 1.88).

Table 5 Production Rate and Duration for Each Section of Storm Drainage Line

Start Station	End Station	L.F. between Two Stations (L.F)	Average Depth (L.F)	Pipe Size (Diameter)	Production Rate (LF/Day)	Durarion of sections	Cumulative Duration (days)
D97-27	D97-26	23	5.14	18”	596	0.04	0.04
D97-27	D97-25	254	6.54	30”	501	0.51	0.55
D97-25	D97-24	25	5.92	18”	596	0.04	0.59
D97-25	D97-23	253	7.23	24”	525	0.48	1.07
D97-23	D97-22	35	7.68	18”	525	0.07	1.14
Total							1.14

Table 6 Production Rate and Duration for Each Section of Sanitary Sewer Line

Start Station	End Station	L.F. between Two Stations (L.F)	Average Depth (L.F)	Pipe Size (Diameter)	Production Rate (LF/Day)	Duration of sections	Cumulative Duration (days)
S97-35	S97-34	216	20.23	8”	640	0.34	0.34
S97-34	S97-33	146	9.71	8”	565	0.26	0.60
S97-33	S97-32	149	10.60	8”	790	0.18	0.78
Total						0.78	

ADJUSTED LINEAR SCHEDULING FOR FLORENCE PATH

Based on the information presented on Table 5 and 6, a Linear Scheduling diagram is shown in Figure 8. The lines show the planned schedule for the storm drainage and sanitary sewer line and are not straight lines which indicate that each section of the lines has different production rate. Both utility lines start from day 0. The storm drainage line will be finished on day 1.74 and the sanitary sewer line will be completed on day 0.78.

However, the two utility lines meet at locations (4298.82, -1.42) and (4554.68, 1.88). Figure 8 shows the interference locations. As planned, the storm drainage crew will arrive at the first and second interference locations at days 0.5899 and 1.1367 respectively and the sanitary sewer crew will arrive at the first and second interference locations at days 0.0949 and 0.5171 respectively. As required, the sanitary sewer line must be constructed ahead of the storm drainage line at the interference locations since its elevation is lower than the storm drainage line. In addition, the time buffer between them has to be at least 1 day. Under this constraint, the drainage line has to be displaced along time axis (y-axis) for 1 day. The upper line shows the adjusted planned schedule for the storm drainage line. It starts at day 1 right after the beginning of sanitary sewer line construction. The storm drainage crew will arrive at the location (4298.82, -1.42) and (4554.68, 1.88) on days 1.0994 and 1.6367 respectively. At the same time the planned schedule of sanitary sewer line remains the same position. Therefore the time buffers at the first and second interference locations are respectively 1.0051 day and 1.1196 days. This adjusted schedule satisfies the construction requirements, avoids the work space interference, and maintains the work continuity of the work crews.

On the other hand, by using the data in Table 5 and 6, a Gantt chart in Figure 9 shows the scheduling of Florence Path constructed by two crews. The linked Gantt chart illustrates how laborious the linked bar chart method is in planning the repetitive projects. The logical links of repetitive activities of each section do not make much sense in the presentation. Neither does it tell the location of the sections, nor does it present the production rate visually and directly.

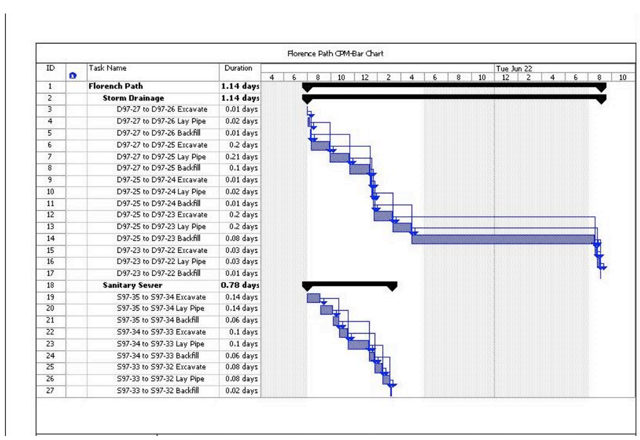

Figure 9: Linked Bar Chart Schedule for the Florence Path

This section introduces the scheduling two crews working on the Florence Path by using modified linear scheduling method and Gantt chart. Comparing to the traditional Linear Scheduling method, the modified linear scheduling method not only clearly presents the production rate of each utility line, the start time and finish time, and true location of individual schedule date, but it also identifies the interference locations and adjusts the schedule to meet construction constraints to avoid the construction interference and keep the crew work continuity. Table 7 shows the result through the comparison of three schedule tools over the real project – Florence Path.

Table 7 Comparison of schedule tools over the project – Florence Path

Compared Items	Linked Bar Chart	Linear Schedule Method	Modified Linear Schedule Method
Time-based chart	√	√	√
Space-based chart	-	√	√
Time buffer	-	√	√
Space buffer	-	√	√
Identification of project progress	Sort of without identifying the exact location	√	√
Production rate	-	√	√
Flow of labor	-	Different production rates indicate the flow of labor	Different production rates indicate the flow of labor
Space Conflicts	-	-	√

CONCLUSION

Construction companies are forced to be more efficient and achieve competitive operational advantage due to an increasingly competitive environment. The benefits of effective planning, scheduling and control of construction projects are obvious. Although popular scheduling methods, such as Gantt chart and Critical Path Method (CPM), are really beneficial to the construction industry, these methods are still criticized while applied to scheduling linear construction projects. The linear scheduling method (LSM) concept was introduced from manufacturing industry to solve the scheduling problems in linear construction projects. LSM and its variations are beneficial to linear construction in its presentation on productivity and project progress corresponding to true location. However, the current LSM and its variations have not studied the scheduling problems on several utility lines which happen often in the utility construction company. These utility lines intersect with each other at some locations as design. Each line at the intersected location has its own elevation. Crews are assigned to work on each line. These crews may arrive in the intersected location simultaneously which cause work space conflicts. The current LSM and its variation do not indicate the interference locations, predict the interference time, and how to avoid the work space conflicts to keep the crew work continuously. This study develops the modified LSM. It can identify accurately the intersected points, estimate the construction interference time, adjust the schedule to avoid the construction interruption, keep the continuity of crew work, and avoid the delay of construction and cost overruns.

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