Automation in Construction 27 (2012) 99–110

Contents lists available at SciVerse ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Advanced linear scheduling program with varying production rates for pipeline construction projects

Greg Duffy [a,1], Asregedew Woldesenbet [b], "David" Hyung Seok Jeong [b,*], Garold D. Oberlender [b]

[a] Engineering Administration, Chesapeake Midstream Partners, Oklahoma City, OK, United States
[b] School of Civil & Environmental Engineering, Oklahoma State University, Stillwater, OK 74078, United States

ARTICLE INFO

Article history:
Accepted 10 May 2012
Available online 15 June 2012

Keywords:
Project scheduling
Linear scheduling
Pipeline construction project
Production rate
Project management

ABSTRACT

Linear scheduling is known to have superior schedule management capabilities specifically in linear construction projects such as oil and gas pipeline projects which typically involve repetitive-work activities with the same crew and equipment throughout a project. This promising scheduling method, however, has not been actively used in practice historically, probably due to the aggressive marketing and the domination of Critical Path Method (CPM) in the U.S. market. This study discusses on developing an automated alignment based linear scheduling program for applying temporal and spatial changes in production rates. An actual 750 mile natural gas liquids pipeline project starting in Wyoming and terminating in Kansas is used to develop a production rate regression model and validate the program successfully. This newly developed program can provide a project team with the ability to better understand how changes in the project plan and schedule will impact production rates for the project.

1. Introduction

The pipeline construction industry is vital to the installation of underground infrastructure assets throughout the world. Pipeline construction projects involve continuous, linear activities such as grading, trenching and welding which are performed along the horizontal alignment of a facility. Although the industry spends large sums to update and create pipeline infrastructure around the world, the current scheduling technologies used to plan pipeline construction projects are not the optimum solutions for linear construction jobs. Linear construction projects typically involve repetitive-work activities with the same crew and equipment from one end of a project to the other. Often the only distinguishing feature for these linear-type projects is the rate of progress of activities [5]. As a result, the main concern of linear-type projects is usually assessing and achieving the optimum production rates necessary for timely completion rather than the sequence of activities. Therefore, a linear (time–location) scheduling technique would best suit linear construction projects such as pipeline projects for effective planning and scheduling purposes.

A linear schedule consists of a chart with location or stationing along one axis and time on the other axis. This time–location chart provides the perfect canvas for depicting the change of production rates when and where they occur. The power of a Linear Scheduling Method (LSM) does not lie in its ability to organize a project's individual activities, but instead it is gained from the multitude of graphical capabilities inherent to this method [5]. The use of graphics and the visual intuitiveness provided by the separate activity types enables project managers, schedulers, owners, and construction personnel to better visualize the plan of action and more easily communicate the plan to everyone involved with the project. Linear scheduling provides many advantages for pipeline projects including: a) the slope of an activity on a linear schedule (production rate) b) ability to show the gaps or obstacles in a project, which aids in risk management, c) better capability for analyzing claims than CPM, and d) a two dimensional picture of the job.

While much research has been performed to predict the production rate based on simulation, probability, or regression analysis [1,2,10,12,16,17], no significant research has been performed to determine when and where the production rates change along the project's alignment. A study conducted by Duffy et al. [5], however, showed the capabilities of linear scheduling that accounts for the variance in production rates by developing a Linear Scheduling Model with Varying Production Rates (LSM_{VPR}). The study showed that changes in production rates due to time and location can be modeled for use in predicting future construction projects. In addition, the study demonstrated a framework to apply the temporal and spatial changes in production rates along a horizontal alignment of a project by illustrating the complexity of construction through a time–location chart.

Although linear scheduling has been in existence for quite some time, its use in the U.S. pipeline industry has been very limited compared to bar charts and CPM. The aggressive marketing of CPM

* Corresponding author. Tel.: +1 405 744 7073.
E-mail addresses: greg.duffy@chk.com (G. Duffy), asreged@okstate.edu (A. Woldesenbet), david.jeong@okstate.edu ("D".H.S. Jeong).
[1] Tel.: +1 405 935 6259.

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doi:10.1016/j.autcon.2012.05.014

software developers has dominated the U.S. market and diminished the use of other scheduling techniques, such as LSM. This study focuses on developing an automated alignment based linear scheduling program based on the LSM_{VPR} for applying temporal and spatial changes in production rates for a given linear pipeline construction project.

The framework is supported by empirically derived production equations with appropriate variables as an input at the appropriate time and location in the project. This program would allow the scheduler to analyze the impact of various routes or start dates for construction and the corresponding impact on the schedule. It has the ability to utilize readily available data, such as weather and terrain information for predicting linear schedules. In addition, the program allows the construction team to visualize the obstacles in the project due to a new feature called the Activity Performance Index (API) that colors the linear scheduling chart by time and location to indicate the variation in predicted production rate from the desired production rate.

1.1. Linear Scheduling Method

Linear Scheduling Method (LSM) is a graphical scheduling technique which aims in the utilization of continuous resources of linear construction projects which involve repetitive activities like roads, tunnels, high-rise buildings and pipeline projects. Mattila and Park [15] define Linear Scheduling Method as visual representation for a repetitive project's construction plan which shows the plan's logic and relationships between activities. A linear schedule consists of a chart with location or stationing along one axis and time on the other axis. The positioning of location and time in the chart depends upon the type of construction project to better visualize the relationship between activities. For example, for a pipeline project, location is plotted on the horizontal axis to illustrate the horizontal nature of the construction, while high rise building projects depict location on the vertical axis to show the vertical nature of the construction. Fig. 1 shows a typical illustration of a Linear Scheduling Method for a linear project which consists of three activities.

In Fig. 1, activity 1 will commence on day 1 from the initial point of the project or Station 0. Activity 1 will take 30 days from station 0 to station 80. Activity 2 starts on day 15 while activity 1 has cleared the way to approximately station 40. Activity 3 will begin on day 60, once activity 2 is completed 75% for the entire project. Based on Fig. 1, all three activities occur along the entire project. The divergence of activity 1 and activity 2 and the convergence of activity 1 and activity 3 imply that

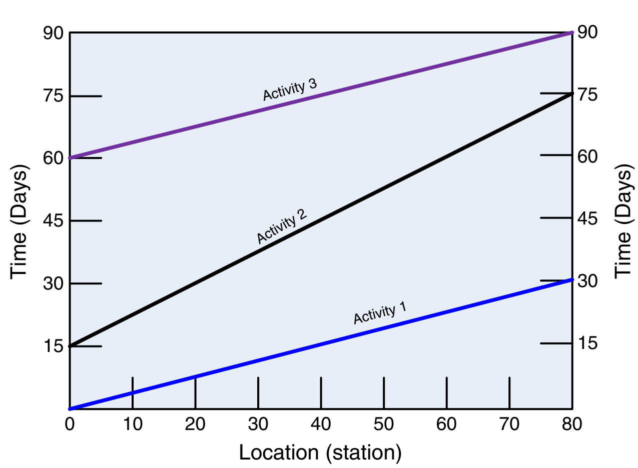

Fig. 1. Typical linear schedule.

activity 2 has a lower production rate than activity 1 and activity 3. Although Critical Path Method (CPM) is a common scheduling technique which uses a network logic diagram to display interdependencies, CPM has certain limitations on scheduling this linear project. The CPM will not be able to accurately model the continuity of resources; repetitive activities will be arbitrarily divided from location to location; activity rates of progress will not be indicated; and information on the location of the current work being performed will not be shown [3,7,15]. Therefore, LSM is one of the efficient techniques that should be utilized for scheduling linear repetitive construction projects.

1.2. Linear scheduling software programs

In 1981, Johnston introduced the term "Linear Scheduling Method" to the highway construction industry [11]. Johnston's work included the utilization of production rates, activity interruptions, buffers, calendar considerations, and project resources to develop linear schedules for highway construction projects. In 1986, Chrzanowski, Jr. and Johnston [3] added to Johnston's previous work by comparing and contrasting CPM and LSM utilizing an as-built highway schedule. Nine years later, Harmelink developed a model of linear scheduling in conjunction with an AutoCAD-based program [7]. His work focused on proving that computerization of linear scheduling is possible and illustrating procedures to identify the controlling activity path in the schedule.

In 1998, El-Sayegh developed a windows-based software package named "Linear Construction Planning Model" (LCPM) which comprises of deterministic and probabilistic models for calculating resource-based linear schedules [6]. The deterministic model can be used to produce a linear schedule based solely on user input. The probabilistic model may be used to produce a linear schedule based on Monte Carlo simulation, which accounts for variability and uncertainty of construction projects. In 1999, Liu defined a method for evaluating resource constraints in linear schedules [13]. He used a heuristic approach to the scheduling of resources that allows the user to input certain criteria for basing decisions on resource usage and allocation. In 2001, Yamin [19] developed an approach to analyze the cumulative effect of productivity rate variability (CEPRV) on linear activities in highway projects. Other Linear Scheduling Model studies include Vorster, Belivieu, and Bafna [18], Mattila [14], Harmelink and Rowings [7], Herbsman [9], Cosma [4], and Yen [20].

Successful implementation of Linear Scheduling Methods will require a software package for ease of calculation and schedule updating. A search for software packages that are capable of producing alignment-based linear scheduling revealed the following commercially available products; Chainlink (England), LinearPlus (England), Spider Project Professional (Russia), TILOS (England/Germany), and Time Chainage (England) [21–27]. The following section will briefly compare these programs. A set of criteria based on the data input and interface, output capabilities and adaptability to scheduling pipeline construction projects is used as shown in Table 1 to distinguish the LSM software packages as each has a unique set of advantages and disadvantages.

Of the software packages reviewed, almost all can be used for scheduling pipeline projects with varying success, but Linear Plus and TILOS displayed the most potential for use by the pipeline industry in the United States. Although both Linear Plus and TILOS produce high quality products, TILOS offers some significant advantages with its ability to draw linear schedules in a CAD-type interface and flexibility with outputting resource and cost information as part of the linear schedule. While Chainlink, Spider Project, and Time Chainage offer excellent solutions for producing linear schedules, they lack some basic features that are necessary to gain acceptance in the U.S. market. For instance, Time Chainage would be more advantageous for pipeline contractors in the United States if it allowed the display and printing of bar charts, CPM diagrams, and custom reports. The software package also does not allow the import or export of project data, which requires the user to re-enter data to obtain a bar chart