Automation in Construction 84 (2017) 315–322

Contents lists available at ScienceDirect

Automation in Construction

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

Computational algorithm to automate as-built schedule development using digital daily work reports

K. Joseph Shrestha[a], H. David Jeong[b,*]

[a] Department of Engineering, Engineering Technology, and Surveying, East Tennessee State University, Johnson City, TN 37614, United States
[b] Dept. of Civil, Construction & Environmental Engineering, Iowa State University, Ames, IA 50011, United States

ARTICLE INFO

Keywords:
As-built schedule
Daily work report
Schedule
As-built-schedule-automation

ABSTRACT

As-built schedules prepared during and after construction are valuable tools for State Highway Agencies (SHAs) to monitor construction progress, evaluate contractor's schedule performance, and defend against any potential disputes. However, previous studies indicate that current as-built schedule development methods are manual and rely on information scattered in various field diaries and meeting minutes. SHAs have started to collect field activity data in digital databases that can be used to automatically generate as-built schedules if proper computational algorithms are developed. This study develops computational algorithms and a prototype system to automatically generate and visualize project level and activity level as-built schedules during and after construction. The algorithm is validated using a real highway project data. The study is expected to significantly aid SHAs in making better use of field data, facilitate as-built schedule development, monitor construction progress with higher granularity, and utilize as-built schedule for productivity analysis.

1. Introduction

An as-built schedule represents the actual sequences and durations of construction activities of a project and it takes account of the change orders and schedule changes from the originally planned schedule [1–4]. For highway construction projects, contractors are generally required to submit the originally planned schedule before the construction of a project starts and update the project progress during the construction. As the owner of a highway project, State Highway Agencies (SHAs) also collect and document various work progress related information from the construction site on a daily basis to make a monthly payment to the contractor and to be prepared for resolving any possible claims.

An as-built schedule is an important tool to ensure that a project will be completed within the contract time [3]. It can be used to verify contractors' progress reports on ongoing activities [5]. Delays can be identified by comparing an as-built schedule with the planned schedule [3,6]. If any delay is identified early in the project, corrective actions can be taken to complete the project on time. When, a delay occurs during construction, an as-built schedule can be used to validate the contractors' claim for delay compensation or the request for time extension. An as-built schedule is also a documentation of durations and sequences of all activities. As such, it can also aid inexperienced schedulers in developing schedules for new projects [3].

Despite the importance of as-built schedules, as-built schedules are not typically developed and maintained throughout the project [3]. An as-built schedule is developed only at the end of the project based on memory and information scattered in various forms and field diaries that may be outdated [7]. Such methods involve manual efforts and are often inaccurate as some useful information may be lost before the end of the project [8,9]. Developing and maintaining as-built schedules throughout the project could be a cost effective approach as they will enable the project team to resolve any potential delay issues as they occur–which can avoid costly claims at the end of the project [3]. However, there is a lack of a systematic methodology to generate as-built schedules [1].

As-built schedule development requires the collection of work activity data over time. However, existing commercial scheduling systems do not allow for the collection and recording of actual activity data over time, but only allow for recording of the latest status of the project [3,10]. As such, current scheduling systems have a serious limitation to collecting data for as-built schedule development throughout the project duration.

Previous studies in as-built schedule development area are mostly focused on either a) utilizing unstructured data to manually develop as-built schedules or b) developing a new data collection system that is customized for developing as-built schedules [3,7,11]. The first approach is time consuming, tedious, and impractical for large scale

* Corresponding author.
E-mail addresses: shresthak@etsu.edu (K.J. Shrestha), djeong@iastate.edu (H.D. Jeong).

http://dx.doi.org/10.1016/j.autcon.2017.09.008
Received 4 April 2017; Received in revised form 27 August 2017; Accepted 13 September 2017
0926-5805/

projects if as-built schedules are to be developed on a regular basis. The disadvantage of the second approach is that many SHAs have already been collecting a vast amount of site activity data using digital daily work report (DWR) systems that can be used to develop as-built schedules if proper data extraction, processing, and visualization tools are developed. Thus, developing a new data collection system would result in wasting resources and doubling the field data collection efforts.

In this study, previous studies in this research area are reviewed and then, four different types of as-built schedules are defined. A systematic methodology that can generate those four types of as-built schedules using structured daily work report (DWR) data is developed and discussed. Based on the methodology, a computational algorithm to automate the data extraction, data processing, and visualization of as-built schedules is developed and demonstrated with real DWR data obtained from a SHA in the U.S. Value of this study and future research directions are also discussed at the end.

2. Prior studies

Prior studies conducted on developing as-built schedules from site records are quite scarce and limited. Most of them recognized the need and value of as-built schedules for delay claim analysis [4,6,12–15] and discussed either a) a process of developing as-built schedules with unstructured project data and information [3,10] or b) a data collection system customized for as-built schedule development [12,13,14].

Several studies are focused on developing as-built schedules by utilizing existing site records [3,10]. Such records include daily work reports, meeting minutes, progress report, payment records, testing records, submittal logs, and change orders. From those records, relevant data such as start and finish dates of work items and project milestone dates can be manually extracted. Activity dependencies can be inferred from the data. For example, the closeness between the finish date of an activity and start date of another activity can be used to infer a potential finish-to-start relationship. Based on those data and inferences, a commercial scheduling system can be used to develop bar chart to visually present as-built schedules. Such as-built schedules can become a valuable tool to defend against claims. However, the required data are scattered in multiple locations, consists of digital and paper-based formats, and hence the entire process could be costly and time consuming. This necessitates automation of the as-built schedule from an existing data.

Other studies are focused on developing methodologies to collect specific set of structured data that can be used to automate as-built schedule development [1,16–18]. In these studies, the required data to develop as-built schedules such as percentage of work completed on various work activities are recorded on a daily basis in a spreadsheet directly or using other methods such as Interactive Voice Response (IVR) or emails. Then, such data are used to develop as-built schedules in a spreadsheet or MS project. This approach has several limitations: a) going through multiple IVR prompts or wring an email to collect and organize a simple piece of field data may be impractical and b) spreadsheet based programs are not ideal choice to store and process data from multiple large size projects [1]. Additionally, collecting data in a new system specifically for as-built schedule development could be tedious for SHAs. As such, such studies generally tend to validate their methodologies using a hypothetical project data. Thus, while this approach reduces data processing time to develop as-built schedules, the significant amount of time is required to collect data.

Thus, prior studies have focused either on automating data processing or on utilizing existing data but not both. Those studies did not clearly recognize the possibility of using systematic field data that is already collected for other purposes such as contract payment. This thought is echoed by Elazouni and Salem [8] and Memon et al. [9] who stated that as-built schedules are possible to be developed, but, current methods are manual, slow, inaccurate, and expensive. Further, Kahler [10] argued that as-built schedules are prepared mostly based on an outdated information and only after construction is completed.

3. Daily work reports

SHAs have started to collect a significant amount of field data digitally such as ongoing construction activities, labor hours, types of equipment used, equipment hours, weather, and significant communications with contractors in Daily Work Report (DWR) system [19]. Site inspectors and resident engineers spend as much as 40% of their time in collecting those data [20]. SHAs have used various type of electronic DWR systems including AASHTOWare SiteManager, AASHTOWare FieldManager, Next Generation, and Field Operations [19]. Currently, 37 SHAs are using various electronic DWR systems based on a national survey [19].

DWR systems have been developed and used with the main objective of making correct payment to contractors and documenting field activity records as preparation for potential claims and disputes. The data attributes recorded in the DWR system have potential to be utilized for other purposes such as as-built schedule development, production rate and work item cost estimation, contract time determination, and contractors' performance evaluation [19]. However, most SHAs have not benefited from those potential applications possibly because of the lack of knowledge on those potential benefits, enabling methodologies, and automation processes.

DWR data attributes are typically linked to pay items or work items. In the U.S. highway industry, each SHA has developed and maintain an extensive list of work items primarily to facilitate the bidding process and contract administration under the typical unit price contracting mechanism. In most design-bid-build projects, those work items are directly used as work activities to develop a project schedule and finally determine the contract time. A typical set of data attributes collected in DWR systems can be classified into six categories: general information, work activities, weather information, equipment, labor, and remarks (Table 1) (19).

Among these six categories, the ‘work activities’ category contains directly relevant and sufficient data needed for developing as-built schedules. The basic data attributes required for as-built schedule development include: ‘Project ID,’ ‘DWR data,’ ‘Work item,’ and ‘Quantities of work performed.’

Table 1
Typical data attributes collected in DWR systems (19).

Category	Data attributes
General information	Project ID DWR date Work suspension and resume time Presence of contractor Day charging Approval
Work activities	Project ID DWR date Work item Quantities of work performed Location Contractors performing the work
Weather information	Low and high temperature, General weather (sunny, cloudy, wind etc.) Rainfall Ground condition (dry, wet, hard to work)
Equipment	Equipment name/type/id Number of equipment Hours used
Labor	Labor type Labor number Labor hours
Remarks	Significant communications with the contractor Significant events Delay cause