Fuzzy Scheduling of Repetitive Construction Projects

*I. Bakry[1], Dr. O. Moselhi[1] and Dr. T. Zayed[1]
[1]Concordia University,
Department of Building, Civil and Environmental Engineering
1455 de Maisonneuve Blvd. West.
Montreal, Québec, CANADA, H3G 1M8
(*corresponding author: bakryibrahim@yahoo.com)

Fuzzy Scheduling of Repetitive Construction Projects

ABSTRACT

Uncertainty is an inherent characteristic of construction projects. Neglecting uncertainties associated with different input parameters in the planning stage could well lead to misleading and/or unachievable project schedules. The objective of this paper is to present a new approach towards scheduling repetitive construction projects while accounting for uncertainty. The paper presents an algorithm that quantifies anticipated delays resulting from different sources of uncertainty in the form of fuzzy time buffers. Through inserting the time buffers in strategic places in a time schedule, the algorithm provides protection against those main anticipated delays. The presented algorithm comprises two integrated components, a scheduling component responsible for producing a basic Linear Scheduling Method (LSM) schedule with deterministic activity durations, and a buffer component that handles fuzzy buffers sizing and insertion. The presented algorithm offers four different buffer insertion techniques covering different cases of interrelations between successive activities. The algorithm is implemented in a spreadsheet application, which automates calculations, yet allows users to fine tune the algorithm to fit the project at hand. With a focuses on highway construction projects as an example of repetitive construction projects, this paper accounts for sources of uncertainty such as weather, site conditions, change orders and equipment related delays. A hypothetical case is studied and explained to further demonstrate how the proposed algorithm works.

KEYWORDS

Repetitive projects, fuzzy scheduling, time buffers, uncertainty.

INTRODUCTION

Repetitive construction projects are identified as construction projects formed of similar recurring units, each unit consisting of the same, usually small, number of sequential activities. The unique repetitive feature of repetitive construction projects paves the way for making considerable savings on time and cost. By maintaining the continuity of different crews and resources working on different activities in this type of projects several benefits could be achieved, such as maintaining a constant workforce by reducing firing and hiring of labour, retaining skilled labour, maximizing the use of learning curve effect and minimizing equipment idle time (Hassanein 2003). However, maintaining resource continuity forms an additional constraint when planning and managing a repetitive project. Based on this fact, using traditional scheduling and planning tools and techniques to manage repetitive projects has been widely criticized (Wong 1993). This calls for developing and utilizing special tools and techniques to properly plan and schedule repetitive projects.

Considerable work have been carried out for scheduling of repetitive construction projects, most of these efforts however, consider deterministic scheduling, despite the fact that uncertainty is an inherent characteristic of construction projects. Deterministic methods include Line of Balance (Lumsden 1968), Linear Scheduling Method (Johnston 1981), LScheduler (El-Rayes 1997) and HWPlanner (Hassanein 2003). On the other hand, less effort was dedicated to modeling of such uncertainties using simulation based approaches (Ashley 1980, Kavanagh 1985, Lutz and Halpin 1992, Chehayeb and Abourizk 1998 and Srisuwanrat 2009). Simulation based techniques share a number of limitations, they commonly depend on an external algorithm to maintain continuity which adds to the complexity of the scheduling process (Lutz 1990 and Yang 2002), they share the need for sufficient amounts of historical data, which is rarely available, and they provide solutions that are in agreement with the historical data utilized as input, but they don’t provide a schedule specifically protected against uncertainty factors that will particularly affect the project at hand.

BACKGROUND

A different approach that can be efficiently used to schedule repetitive projects under uncertainty is using time buffers to protect the schedule against different delays. The idea of using different buffers in the construction industry is not new. Time and resource buffers have been used for different purposes, for both repetitive and non-repetitive projects. One of the most common uses of buffers in construction scheduling is in scheduling repetitive construction projects using Line of Balance technique (LOB). LOB utilizes time buffers to represent technological limitations like the need to wait for a specific duration for poured concrete to harden before forms are removed. Also distance or space buffers are sometimes used to avoid crews overlapping and site congestions during execution. In search of a more objective approach for the delicate matter of buffer sizing, efforts were located in existing literature offering more objective solutions. However, these efforts were mainly carried out addressing non-repetitive projects. Non-repetitive projects started utilizing buffers after the introduction of Critical Chain Project Management (Goldratt 1997) which proposed utilizing time and resource buffers to protect projects schedules against various delays. Unfortunately, buffer estimation in Critical Chain is a purely subjective technique. But it paved the way for adopting more methodological buffer sizing techniques. Buffer sizing techniques located in literature can be grouped into two main groups.

The first group consists of techniques that build time buffer based on general representation of uncertainty, without addressing specific sources of uncertainty. These techniques either depend on historical data or fuzzy schedules to evaluate uncertainty inherent in the schedule at hand. Activities reflecting higher levels of uncertainty require longer time buffers to provide them with adequate protection and vice versa. Different measures have been utilized to evaluate the amount of uncertainty in an activity based on the statistical distribution of the duration, examples of which are the ratio of the standard deviation to the mean (Shou and Yao 2000), the coefficient of variation (Rezaie et al. 2009), and the difference between the 90% completion duration and the mean duration (Hoel and Taylor's 1999). Alternatively, the second group contains techniques that build buffers specifically to provide protection to activities while taking into consideration specific factors. These specific factors can be either related to the project environment, or to the project schedule. Factors related to project schedule don't cause delays by themselves; however, they magnify the impact of uncertainties on project schedule, hence, have an impact on the size of the needed buffer. Examples of schedule factors affecting buffer duration are activities location in schedule (Grey 2007) and activities durations (Grey 2007 and Farag et al. 2010), while project environment related factors comprises parameters reflecting the uncertainty in the law, economy, social and technological environments of the project (Zhang and Zuo 2011). To conclude, existing buffer sizing techniques based only on general representation of uncertainty require historical data, and don't guarantee producing a schedule fine-tuned to account for uncertainties affecting the project at hand. On the other hand, existing buffer sizing techniques built to address specific factors are scattered attempts, with no holistic approach addressing main sources of uncertainty. This paper presents a novel two-step algorithm for modeling uncertainties in repetitive construction projects. Uncertainty is modeled using fuzzy set theory in forming buffer times between successive activities and their respective insertions.

METHODOLOGY

In the context of this paper, buffers are built and inserted to protect against main delays affecting construction projects. Accordingly, a key step is to clearly identify causes of uncertainty. Construction projects involve many parties and are executed in highly dynamic environments, which results in a large number of uncontrolled variables that affect each process in each project. Accounting for each and every variable is an unrealistic approach. This is because it requires enormous efforts that are frequently based on subjective estimations, thus resulting in a too long scheduling stage and doesn't necessarily produce a schedule that would exactly match the project during execution. This paper aims at providing an algorithm that would introduce objectivity, in an open computational platform that allows the user based on their own respective experience to participate in modeling these buffers as will be described subsequently. The algorithm's flowchart is illustrated in Figure 1.

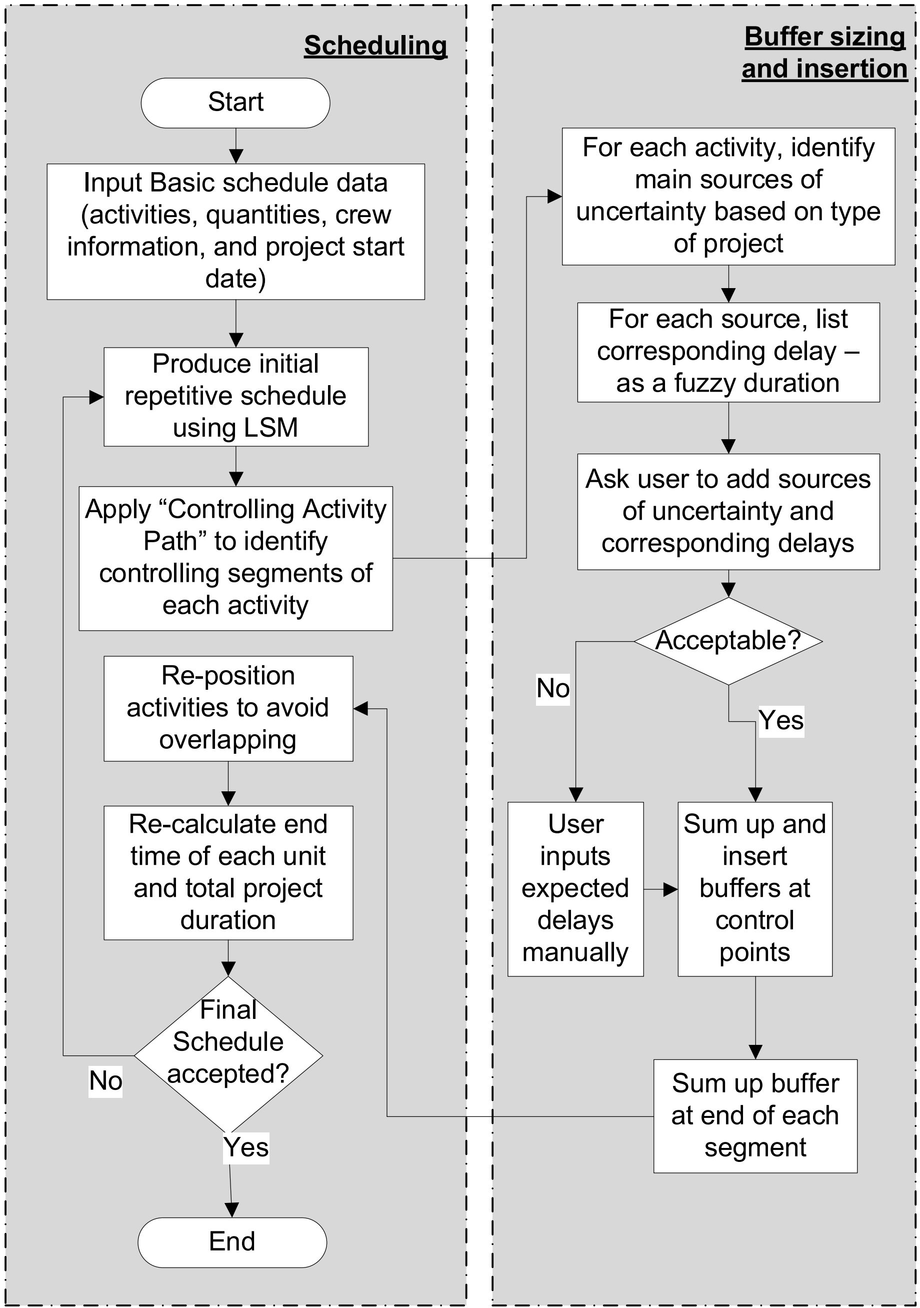

Figure 1 - Complete Algorithm's Flowchart

Buffer Sizing

The proposed algorithm focuses in application on a single type of construction projects, which are highway construction projects. However, the suggested algorithm is applicable to any repetitive construction project, given that the relevant sources of uncertainty and their respective delays are correctly identified. The algorithm integrates a list of sources of uncertainty, gathered from literature, pertinent to highway construction projects. This algorithm addresses sources of uncertainty at the activity level, while strategic risk factors extend beyond the scope of the current paper. Examples of the proposed factors are weather conditions, soil conditions, equipment related delays and change orders.

Delays expected to result from different sources of uncertainty for each activity at each unit are aggregated to form a single buffer for each segment represented by a fuzzy number. Later successive segments' buffers will be pooled and inserted in specific places in the schedule. This is done by suggesting to the user a list of sources of uncertainty according to the type of the project at hand. Then for each source of uncertainty in the list, the user expresses the anticipated resulting delay in a fuzzy number. The user is given the freedom of augmenting the list of uncertainties as he sees appropriate. Fuzzy triangular membership functions are being utilized to model the associated uncertainties with the above listed variables; this is due to their relative ease in data input and processing. The triangular distribution is commonly used in construction management for its simplicity and its need for less input in comparison to other distributions. The changes the user introduces to the list of suggested sources of delay and the corresponding delays are stored, which provides accumulative experience based on lessons learned from previous projects. The aggregated buffers are also triangular fuzzy numbers, and the user has the freedom of defuzzifying the buffer or utilizing it as a fuzzy number.

Buffer Insertion

Now expected delays are quantified and aggregated in a time buffer for each segment separately expressed in a triangular fuzzy number. However, final buffers inserted in the schedule will be built of the summation of more than one segment's buffer depending on successive activities rates. After buffers are inserted, successor activities must be shifted to accommodate the intermediate buffers inserted. The buffer insertion and activity re-positioning can take one of four forms, depending on the setting at hand. Each of these four forms is explained through the following 4 cases and illustrated through Figure 2.

The first case is when the predecessor activity (A) has a higher productivity rate than its successor (B). In this context, having a lower rate refers to the worst possible rate, based on calculating the duration plus any possible delays (worst case delay). The successor isn't affected by the predecessor, as it starts after the predecessor and proceeds at a slower rate and is positioned after the end of the first segment of the predecessor. The second case addresses the scenario where the one or both of the two activities is a non-typical activity. Non-typical activities are activities having different quantities for different units and/or are performed by crews with varying productivities, and are accordingly represented by a broken line with varying slope. In this case the least distance between the two activities is to be located, and this is where the cumulative buffer of the successor is inserted. This case is also found in Figure 2Figure, where activity (C) has a higher productivity for the first 3 units and then a lower productivity for the remaining two units. The least distance between activities (B) and (C) is after unit 3, so the buffer is inserted in this place, and its value is equal to the summation of the buffers of the 3 first units. The third case represents the situation where the predecessor activity (C) has a lower productivity rate than its successor (D). In this case, the successor activity is usually positioned according to the end date of the last segment of the predecessor. The buffers calculated separately for each of the segments of the predecessor are aggregated and inserted after the end date of the last segment; accordingly, the successor is scheduled backwards. The fourth and final case is the special case of the last activity in the schedule, activity (D). In this activity the buffer is placed after the end date of the last segment. This buffer provides protection for the project end date against possible delays affecting the last activity. Utilized time buffers are triangular fuzzy numbers, and they are being displayed as lines for simplicity.

After buffers have been inserted, the scheduling module shifts activities when necessary to accommodate the inserted buffers between activities. This guarantees that successor activities are protected against possible delays of their predecessors. This protection is effective as long as the actual delay is less than the inserted buffer. The project end date is then updated. Finally, the module checks if the user accepts the produced schedule or wants to go back and modify it.

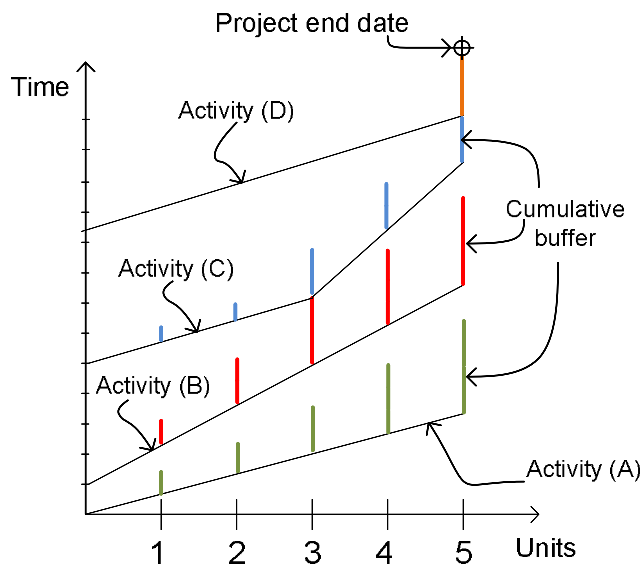

Figure 2 - Buffer Insertion Case 3

CASE STUDY

The presented algorithm was applied to a case study drawn from literature to demonstrate its use and basic features. The case study presented in literature (El-Rayes 1997) is a 15 Km three-lane highway project, consisting of 5 repetitive activities. These activities, in their order of precedence, are: (1) cut and chip trees; (2) grub and remove stumps; (3) excavation; (4) base; and (5) paving, and all precedence relations are finish to start, with no lag time. The project is divided into 15 segments of equal lengths, each is 1km. This project includes typical activities and non-typical activities. Typical activities are (4) base and (5) paving, as they have same quantities for each segment and same crew productivity for different crews. While activities (1) cut and chip trees, (2) grub and remove stumps and (3) excavation are non-typical activities, as their quantities change from one unit to another and also their different crews have different productivities. The included activities are all sequential except for activity (3) excavation; this activity is non-sequential as its starts by units 4 to 1, then units 5 to 15. The original project data can be found in (El-Rayes 1997), the initial schedule had a normal duration of 83 days.

As the original case study was not addressing uncertainties, some assumptions had to be made. Out of the 5 activities forming the schedule, it was found reasonable to assume that uncertainties would have the biggest impact on the earthmoving activity. This could be justified by the presence of unexpected soil conditions or by experiencing equipment related delays. Table 1 shows the original durations of the earthmoving activity and the fuzzy numbers used to model the anticipated delay for each unit. When utilizing the presented algorithm in a real case, the fuzzy buffer protecting against anticipated delays is entered by the planner based on his experience and evaluation of every source of uncertainty pertinent to the activity at hand. Moreover, Table 1 shows how buffers for each unit are aggregated.

Table 1- Activities Earthmoving and Base

Earthmoving												Base					
Unit	sequence	Crew #	Dur. (days)	Activity delay			Cumulative delay			Start Date	Finish Date	Unit	sequence	Crew #	Dur. (days)	Start Date	Finish Date
				a	b	c	a	b	c								
1	4	2	8	0.4	0.8	1.0	0.8	1.6	1.9	20.0	28.0	1	1	1	10	**29.9**	39.9
2	3	1	5	0.3	0.5	0.6	0.6	1.1	1.3	17.0	22.0	2	2	2	10	36.9	46.9
3	2	2	8	0.4	0.8	1.0	0.4	0.8	1.0	12.0	20.0	3	3	3	10	37.9	47.9
4	1	1	6	0.3	0.6	0.7	0.3	0.6	0.7	11.0	17.0	4	4	4	10	37.0	47.0
5	5	1	8	0.4	0.8	1.0	0.8	1.6	1.9	22.0	30.0	5	5	1	10	39.9	49.9
6	6	2	9	0.5	0.9	1.1	1.2	2.4	2.9	28.0	37.0	6	6	2	10	46.9	56.9
7	7	1	6	0.3	0.6	0.7	1.2	2.4	2.9	30.0	36.0	7	7	3	10	47.9	57.9
8	8	1	5	0.3	0.5	0.6	1.5	3.0	3.6	36.0	41.0	8	8	4	10	47.0	57.0
9	9	2	8	0.4	0.8	1.0	1.7	3.3	4.0	37.0	45.0	9	9	1	10	49.9	59.9
10	10	1	5	0.3	0.5	0.6	1.8	3.5	4.2	41.0	46.0	10	10	2	10	56.9	66.9
11	11	2	8	0.4	0.8	1.0	2.1	4.1	4.9	45.0	53.0	11	11	3	10	**57.9**	67.9
12	12	1	5	0.3	0.5	0.6	2.0	4.0	4.8	46.0	51.0	12	12	4	10	57.0	67.0
13	13	1	5	0.3	0.5	0.6	2.3	4.5	5.4	51.0	56.0	13	13	1	10	59.9	69.9
14	14	2	8	0.4	0.8	1.0	2.5	4.9	5.9	53.0	61.0	14	14	2	10	**66.9**	76.9
15	15	1	5	0.3	0.5	0.6	2.5	5.0	6.0	56.0	61.0	15	15	4	10	**67.0**	77.0

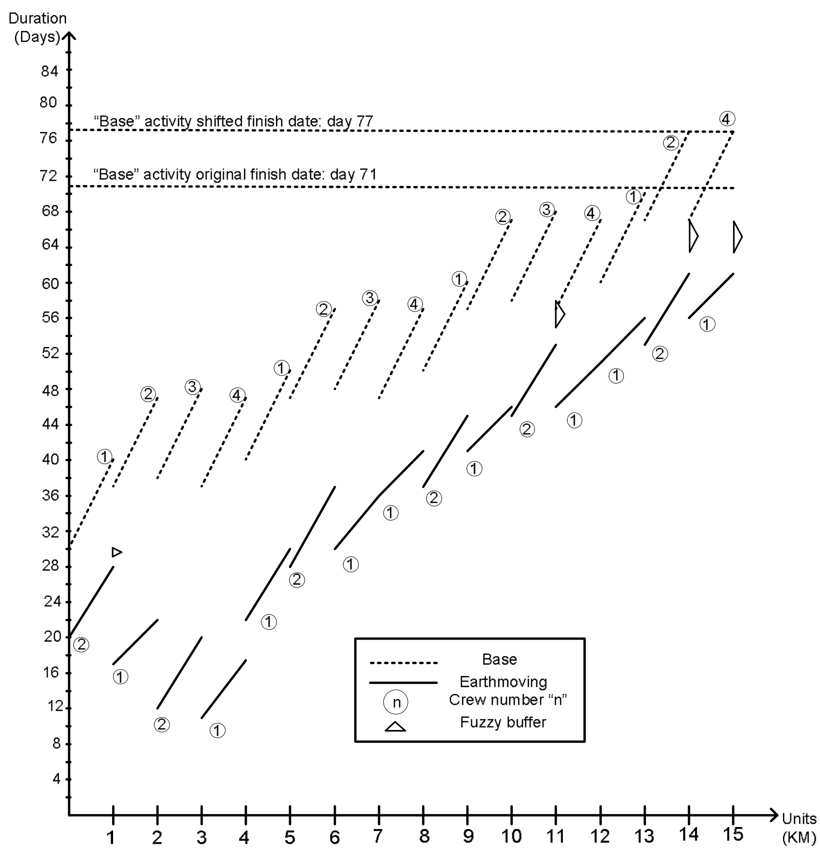

Figure 3 - Earthmoving and Base Activities

Buffers are cumulated in the same sequence of execution, and cumulated separately for each group of units executed by the same crew. Buffers are aggregated as triangular fuzzy numbers, and the planner has the choice to utilize these buffers in many forms. In the case at hand, a conservative approach has been adopted. This is done through utilizing the maximum value “C” of the fuzzy number forming the buffer. This value is added to the ending date of the Earthmoving activity to get the earliest starting date of the Base activity, thus forming a buffer between the two consecutive activities. The next step is to identify where will the buffers be inserted. This identification depends on the relation between the earthmoving activity and its successor the base activity. The base activity is executed by 4 crews, each works continuously without interruptions, and the point determining the starts of each crew’s work is preceded by an inserted buffer to protect this start point. The base activity progresses at a higher rate than its predecessor, the earthmoving activity. This necessitates that the point determining the starts of each crew’s work for the base activity is the finish date of the last units of the earthmoving activity, and the rest of the base activity is scheduled backwards. Accordingly, the beginning of the last unit to be executed by each crew is where the cumulated buffers will be inserted. However, there is an exception for the first crew of the base activity. This crew’s work’s start is determined based on the first unit of the earthmoving activity. This is due to the fact that the earthmoving activity is not executed in the serial order, but in the order explained earlier and listed in Table 1. Figure 3 illustrates how the 4 intermediate buffers are inserted between the 2 activities. It can be seen that the activity earthmoving didn’t change, while the activity base now ends on the 77th day instead of the 71st. Also the project’s total duration became 89 days instead of 83 days.

CONCLUDING REMARKS

This paper presented an algorithm for scheduling of repetitive construction projects under uncertainty. The presented algorithm performs two main tasks, the first task is deterministic linear scheduling and the other task is buffers sizing and insertion. The algorithm helps quantify different delays affecting the project activities in the form of fuzzy time buffers, then aggregates and inserts these buffers between successive activities to provide protection against various sources of uncertainty. The discussed algorithm offers a number of improvements to the existing scheduling techniques. It addresses the issue of scheduling repetitive projects under uncertainty based on modeling of time buffers rather than allocating them in a subjective manner. Modeling anticipated delays in isolated buffers helps quantify the delays and better visualize their impact on the schedule. Also the use of triangular fuzzy numbers facilitates data input. The ability to store changes made by the user to the list of the suggested delays and their corresponding magnitudes provides accumulative experience based on lessons learned from previous projects. The analyzed case study illustrated how time buffers can be introduced without compromising work continuity. The case study demonstrated the algorithm’s capability of incorporating typical and non-typical activities, as well as non-serial activities.

REFERENCES

Ashley, D. B. (1980). Simulation of repetitive-unit construction. *Journal of the Construction Division, 106*(2), 185-194.

Chehayeb, N., & Abourizk, S., (1998). Simulation-based scheduling with continuous activity relationships. *Journal of Construction Engineering and Management.* 124, 2, 107-115.

El-Rayes, K. A. (1997). *Optimized Scheduling for Repetitive Construction Projects,* PhD Dissertation, Concordia University, Montreal, QC, CA.

Farag, M., Gehbauer, F., & Bhatla, A. An integration of a buffer assessment model based on fuzzy logic with LPS™ for improving highway construction process. International Group of Lean Construction 18th Conference, 264-273.

Goldratt, E. M. (1997). *Critical chain* North River Press Great Barrington, MA.

Grey, J. R. (2007). *Buffer Techniques for Stochastic Resource Constrained Project Scheduling with Stochastic Task Insertions Problems,* PhD Dissertation, University of Central Florida, Orlando, FL, USA.

Hassanein, A. (2003). *Planning and scheduling highway construction using GIS and dynamic programming,* PhD Dissertation, Concordia University, Montreal, QC, CA.

Hoel, K., & Taylor, S. G. (1999). Quantifying buffers for project schedules. *Production and Inventory Management Journal, 40*, 43-47.

Johnston, D. W. (1981). Linear scheduling method for highway construction.*Journal of the Construction Division*, *107*(2).

Kavanagh, D. P. (1985). SIREN: A repetitive construction simulation model. *Journal of Construction Engineering and Management, 111*(3), 308-323.

Lutz, J. D. (1990). *Planning of linear construction projects using simulation and line of balance*. Unpublished PhD Dissertation, Purdue University, Lafayette, IN, USA.

Lutz, J. D., & Halpin, D. W. (1992). Analyzing linear construction operations using simulation and line of balance. *Transportation Research Record*, 1351, 48-56.

Rezaie, K., Manouchehrabadi, B., & Shirkouhi, S. N. (2009). Duration estimation, a new approach in critical chain scheduling. *Modelling & Simulation, 2009. AMS'09. Third Asia International Conference on,* 481-484.

Senior-Brown, B. A. (1993). *A study of the planning and integrated cyclic analysis of serial system operations*. Ph.D. Thesis, Purdue University, West Lafayette, IN, USA.

Shou, Y., & Yao, K. (2000). Estimation of project buffers in critical chain project management. *Management of Innovation and Technology, 2000. ICMIT 2000. Proceedings of the 2000 IEEE International Conference on, , 1 162-167 vol. 1.*

Srisuwanrat, C. (2009).*The sequence step algorithm: A simulation-based scheduling algorithm for repetitive projects with probabilistic activity durations. PhD Dissertation, Michigan University, MI, USA*

Wong, W. C. M. (1993). New generation of planning structures. *Journal of Construction Engineering and Management, 119*, 196.

Zhang, X., Cui, N., Bie, L., & Zuo, F. (2011). Buffer sizing method with considering effect of various uncertainties based on fuzzy comprehensive evaluation method in critical chain scheduling. *Emergency Management and Management Sciences (ICEMMS), 2011 2nd IEEE International Conference on,* 566-569.

Yang, I. (2002). Repetitive project planner: Resource-driven scheduling for repetitive construction projects. *PhD Dissertation, The University of Michigan, MI, USA*