AN INTEGRATION OF A BUFFERING ASSESSMENT MODEL BASED ON FUZZY LOGIC WITH LPS™ FOR IMPROVING HIGHWAY CONSTRUCTION PROCESS

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ABSTRACT

Highway construction projects have special attributes, owing to their usual execution in an environment characterized by varying degrees of uncertainty. This paper aims at testing the vital role of buffers design and management for increasing the reliability of scheduling as well as mitigating the influences of uncertainty on the construction project from the Lean Construction viewpoint.

This research paper develops a sound and rational integration system framework of Last Planner System™, as a production control tool, and a proper buffering assessment model called FLBM, which is based on fuzzy logic system. FLBM also focuses on increasing the reliability of buffers to match the actual degree of variation by considering a set of factors contributing to variability in the execution of a project. Simulation of the model is accomplished in MATLAB using sample data to verify the model theoretically. A case study was simulated through FLBM to validate the credibility of the model practically. The results of the simulation gave a positive feedback, reflecting the actual conditions. A set of scenarios were simulated using the FLBM in order to validate the model. In a further step, the proposed model was also employed in the course of the implementation of LPS™.

KEY WORDS

Last Planner System, Buffer design and management, Fuzzy logic, Highway.

INTRODUCTION

Construction process has different types of waste that transforms a good project into a bad one. Determining the reasons of waste has usually been a challenge for construction managers because most of the reasons are often invisible. Many researchers, (Lorterapong, *et al.*, 1996,El-Rayes, *et al.*, 2001,Pan, *et al.*, 2005,Ko, 2006), have advocated that the construction of highway projects has unique features due to its execution in an environment characterized by varying degree of uncertainty, hence, such projects experience numerous challenges as they strive for success.

This work focuses on the planning and control for highway projects, particularly in Egypt. Nearly 105 highway projects with total investments of US$ 82.7 billion will be constructed within the next three years in the Middle East. Egypt has approximately US$ 20 billion of the total highway investments. The current management process of the highway construction in Egypt commonly results in much waste. Characteristics of this management process were addressed by (Farag, *et al.*,

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2008) as listed in Table 1. Waiting and idle times were found to be the most critical waste resulting in delays in highway construction projects. The source of such a waste was traced to the inability to deal with uncertainty. Exacerbating this situation is the funding shortfalls plaguing most Egyptian highway agencies.

Table 1: The existing management features of the highways construction in Egypt

Shareholders	Characteristics
Organization	○ Hierarchical organization; command order flow. ○ Collaboration among project members is invisible.
Scheduling	○ Deterministic and not continuously updated;
Execution	○ Personal relationships play a vital role in management;
Process	○ Regular (short-term) meetings are rarely organized.
Resources	○ Lack of resources requirement plan.
Workforce	○ Lack of communication between manager and sub-employees; ○ Unfair distribution for workers incentive.
Uncertainty	○ Inefficient dealing with unforeseen conditions. ○ No buffers mechanism in planning / schedules.
Others	○ Bureaucracy/RED TAPE.

Tackling the problem of waiting and idle time the plaguing construction process is the focal issue of this research paper. Therefore, the research aims at examining the vital role of buffers design and management in eliminating such waste. The main questions promoting this research are stated through a set of *3-HOWs* as follows:

- How is the mitigation of uncertainty impacts ideally established?
- How can reliability of scheduling be enhanced?
- How lean can lean buffers be?

RESEARCH OBJECTIVES

In order to answer these three questions, this paper focuses on developing an integrated system framework to provide collaborative actions between the LPS®, and a **F**uzzy-**L**ogic-**B**uffering **M**odel (FLBM), which is developed to match the buffer size to the actual degree of variation in order to enhance the reliability in the scheduling.

BUFFERS DESIGN AND MANAGEMENT (BDM)

In most fields, buffers are as a significant solution to mitigate variability as they allow two activities to proceed independently.

Buffer design in construction has been studied quantitatively for over 10 years and numerous publications are available based on PERT, Goldratt, or CCPM. Nevertheless, they have not supported a sufficient treatment because most of the approaches identifying the buffer size presented in sources were very empirical. Such inefficiency often results in unnecessarily adding time (waste), and consequently, fails to protect the project schedule performance. The first shortcoming of the previous attempts is the inability to figure out probability distributions for activity durations because of a lack of historical data, especially for highway constructions. The other drawbacks associating with buffer design approaches are lack of activity characteristics, the actual degree of variation, and the degree of confidence in the duration estimate. In order to tackle the first shortcoming regarding imprecise and uncertain information, *Fuzzy Logic* (FL) has been proven to be an effective method to process such information, and to simulate the high-level human decision-making process (Ko, 2006). In 1965, Zadeh introduced the concept of a fuzzy set as a model of a vague fact. Since its inception, the theory of fuzzy sets has evolved in many directions, and is currently finding applications in a wide variety of fields. In the construction field, fuzzy set theory was developed specially to deal with uncertainties that are not statistical in nature. The first attempt addressing the project-scheduling problem from a fuzzy viewpoint was by Chanas and Kamburowski (1981). Afterwards, several researchers have used fuzzy logic for construction project planning and scheduling. The use of fuzzy logic theory in buffer design has been extensively discussed in the field of IP networks control and management. However, attempts to the use of fuzzy logic for buffer design regarding construction management are still few.

Buffer management is a process, which deals with buffers in order to enable an efficient management for the execution of projects, predicting the shape of project once it gets started without a specific deadline. In addition, it focuses on schedule management, avoids unnecessary distraction, and allows recovery planning to take place when needed, but well before the project is in a trouble. No doubt, some of the most significant deficiencies in buffer design and management are how to precisely size buffers, and then allocating them properly.

The heart of Lean Construction is the waste elimination, yet it does not sound very convincing. Hopp and Spearman pointed out the fact that while lean is certainly concerned with driving out waste, it represents a more fundamental framework for enhancing efficiency. Therefore, a production process performed in lean only when it is accomplished with minimal buffering. As described by (Hopp, *et al.*, 2004), buffers are "evil" because they hide construction problems. Thus, the heart of lean production of managing buffers is to reduce the inventories/buffers to reveal the problems and to deal with them. The most famous articulation of this philosophy was Taiichi Ohno's recommendation to 'lower the river to reveal the rocks'; i.e., to periodically reduce the buffers of inventory, capacity, time and money that absorb waste-causing variation in order to stress the production system and reveal where it needs improvement. At the lower water level, proper estimation of buffers can reduce the unnecessary inventories due to the actual status, and may consequently reveal the rocks (problems) which need to be removed and enable managers to deal with them.

Managing buffers from the lean viewpoint is an improvement cycle as suggested by Ballard (2008), as shown in Figure 1. He remarked that once variation is reduced, the next step is to match buffers to actual variation. Matching buffers with variation involves first selection of the right type of buffer, and then proper sizing of the buffer. Reducing variation and matching buffers to the remaining variation stabilizes the production system. The next step is to deliberately de-stabilize it by reducing buffers below what is needed to absorb the existing variations. Since there is not much time to react to fluctuations in uncertainty at the operational level as well as at the strategic level, many phenomena are too variable to base a long-term decision on. Hence, the suitability of managing buffers at the tactical level (lookahead) planning to deal with uncertainty was emphasized (Eck, 2003,González, *et al.*, 2009a). One of the recent attempt with respect to the focus of this research is the Multiobjective-Analytic-Model (MAM) (González, *et al.*, 2009b). The MAM focused on design and management WIP buffers in repetitive projects based on a Rational-Commitment-

Model (RCM) throughout the three levels of planning. The design of appropriate WIP Bf sizes through the MAM was based on a Simulation-Optimization (SO) model using statistical selection procedures. The historical date-based PDF of the activity duration is the main element in the SO model, which cannot be calculated with activities characterized by imprecision.

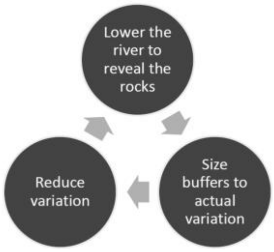

Figure 1: Improvement Cycle (Ballard, 2008)

RESEARCH METHODOLOGY

The methodology involved in this research consists of three stages: firstly, modeling of the *FLBM*, secondly, validation of this model theoretically and practically through conceptual scenarios and real case study of a highway project in Egypt, and eventually, the proposed framework of the integration system of FLBM and LPS.

FUZZY LOGIC BUFFERING MODEL (FLBM)

Data used in developing the FLBM depends on findings of experts emanating from both the review of the related literature, and a form of survey. This survey was conducted to find out the actual data that may assist in making the model more trustworthy and credible. The survey was divided into in-depth interviews and an online questionnaire[4], which has been limited to only academic researchers and companies working in the highway construction sector. Analysis of survey formed the input variables of the model and the rules that were established to link between the inputs to the output. Modeling process of FLBM is based on a set of criteria:

- Input variables are independently defined, and linguistically expressed.
- Triangles and trapezoidal membership function types are used in FLBM.
- Modeling process is simulated using MATLAB program.
- Fuzzy inference system (FIS) is based on Mamdani’s method.
- “*OR*” operator is used for the composition, whereas “*AND*” is used for the combination with the fuzzified inputs.
- *Centroid* technique is employed to come up with crisp output number.

Input/output variables

Input variables of the Degree of confidence, duration, the degree of uncertainty, and the degree of influence have the same membership function, which is linguistically described using the triangle. As shown in Figure 2, it has five linguistic values that are very low (*VL*), Low (*L*), medium (*M*), High (*H*), Very High (*VH*).

[4] URL: http://www.kwiksurveys.com/online-survey.php?surveyID=HKJJH_ed285d92

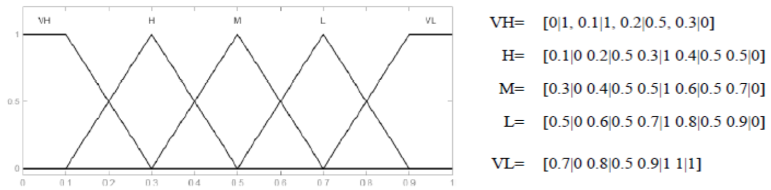

Figure 2: Membership function for input variables with the mathematical expressions

Buffer time is the output variable in FLBM, which is represented by the membership function as shown in Figure 3. Sizing of buffers is expressed through five sub-sets of buffer sizes. It may be of very short, short, medium, large and very large size depending upon the degree of variation and activity characteristics.

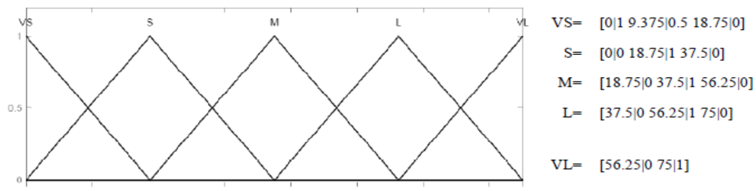

Figure 3: Membership function for the output variable of buffer

FLBM rules

Rules are developed in order to describe the interrelationship between the probability of input variables and their consequent impact on the buffer size. These rules are representations of expert knowledge and are often expressed using syntactical forms. A set of fuzzy rules, consisting of 625 rules for FLBM, were identified by interviewing experts in the highway construction sector. For instance, ***IF*** *duration* is very small (VS) ***AND*** the *degree of confidence* related to its estimation is very low (VL) ***AND*** *uncertainty level* has a medium effect (M) ***AND*** the activity has a very high *influence degree* (VH) ***THEN*** the consequent buffer size should be very large.

FLBM VALIDATION: THEORETICAL

When no large data sets are available, assessing model performance and fine-tuning of the system is based on experts' judgments. By using different real inputs and observing crisp outputs, judgment is possible by experts. They can assess several scenarios and conclude whether the performance of the model is (not) reasonable (Azadi, *et al.*, 2009). Therefore, a set of twelve-scenarios were simulated for calculating the buffer size as listed in Table 2. For instance, as depicted in Figure 4, a user enters all four inputs variables independently. Each input is categorized into major and minor intervals in order to be more accurate. The major intervals for each input consists of the subsets of each membership function, while the minor intervals describes closely the effect of each input.

Table 2: Conceptual scenarios

Nr	Duration		Degree of Confidence		Uncertainty level		Influence Degree		Buffer
	Major	Minor	Major	Minor	Major	Minor	Major	Minor	**(%)**
1	VS	LE	Very H	LE	VS	LE	VS	LE	**6.0 %**
2	S	SL	M	SL	VL	N	S	SL	**28.0 %**
3	M	SMO	H	SMO	S	N	VL	N	**46.9 %**
4	M	SMO	H	SMO	S	LE	VL	N	**31.1 %**
5	L	LE	LO	MO	L	N	VS	SL	**18.8 %**
6	L	N	VH	N	M	SL	V L	N	**49.8 %**
7	L	N	V H	N	S	SL	VS	N	**16.3 %**
8	L	MO	V H	SL	M	SL	VS	N	**25.2 %**
9	S	LE	H	LE	VS	MO	VS	MO	**18.8 %**
10	S	LE	LO	SL	M	MO	VS	MO	**46.9 %**
11	VS	LE	VLO	LE	VS	N	S	MO	**37.5 %**
12	VS	LE	VLO	LE	VS	MO	S	MO	**56.3 %**

VS: very small, S: small, M: medium, L: large, N: normal, Very large, SL: slightly less, and MO: more, VLO: Very Low, LE: less, LO: low, MO: more, H: high, VH: very high, and SMO: slightly more.

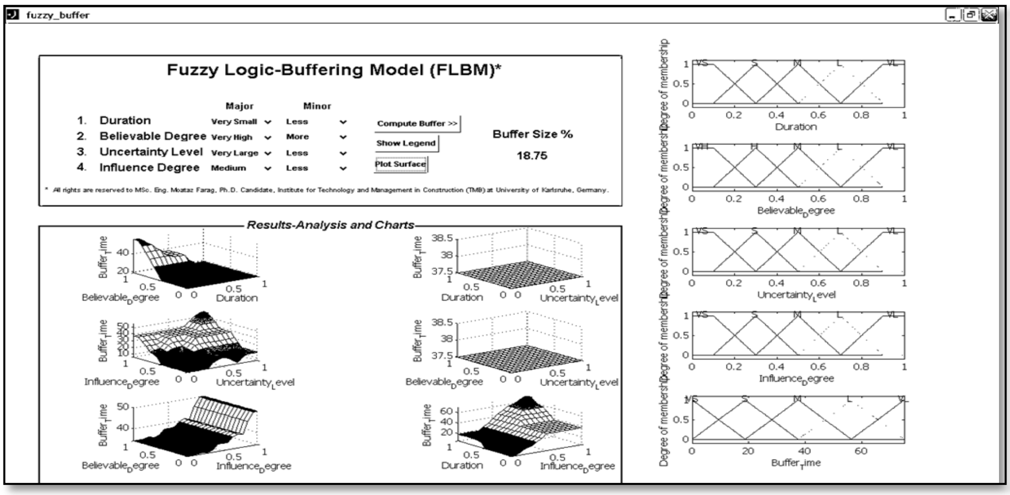

Figure 4: FLBM's User Interface

Scenarios' Analysis

A vital observation from the developed model is attained by comparing the scenarios no. 1 and 12. Even though both have the same uncertainty level and the influence degrees; the degree of confidence associated with the estimate of duration is more in scenario no.1. The buffer times computed by the model show a resounding difference (6 % in scenario 1 whereas 56.3 % in scenario 12). This clearly emphasized the significant role of the degree of confidence in the estimation of the buffer times. Another significant observation comes by comparing scenarios no. 6 and 7. Both have similar durations and the degree of confidence, the difference arises in the uncertainty level and the influence degree. In scenario 6 the uncertainty level is medium with a very large influence degree whereas in scenario 7 the uncertainty level is small with a very small influence degree. This difference in the uncertainty level results in a considerable difference in the computed buffer times (50 % in scenario 5 to 16 % in scenario 6). This goes to show that the uncertainty level and the influence degree of the activity also play a crucial part in the determination of buffer times.

FLBM CREDIBILITY: CASE STUDY

In order to test the reliability of the model, a case study of a highway construction project was simulated using FLBM. The total length of project is around 113 kilometers and 32 meters width with an approximate budget of 35 million US$. As depicted in Figure 5, FLBM provides a more realistic buffered plan. Namely, by focusing on some facts of the case study;

ES=AS=1/5/2007, EF=1/7/2009……….(Total estimated duration= 26months)
AF=27/05/2010 ……….(Total Actual duration= 37 months)

The reliability of the master plan had been = 1-((37-26)/37) = 70.2 %. However, after using FLBM the reliability of the master plan was = 1-((37-(26+9 buffers)/37) = 94.6 %, which means that FLBM could increase around 24% in the reliability of scheduling. Hence, the implementation of FLBM to the study project emphasizes its benefits on the master schedule. In addition, FLBM does not provide a set of unstudied additional times to activities. It indeed allots a specific buffer time to an activity appropriate to the activity characteristics and uncertainty levels.

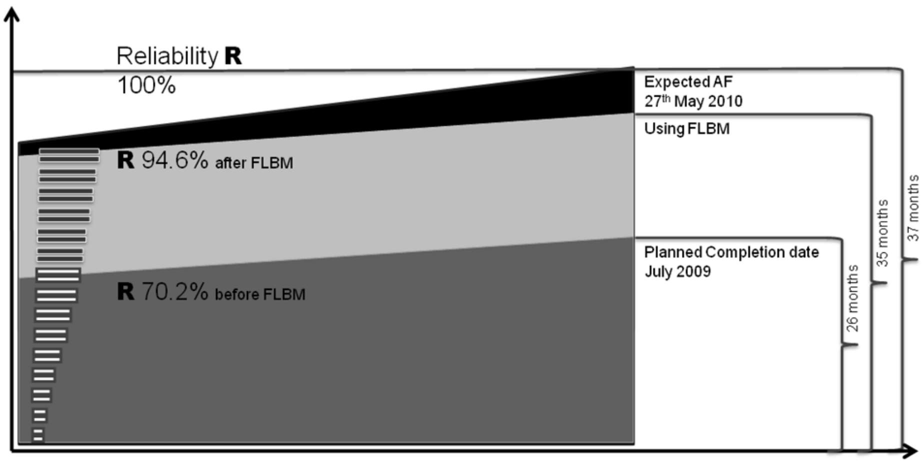

Figure 5: Impact of using FLBM on the master plans

A comparison to Goldratt method, as an example of the previous approaches, was established from sizing and allocating buffers throughout activities on the critical path (CP). The outcomes of both methods emphasized the agreement in their results. Namely, FLBM predicted around 9.5 months extra as a whole project buffer, whereas Goldratt gave around 13 months as an entire project buffers. Nevertheless, the reliability of each method could be concluded from the distribution of buffers not only from the total size of buffer. In Goldratt method, sizing buffers depended mainly on the span of durations regardless the characteristics of the activity. With FLBM, as well as focused on sizing buffer, it focused also on doing a well distribution of buffers according to the actual circumstances associating each activity individually. The difference between Goldratt and such methods from one side, and FLBM from the other side that the former considers only the duration of activity in sizing buffers, whereas the latter considers many intrinsic factors in sizing buffer.

INTEGRATED SYSTEM FRAMEWORK

A sounder and more rational integrated system framework based on the FLBM as a buffers design tool, and LPS as a production control tool is developed. The proposed system moves towards a successful achievement of an improvement cycle discussed by Ballard (2008). FLBM as an element of this system is responsible for dimensioning buffers to match the actual degree of variation. Through LPS, optimization of pre-dimensioned buffers and re-dimensioning them is in iterative demonstrated to obtain the optimal lean level of buffering.

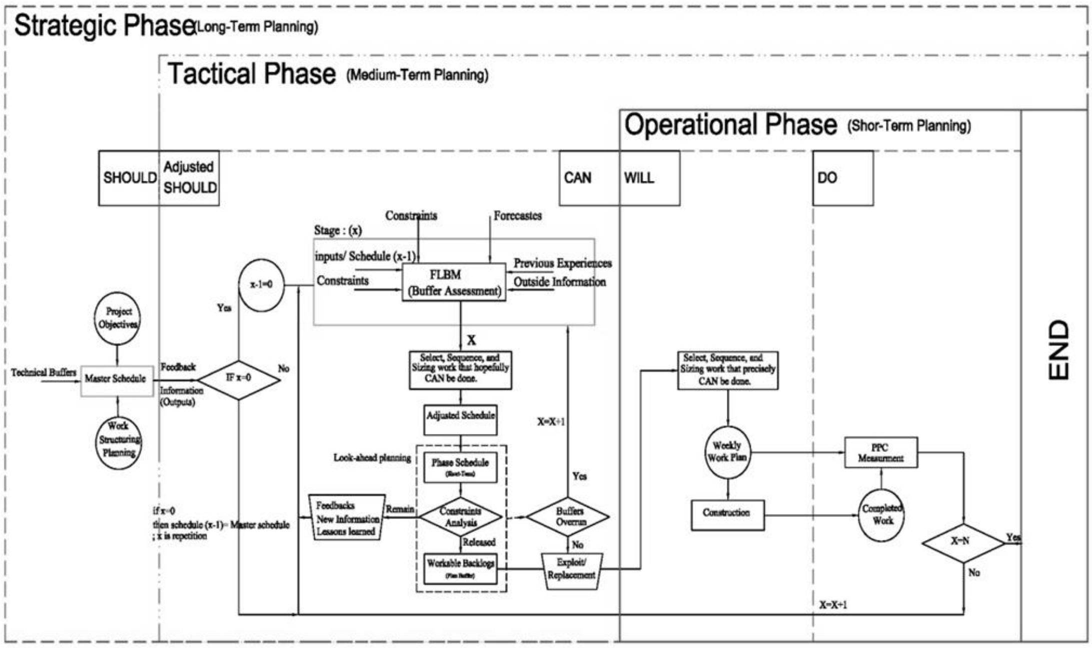

Figure 6: The proposed integration system framework

To understand the integrated system, knowledge of the construction environment is the first priority. Hence, acquiring a sufficient knowledge for making a decision should be established through observation. This requires recognition of data, and feedbacks from various other phases to make the system framework in a loop form. As depicted in Figure 6, the integration of FLBM and LPS is employed through three levels of planning: Strategic planning (Long-Term), Lookahead or Tactical planning (medium-term), and work plan or operational planning (short-term), which are progressively more detailed from top to bottom. At a lookahead plan or tactical plan level, design of buffers is more dynamic where uses the FLBM in a loop/cycle form. At this level, we re-dimension the buffers and then adjust the master schedule as well as the phase schedule to adjust SHOULD. This scheduling level considers a smaller time window and it is closer to the work front where a higher detail for the construction process is represented. The feedback from the site goes directly through the FLBM at x sequence for updating the lookahead plan.

From the buffered master plan formed at strategic level, a lookahead plan is defined for 3-6 weeks. Based on the updated feedback from the closer view to the construction site, actual resources, and the experts' judgment, an updated buffers size is calculated by rerunning the FLBM with new inputs. As a consequence, the decision-makers adjust the schedule by adjusting SHOULD. In this stage the designed buffers, are incorporated in a buffered lookahead plan, can be different due to the stochastic nature of process, with different uncertainty levels. Thus, the buffered lookahead plan is represented with more realistic information, therefore, the planning date may be more accurate. That may make up for the lack of production information (historical or experts opinion) at the beginning of the project execution.

At the operational level, make-ready process should be further established by releasing constraints from activities and then being in a workable backlog. The status of consuming buffers should be monitored. Buffers that could be taken off, as unused buffers, should be exploited by their replacement with workable backlogs (a plan buffer). Whereas the buffers being overrun are recalculated through the FLBM to refine them in the lookahead plan. Afterwards commitments (free of constraints) are assigned to be performed (CAN). Feedbacks received from this stage should be considered for the next phase of a lookhead planning. From the latter level, we get a set of tasks that CAN be done. Promise is the key to convert what CAN be done into WILL be done. At this phase of operational level, the importance of keeping Will or keeping promises takes place. Furthermore, the work performed involves even more sensitive variation and dynamic conditions. Modeling framework is then developed to allow for predicting the progress of weekly work using a historical site information is developed. Lastly, performing work execution is measured in terms of PPC.

CONCLUSION

In traditional approaches, the buffers time has often been incorrectly determined leading to an immense loss of money and time (waste). Hence, FLBM focuses upon enhancing the reliability of both buffers and scheduling according to the actual degree of variation. Simulation using FLBM model was carried out in MATLAB using sample data to verify the model theoretically. The paper advocated that sizing buffers be essentially influenced by characteristics of each activity, and its influence degree under variability. Furthermore, the duration alone does not affect the size of buffers; the degree of confidence also has to be considered while estimating the size. Likewise, uncertainty in general has no effect without the vulnerability of activities to its impact.

The benefits gained from the implementation of FLBM to the study project through the master schedule were emphasized. Obviously, implementation of FLBM through the scheduling phase increased the level of reliability for the Master Schedule from 70% to 94%. In addition, through the integrated system, LPS optimizes the buffer size through the levels of planning to match the actual circumstances of the construction process. Optimization of buffers as well as of the entire process was performed in a loop or cyclic manner through the integration between LPS and FLBM in one system. Although the implementation of the integrated system could not be demonstrated, a general consensus on its ability has been achieved. The use of the integrated system through a studied project might play an important role in removing the wasted time that is hidden in buffers before the refining process, and consequently reduce the project completion time. These benefits of the system are advocated by the highway construction practitioners, who emphasized on the optimization of the completion date for the studied project to around seven months and around eleven months before the buffered schedule at level three and actual schedule at level four respectively. From this point, it is recommended to continue this system for future researches, which should test the improvement in the efficiency of construction projects using integration between buffer model and LPS in a single unit in order to achieve a more significant success. In addition, immense potentials for implementing the integration system to pilot projects should be established. For other construction sectors, FLBM will probably not be as efficient as for highway construction. Hence, it is further recommended for future researches to refigure the fuzzy rules set as well as the domain of the output variable of the buffer size to match the other sectors.

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