A Bridge between Increasing Reliability and Reducing Variability in Construction Work Flow: A Fuzzy-Based Sizing Buffer Model

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Abstract—Diverse attempts have shown that variability is a well-known problem in construction projects, which leads to a general deterioration of project performance on dimensions of both project cost and planning efficiency. The main aim of lean management is to eliminate any forms of waste from construction process and then to stabilize the work flow of the process. The strategy of buffer management is the key-play making in the lean goal, which able to absorb variability from the construction process. Inefficient sizing buffers often results in unnecessarily added time (waste), and consequently, fails to protect the project schedule performance. So, this work focuses on developing a Fuzzy Logic-based an appropriate buffers size evaluation algorithm, to match the imprecise nature of the construction process. Besides, as common, considering the level of uncertainty, the characteristics of the activity are taken into account. The assessment of the reasoning of the model performance is achieved through simulation of a set of scenarios. The research argues that the buffer size is incompletely and inefficiently evaluated in the absence of any variables.

Index Terms—buffer management, fuzzy logic, scheduling, lean management, variability

I. INTRODUCTION

Construction projects have obviously special, unique attributes, owing to their complicated execution in an environment characterized by varying degrees of variability. Diverse attempts have shown that variability is a well-known problem in construction projects, which leads to a general deterioration of project performance on dimensions of both project cost and planning efficiency. A consensus of the obsolescence of such conventional theory has been built due to the limited view of the construction management to a project as a transformation-based endeavor. Unlike this conventional way of thinking, a construction project needs in real to be in more widely viewed.

Lean thinking in construction provides a new possibilities as well as tools for eliminating all forms of waste encountering construction processes. The theory beyond lean construction views projects in tripartite view; as a Transformation (T), as a Flow (F) of the raw material

and information through various processes, and as a Value (V). In this new view of management, a profound implication of TFV concept changes the conceptualization of construction to three complementary ways [1]. Therefore, a growing number of companies, overall the globe, have commenced to recognize the benefits that could be achieved from implementation of lean construction concepts. However, a number of studies in countries worldwide have revealed that applications of lean principles to construction process have been neither completely efficient nor effective, because of a set of critical barriers. The vast majority of these barriers are in respect of the failure to use appropriate approaches revealing a form of incompatibility between problems and methods, which is crucial to support the implementation of Lean Construction LC [2]-[4].

II. PROBLEM STATEMENT

Construction is looked at as a complex phenomenon and it is shown that construction is indeed very complex, non-linear and dynamic, not only seen by the individual project but from an industry and a social perspective as well. Bertelsen 2003 [5] discussed that complex systems were not always chaotic or completely chaotic. However, he showed that the perception of the project's nature as ordered and linear is a fundamental mistake, as the dynamics of the surrounding world is not taken into account. For instance, the weather forecasts is unpredictable for more than say five days ahead, whereas the weather as such – in the form we call climate – is fairly predictable over a large number of years. The weather stays within certain limits even though it in its details shows a chaotic behavior [5].

The problem that be addressed by this work, is to how manage construction complexity and make the flow of construction process more predictable as well as reliable. Admittedly, the more reliable workflow the more reduction of variability. Lean construction by eliminating waste optimizes the system responsiveness and consequently reduces variability. Many researchers demonstrated the fact that improving performance of the process by permitting a proactive actions as required can be arrived at through flexibility in pre/post responding to variation [6]-[8].

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III. HYPOTHESIS

Obviously, given a well-structured schedule, if everyone keeps to his part of the schedule, the work flows smoothly and maximum performance is achieved. If a schedule has sufficient slack in the impacted activities, changes may not impact end dates. When there is little or no slack, players are pressured to make it up in accelerated production. The buffers issue has been advocated as a significant solution to withstand variability for different construction fields [9]-[12]. Espino et al 2012 [9] reported that the variability experiencing earlier stages in the work has been resulted from the unstudied variation in estimates of task duration, which has been developed in pull planning session. With schedule buffers, as Fig. 1 illustrates, the buffered performance curve will be in a certain place between the planned and closed to the actual performance. Through pulling the performance from a planned to the buffered adjusted schedule, the efficiency ε of the performance

increases from the planned-based efficiency $\left(\epsilon = \frac{P_A}{P_P}\right)$ to

the buffered-based efficiency ($\varepsilon = \frac{P_B}{P_P}$). Where the P_A,

 P_B , P_P are the task performance in cases of actual, buffered and planned respectively. Consequently, the increase in performance efficiency results in increase in reliability and decrease of the variability. As moreover presented in Fig. 1, a reduction in inventory level from i_1 to i_2 is obviously tangible. In addition, the waiting time t_1 is shortened to a time buffer designated t_2 .



Figure 1. Variability vs reliability relation by using buffers

Thus far, buffers between operations are an important tool that allows two activities to proceed independently. Using buffers can so serve at least three functions in relation to shielding work by providing a workable backlog [13]:

- 1- To compensate for differing average rates of supply and use between the two activities;
- 2- To compensate for variability in the actual rates of supply and use;

3- To allow differing work sequences by supplier and using activity

Undoubtedly, some of the most significant deficiencies in Buffers Management (BM) are how to precisely size buffers and then allocate them properly matching with the degree of variation. Inefficiency in the sizing of buffers often results in unnecessarily added time (waste), and consequently, fails to protect the project schedule performance. So, the main hypothesis of this work, to answer the question of this research, is to test evolving a proper buffers size evaluation algorithm through planning process to absorb variability.

The management of buffers from the lean viewpoint is an improvement cycle as presented in Fig. 2 that can be clearly also shown in the behavior of the dashed lean curve in Fig. 1. Ballarad (2008) [14], discussed the improvement cycle that once the reduction of variability takes place by using buffers, the next step is to match buffers to actual variation. Matching buffers to the degree of variability involves first selecting the right type of buffer–inventory, capacity, time or contingency– then locating the buffer appropriately in the process, and finally sizing the buffer. Reducing variability and matching buffers to the remaining variation stabilizes a production system. The next step is to deliberately destabilize it by reducing buffers below what is needed to absorb existing variation.



IV. LITERATURE REVIEW

Goldratt's method of estimating average activity time and project buffer has been regarded as improper in most cases because of its arbitrary assumption. It neglects to take into account not only the different sources of variability, but also the characteristics of diverse projects as well as activities. Recently, in 2006, Gonz dez et al. [15] presented a conceptual model framework, for the design of buffers. Client requirements, general characteristics of the project, required estimated costs and duration, needed resources, available resources, and other initial requirements are such examples of inputs to their conceptual model. The same year witnessed also one of the pioneering attempts towards the improvement of fuzzy buffer management. That research was demonstrated to protect precast fabricators against the impact of demand variability. A time buffer was then

analyzed using fuzzy logic to avoid fabricators losing capacity. Since some characteristics of a project indeed have more chances inducing demand variability, three factors were identified in the buffers assessment model based on the experts' survey: the function of the building, the number of ownership, and the type of used precast element used [12]. A year later, a fuzzy method was tested to estimate the buffer size in critical chain scheduling to reduce variability in the workflow. The test was to analyze the principles of project buffer under the comparison of critical chain and classical network scheduling techniques. This test came up to that improvement of flow reliability as well as stability in scheduling is significantly tangible through using fuzzy techniques for buffers evaluation [16]. Ko and Chen 2012 [17] developed a time buffer evaluation model to deliver products on time. They analyzed the time buffer from a pessimistic perspective in a crashing scenario. In 2013, Bakry et. al. [18] constructed an algorithm, in order to help for quantifying different delays affecting the project activities in the form of fuzzy time buffers, then they aggregated these calculated buffers to be inserted between successive activities, to provide protection against various sources of variability.

The previous studies have arrived at the remarkable weakness of traditional schedule buffer to guarantee the completion time of either an activity or a project. Nonetheless, some criticisms have been raised that existing buffer evaluation techniques have been based only on general representation of variability require historical data, and have not been able to guarantee producing a fine-tuned schedule to account for uncertainties affecting the project at hand. Moreover, almost recent studies have been moved towards increasingly considering different sources of uncertainties [17], [18]. However, flaws of the previous traditional methods concerning time buffers are still resulting from the lack of consideration for many factors affecting on buffers size. Different influence levels of variability, due to variation of activity characteristics, and the degree of confidence associated with the activity duration assumption are some examples of these factors.

These studies advocated the fact that beyond approach based on fuzzy logic, others explicitly need a massive pile of data to be able to draw initially the probability distribution function. However, in many cases, the distribution of probability of an activity is impossible to determine because of the lack of historical data. Despite the remarkable success of using the fuzzy logic approach in evaluating buffers properly, more efforts are still needed that are focused on the influence of many factors on many activities in a project such as weather, labor skills, equipment, and management quality [19].

V. RESEARCH METHODOLOGY

The high-level decision-making process can explicitly be simulated through fuzzy logic concepts, in which imprecise modes of reasoning is sought to make a rational decisions in both uncertain and imprecise environment. Thus far, the fuzzy logic provides approximate but effective descriptions highly complex, ill-defined, or difficult- to analyze mathematical system [17].



Figure 3. FLSB schema (adapted from [20].)

The overall objective of this work is to develop a methodology for a proper buffers assessment model, which is based on fuzzy logic system. This model focuses on increasing the reliability of sizing buffers by considering the intrinsic factors contributing to variability in the execution of a project. Simulation of the model is demonstrated in MATLAB using the Fuzzy Logic toolbox. In the following lines of this part, the methodology of fuzzy logic-based model for Sizing Buffers (FLSB) is explained. The main objective of this model is to evaluate schedule buffers size properly to protect the execution of a project against the impact of both variability and imprecision. Most of shortcomings addressed by many researchers as highlighted in the former literature are taken into the consideration in building the FLSB. Essentially, there are seven fundamental stages in the FLSB construction of as shown in Fig. 3. These are:

- 1- Determining the input and output variables;
- 2- Defining linguistic values;
- 3- Constructing membership function;
- 4- Determining the fuzzy rules:
- 5- Determining the approximate reasoning;
- 6- Computing crisp output (defuzzify); and
- 7- Assessing the model performance.

A. Conceptual and Modeling Framework

Analysis of the literature review results assist in forming the input variables of the model and the rules established to link the inputs and outputs. The triangular distribution is commonly used in construction management for its simplicity and its need for less input in comparison to other distributions [12, 16-18, 21]. In addition, the overlapping for the linguistic variables was chosen at the completeness of 0.5 ($\mathcal{E} = 0.5$), as referred in Fig. 4. At this level of the overlapping, certain robustness may be given to the fuzzy controller. Moreover, at the completeness $\mathbf{\mathcal{E}} = 0.5$, for every value of the input there is always a dominant rule with a membership grade for that input exceeds than or equals to 0.5. Explicitly, when completeness decreases there are more regions in the universe of discourse characterized by a low maximal truth degree of the rules they activate, thus creating the risk of an inefficient control. When completeness increases, there are zones characterized by some useless, if not harmful, redundancy [22].



Figure 4. Typical membership function and the degree of overlapping

The main criteria are controlling the FLSB are as follows:

- Input variables are independently defined.
- Input / Output variables are linguistically expressed in the shape of membership functions.
- Fuzzy inference system (FIS) is based on Mamdani's method.
- Moreover, "OR" operator is used in the composition process to get the maximum value, whereas "AND" is used in the combination with the fuzzified inputs according to rules to establish a rule strength as formulated in (1) and (2) respectively.

$$\max(A,B) = \begin{bmatrix} v & a_1, a_2 \end{pmatrix}, v & b_1, b_2 \end{pmatrix}, v & c_1, c_2 \end{pmatrix}, v(d_1, (1))$$

$$\min(A,B) = [\land a_1, a_2), \land b_1, b_2), \land c_1, c_2), \land d_1, \qquad (2)$$
$$d_2), \dots \dots]$$

• Centroid is employed to come up with the crisp output number as formulated in (3).

$$z = \frac{\sum_{j=1}^{q} Z_j u_c(Z_j)}{\sum_{j=1}^{q} u_c(Z_j)}$$
(3)

where z is the center of mass and u_c is the membership in class c at value z_j .

B. Input/ Output Variables as General

This model is based on a set of inputs to enable buffer sizing to be more realistic and reliable. There are four input variables: the duration of activity, the degree of confidence, variability level, and the degree of influence.

Evidently, considering the activity duration alone is not the most crucial element in buffer sizing. Activity duration may play an intrinsic role in sizing buffer properly when the degree of confidence associated with the duration is considered simultaneously. Some of the activities have duration either quite less or much more than the actual duration. The degree of confidence assists in amending this feeble estimate of duration. The term of degree of confidence indicates the deviation degree of the planned durations from what should have been estimated. For example, an activity has a planned duration of three weeks, whereas the experts advocate that the estimated duration is not reliable because it should have approximately been a couple of weeks. Hence, the ratio of the deviated estimates (one week) to the normal activity duration equals 33%, which indicates a low degree of confidence. Thus, the greater degree of confidence, the smaller deviation, and vice versa. Activity duration is described into five linguistic subsets; very short (VS^*) , short (S^*) , medium (M^*) , long (L^*) , and very long (VL^*) duration. Whereas, the degree of confidence has five linguistic values of very low (VL), Low (L), medium (M), High (H), and Very High (VH).

On the other hand, every uncertain event has a different influence level on the activity duration. Each activity has own characteristics that leads to a unique response under the same variability level. For instance, weather impact, as an uncertain event, has a higher

impact level on an activity, than the impact of design errors. So, the level of variability as an input variable should be associated with the degree of influence variable. The membership functions of the level of variability and degree of confidence are linguistically described using the triangle. Each has five linguistic values of Very Low (VL^{**}) , Low (L^{**}) , Medium (M^{**}) , High (H^{**}) , Very High (VH^{**}) .

The membership function of all input variables are in similar mathematically expressed as (4 to 8):

$$VS^* | VH | VL^{**} = [0|1, 0.1|1, 0.2|0.5, 0.3|0]$$
(4)

$$S^* \mid H \mid L^{**} = \begin{bmatrix} 0.1 \mid 0.0.2 \mid 0.5, 0.3 \mid 1.0.4 \mid 0.5, 0.5 \mid 0 \end{bmatrix}$$
(5)

$$M^* \mid M \mid M^{**} = \begin{bmatrix} 0.3 \mid 0.0.4 \mid 0.5, 0.5 \mid 1, 0.6 \mid 0.5, 0.7 \mid 0 \end{bmatrix}$$
(6)

$$L^{*}|L|H^{**} = \begin{bmatrix} 0.5|0, 0.6|0.5, 0.7|1, 0.8|0.5, 0.9|0 \end{bmatrix}$$
(7)

$$VL^* | VL | VH^{**} = [0.7|0, 0.8|0.5, 0.9|1, 1|1]$$
 (8)

Sizing of buffers, as the output variable of the model, is expressed through five subsets of buffer sizes. Namely, it may be of very short, short, medium, large and very large size. Equations (9-13) describe the subsets of buffers time's membership functions.

$$VS = \begin{bmatrix} 0 | 1, 9.375 | 0.5, 18.75 | 0 \end{bmatrix}$$
(9)

$$S = \begin{bmatrix} 0 | 0, 18.75 | 1, 37.5 | 0 \end{bmatrix}$$
(10)

$$M = \begin{bmatrix} 18.75 | 0,37.5 | 1,56.25 | 0 \end{bmatrix}$$
(11)

$$L = [37.5|0,56.25|1,75|0]$$
(12)

$$VL = [56.25|0,75|1]$$
(13)

C. FLSB Rules

As stated above, rules are developed in order to describe the interrelationship between probability of input variables and their consequent impact on the buffer size. These rules are representations of expert knowledge and are often expressed using syntax forms. A set of fuzzy rules, consisting of 625 rules for FLSB, are demonstrated. A sample of the rules created for the model is represented in Fig. 5. As commonly known, rule execution weights provide the model designer with a way of a concentrating force in the rule set. In most of the fuzzy models you can weigh the importance of rules by supplying a weight multiplier. By default, rules have weight of [1.0]; this indicates that the truth inherent in these rules is multiplied by [1.0], and as a result, the force of those rules is not reduced. However, consider the instance when a rule has a weight of [0.8], then the truth value of that rule is multiplied by [0.8], which, reduces its force by 20%.

D. Scenarios and Analysis

Having available a large set of input-output data, the performance of the system can be evaluated and parameters of the system can be fine-tuned in order to achieve a low generalization error. In such a data-rich situation, a training set is used to fit the models, a validation set is used to estimate the prediction error for model selection and a test set is used for assessing the generalization error of the final model chosen. If, like in our case, no large data sets are available, the best way to assess model performance and fine-tune 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 [20]. Hence, on the basis of the abovedeveloped model for evaluating the buffer size, some simulations were run for calculating the subsequent buffer size (Table I).



Figure 5. Fuzzy rules for FLSB| MATLAB interface

For instance, when the input activity was estimated to be of very small duration, of very low degree of confidence, and has very high effect on both variability level and the influence degree, the buffer time calculated was 69% of the activity time. Taking another scenario based on both major and minor choices, even though both scenarios 9 and 10 have the same major inputs, the buffers time is different because of considering the effect of the minor inputs. A further vital observation from the model developed comes by comparing the scenarios no. 1 and 11. Albeit both scenarios have been run under the same degree of variability at similar level of influence, the confidence degree in the estimate of duration is quite more in scenario no.1. The buffer times as a consequence, which are computed by the model, show a resounding difference (6 % in scenario 1 and 37.5 % in scenario 11). This clearly express how the degree of confidence plays a vital role in the evaluation of the time buffer size. Another significant observation comes by comparing scenarios no. 7 and 8. As tabulated, both have similar durations, degree of confidence, and variability level, yet the difference arises the influence degree. In this case, the time buffer that should be allotted to scenario 7 is 46.9% with a significant difference rather than that should be

allotted to scenario 8, which is 16.32%. Therefore, the model outcomes discussed that it is not important to recognize the source of uncertainty, but the intrinsic point

is the fact that the vulnerability degree of the activity to this uncertain event. This interprets the vital role of the activity characteristics.

Scenario	Duration		Degree of Confidence		Variability level		Influence Degree		Buffer
	Major	Minor	Major	Minor	Major	Minor	Major	Minor	(%)
1.	Very small	Less	Very High	More	Very small	Less	Very small	Less	6.0 %
2.	Small	Slightly Less	Medium	Slightly Less	Very large	Normal	Small	Slightly Less	28.0 %
3.	Medium	Less	High	More	Small	Less	Very small	Normal	6.4 %
4.	Small	Less	Medium	Less	Very small	More	Very large	More	69.0 %
5.	Very small	Less	Very Low	Less	Medium	More	Very small	More	56.3 %
6.	Very small	More	Very Low	More	Very small	Less	Very small	Slightly more	28.1 %
7.	Medium	Slightly more	High	Slightly more	Small	Normal	Very large	Normal	46.9 %
8.	Medium	Slightly more	High	Slightly more	Small	Normal	Very small	Less	16.32 %
9.	Larg	Less	Low	More	Large	Normal	Very small	Slightly Less	18.8 %
10.	Large	Normal	Very High	Normal	Medium	Slightly Less	Very large	Normal	49.8 %
11.	Very small	Less	Very Low	Less	Very small	Less	Very small	Less	37.5 %
12.	Very small	More	Very Low	More	Very small	Less	Very small	Slightly more	28.1 %
13.	Medium	More	Medium	Less	Very small	Slightly more	Very small	Slightly Less	7.1 %
14.	Medium	More	Medium	Less	Very small	Slightly more	Small	Slightly Less	16.3 %
15.	Medium	More	High	Slightly Less	Small	Slightly more	Small	Slightly Less	18.8 %

TABLE I. SCENARIOS

E. Discussion

The scenarios results emphasized the necessarily prerequisite of the input variables collectively for increasing the reliability of buffer size evaluation, and consequently increasing the stability as well as reliability of scheduling. The buffer size is incompletely evaluated in the absence of any variables. As shown in Fig. 6, the effect of the degree of variability on the buffer size for any activity duration will not be visible, unless the variability has a significant influence. Hence, the degree of variability should be measured by a certain degree of influence to get a suitable buffer.



Figure 6. Surf view: Buffer size according to only duration and the degree of variability.

However, the buffer size evaluation significantly changes, as presented in Fig. 7, when both the confidence degree of duration estimate and influence degree of variability on the activity are taken into account. The surf-view discusses the fact that the buffer size may be increasingly changed at either low confidence levels or a higher influence degree. As a result, the buffer surface level moves down in the direction of the increase of confidence, and vice versa.

Furthermore, it could be touched the effect of both degree of variability and the influence working together on the reliability of the buffer size. Namely, the degree of influence plays more important role in sizing buffers rather than the degree of variability as depicted in Fig. 8. The view shows the changes of buffer size is gradually taken place towards the far top corner along with increasing in the influence degree.



Figure 7. Surf view: changes on buffer size due to the degree of confidence and the influence degree of variability

For instance, we have two examples of activities, first is earthwork and the second is installations work. At a certain degree of variability, i.e. rainy weather, the influence degree of the first activity is rather significant than the second one. Therefore, buffer allotted to the first activity should be quite larger than second.



Figure 8. Surf view: the vital role of the influence degree of variability in evaluating buffer size

VI. CONCLUSION

Inefficiency in the sizing of buffers often results in unnecessarily added time (waste), and consequently, fails to protect the project schedule performance. So, the main hypothesis of this work is to test using of a proper buffers size evaluation algorithm. Development of this model is essentially performed using a suitable algorithm matching the imprecise nature of the construction process. Thus, due to the impossibility of gathering a massive pile of historical data to draw the probability distribution of an activity, Fuzzy Logic algorithm was used for the model.

The development of FLSB was constructed on a set of effective variables are significantly affecting on the reliability of the buffer size. Besides, as common, considering the level of uncertainty and the duration of an activity, the research further considered not only the confidence degree associated with the activity duration, but also the characteristics of the activity. The characteristics of activity were processed in the model as a factor of the influence degree to a certain degree of variability.

The model outcomes stressed the important prerequisite of the input variables collectively for increasing the reliability of buffer size evaluation, and consequently increasing the stability as well as reliability of scheduling. Neglecting theses variables explicitly explained the inefficiency of the buffer size, which had resulted in either adding unnecessarily time (Waste) or hidden a required time. Therefore, the research proved that the buffer size is incompletely and inefficiently evaluated in the absence of any variables.

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