International Journal of Engineering Research (ISSN:2319-6890)(online),2347-5013(print)
Volume No.3, Issue No.1, pp : 34-39 01 Jan. 2014

A Quantitative Model for Measuring the Project and Feeding Buffers in CCM Method by Fuzzy Approach (Case Study: Construction of Industrial Wastewater Treatment Unit at Lorestan Petrochemical Company, Iran)

Hadis Yaghoubzadeh[a*], Emad Roghanian[b]
[a]M.Sc Student of Industrial Engineering-- System and Productivity Management,
Arak Islamic Azad University, Iran.
[b]Assistant Professor, Faculty Member, Khajeh Nasiredin Toosi University, Iran.

Corresponding E-mail: hyaghoubzadeh@yahoo.com

Abstract

Uncertainties in a project's environment are one of the most significant reasons for its incompletion based upon a predetermined schedule. Today, it is unavoidable for project managers to face uncertainties. Therefore, they strongly require a systematic method considering not only resource constraints, but also uncertain conditions in project scheduling. Limits in the common methods of scheduling have encouraged researchers to use the approaches in the theory of constraints. Goldratt (1997) developed the new method of critical chain management (CCM) creating considerable changes in various project-centered organizations and industries. However, it lacked mathematical relations and quantitative models. Due to the main drawback of the CCM method in estimating project activity duration and determining project and feeding buffer sizes, this study tries to remove uncertainties by applying the proposed fuzzy critical chain method (FCCM), integrating both CCM and fuzzy logic (FL) methods. While solving the problems, it may provide project execution time and delivery date safety. Finally, by comparing the scheduling results of a practical project with those of FCCM, CPM, and critical path method (CPM), it is concluded that the planned duration of project scheduling by FCCM is shorter than those of the other two.

Keywords: **critical chain method (CCM); feeding buffer (FB); fuzzy critical chain method (FCCM); project buffer (PB); project management (PM)**

I. Introduction

The non-completion of a project within a planned duration is one of the greatest problems for organizations in the process of its execution. This issue may cause problems such as increasing the variable costs of the project compared to the predicted figure or its delayed delivery to the employer, bad promise, and decreasing the credit of the project's supervisors [1]. American Project Management Institute (PMI), in the book *project management body of knowledge* (PMBOK), defines project as a set of transient attempts to realize a commitment and establishment of a unique product or service [2].

Generally, a project's uniqueness creates its uncertainty; consequently, we may not deliver it on time. Uncertainly about the duration of activity is basic reason for requiring project management. In other words, uncertainly management is one of the most significant tasks of project managers so that they may deliver a project with higher certainty on time [1]. In the common project scheduling methods such as CPM, Gantt chart, project evaluation and review technique (PERT), as well as graphical evaluation and review technique (GERT), attempt is made to remove the deficiency by increasing the time of each activity. However, this solution itself may bring about such problems as increasing the variable costs and balance during work-in-process (WIP). Hence, we require a new method for a better result and faster time [3].

Critical chain management (CCM) method, actually adapted from disseminating the theory of constrains in project management, was first developed by Goldratt in 1990s. Considering project uncertainties and constraints, this method applied all the resources to eliminate their undesirable effects. In other words, the method focused on the constraints that could prevent the project from reaching its objectives [4]. In CCM, all safety times related to the activities on the critical chain are transferred to the end of the project, known project buffer [5]. Critical chain is the longest path in a project network, including the dependency of resource activities and constraints [6]. Since Goldratt introduced the concept of critical chain in his book with the same title in 1997, it has been deeply discussed in project management associations and papers. Some authors know critical chain as an unexpected significant progress for project management from the emergence of CPM method, considering it as a method that may lead project management in the twenty-first century [7, 8]. However, some others question its novelty and believe that critical chain includes the same conventional concepts presented in a different way [9, 10, 11]. In recent years, a number of books have been published that describe the concepts involved in critical chain [7, 12]. Some studies have discussed the essential concepts of critical chain and its difference with critical path at a conceptual level [11, 13]. Other researches have focused on the technical aspect of critical chain scheduling [6, 14]. Although these studies proved to be useful, the discussions were too general to be used as a guideline for the advantages and drawbacks of CCM compared to the common CPM.

Though the algorithms and methods adapted from the theory of constraints have caused changes in productive industries and project-centered organizations, they simply lacking mathematical relations and quantitative models. A group of researchers was trying to bridge this gap through statistical reasoning. Project activity time is considered as a random variable in a statistical method and distribution function is assumed for it so that we may estimate the activity duration by using its mean and variance [15]. However, due to the uniqueness of project activities and lack of historical data concerning their duration, project managers could not often depend on random variables and assumed distribution functions. Many unexpected events may occur during project execution. Thus, project managers have to rely on their mental judgment and knowledge to present real solutions to overcome the interruptions. Application of the methods based on fuzzy data may greatly help the managers and those involved in projects. Considering uncertainty in decision-making parameters and using expert's mental models, fuzzy theory serves as an approach to bring project-scheduling models nearer to reality.

Therefore, considering the researches and the deficiencies of CCM method, this paper is intended to remove the problems in Goldratt's method, and have a more accurate prediction on the duration of activities as well as feeding and project buffer sizes by introducing the proposed FCCM that is actually a combination of fuzzy logic and CCM method. This method may lead to the elimination of extra time due to the wrong methods for predicting the duration of activities and buffer sizes; consequently, the planned duration of the project becomes more reasonable and shorter.

In this research, to conduct the case study as well as implement and evaluate the proposed model, constructing the Electrical and Control Unit, a part of the project still underway at the Project Control and Scheduling Unit of Lorestan Petrochemical Company, is considered. It is also worth noting that the research may be innovative in presenting an algorithm to plan and control projects by FCCM and a method to estimate the sizes of project and feeding buffers.

II. Material and Methodology

A. FCCM Algorithm

As shown in Fig.1, you may observe that the major difference between Goldratt's CCM method and FCCM lies in the first and fourth steps of the algorithm. That is, unlike Goldratt's CCM method whose time of activities is half of the one achieved in CPM method and set as benchmark, trapezoidal fuzzy numbers (based upon four-point estimation) are used in FCCM to estimate the time of activities. In the fourth step of the algorithm mainly focused by the research, Goldratt's CCM method considers half of the time of the activities on the critical chain as buffer for no logical reason. However, in FCCM method, while studying the factors influencing buffer sizes, a comprehensive quantitative model is applied to determine them more accurately.

When the time of activities is obtained based upon trapezoidal fuzzy numbers in the first step of the algorithm, we follow its second and third steps according to CCM method. Then, we enter the fourth step of the research, that is, "determining the sizes of project and feeding buffers through fuzzy logic and applying them in the project network."

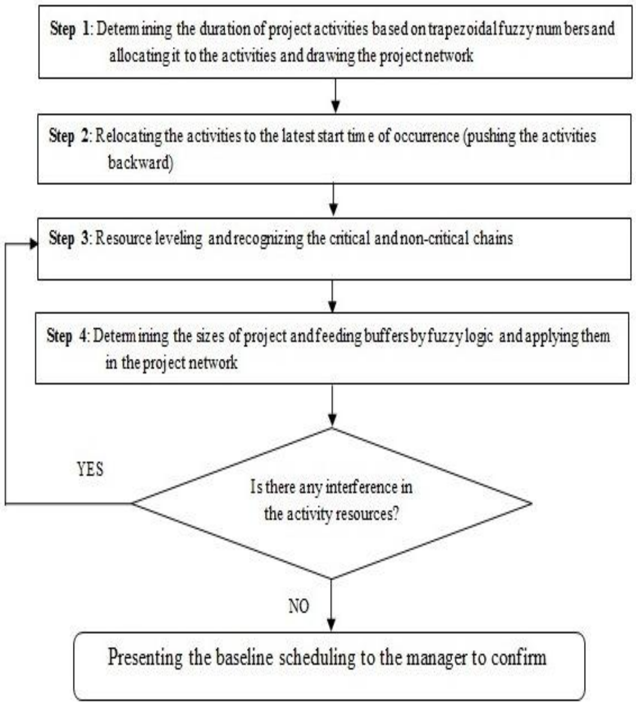

Fig. 1. Steps of the proposed algorithm for FCCM

B. Project and feeding buffers sizing considering the most effective factors

1. *The study and estimation of an (experienced) project manager's risk-taking*

In this stage, the duration of each activity (t_j) is first estimated as a trapezoidal fuzzy number $t_j = (a_j, b_j, c_j, d_j)$ based on the project manager's opinion (*See* Fig. 2). Then, to calculate the project manager's level of risk-taking in estimating the duration of each activity, two parameters F_j and D_j are used [16, 17]. The parameter F_j denotes the fuzzy degree of the *j*-th activity, and D_j denotes the ratio of the distance of the *j*-th activity to the start to the duration of the overall project. To calculate these two parameters, equations (1) and (2) are used as follows [17, 18]:

$$F_j = 1 - \frac{\int_a^b \frac{x-a}{b-a} dx}{d-a} - \frac{\int_b^c 1 dx}{d-a} - \frac{\int_c^d \frac{d-x}{d-c}}{d-a} = \frac{b_j + d_j - a_j - c_j}{2(d_j - a_j)} \quad (1)$$

$$D_j = \frac{ES_j}{T} \quad (2)$$

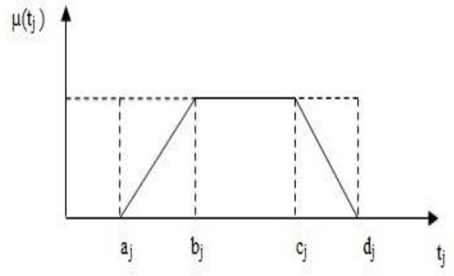

Fig. 2. Duration of each activity based on trapezoidal fuzzy number

If β indicates the weight (i.e., the degree of importance) of each foregoing parameter from the viewpoint of a project manager, equation (3) will show the manager's level of risk-taking:

$$1-\alpha = (1-\beta) F_j + \beta D_j \qquad ,0 \le \beta \le 1 \qquad (3)$$

In the equation above, the amount of $1-\alpha$ indicates the (experienced) project manager's uncertainty about the estimated duration of the activities. The more $1-\alpha$ is, the more uncertain is the project manager of the duration. Therefore, the project manager's level of risk-taking is lower. In this paper, based upon the viewpoint of the project manager, $\beta = 0.5$, that is, the parameters F_j and D_j have the same effect on the project [19].

2. Estimating the initial safety time of the activities (St_j)

In this stage, the amount of $1-\alpha$ showing the project manager's risk-taking level through determining the parameters F_j and D_j ,is obtained. Then, the cut surface α-cut is calculated from this equation. Exercising α-cut on the fuzzy duration figure for each activity, the amounts of lower and upper bands for their duration is obtained through equation (4) as follows:

$$t_\alpha(j) = \left[t_\alpha^l(j), t_\alpha^u(j)\right] : \begin{cases} t_\alpha^l(j) = b_j - (b_j - a_j)(1-\alpha) \\ t_\alpha^u(j) = c_j + (d_j - c_j)(1-\alpha) \end{cases} \qquad (4)$$

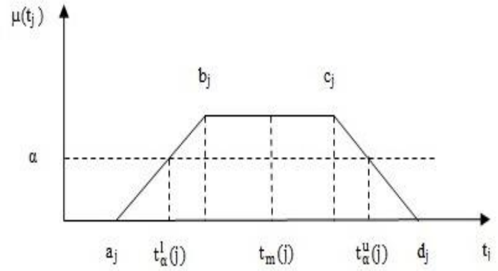

Fig. 3. Amounts obtained from α-cut

Considering the values obtained from exercising α-cut, the amount of the initial safety time is calculated through equations (5) and (6):

$$St_j = t_\alpha^u(j) - t_m(j) \qquad (5)$$

$$t_m(j) = \frac{(a_j + 2*b_j + 2*c_j + d_j)}{6} \qquad , b_j \le t_m(j) \le c_j \qquad (6)$$

Based upon the equations above, $t_m(j)$ is actually one of the most possible times for conducting the *j*-th activity determined by the project manager.

3. Estimating the effect of resource compression on buffer sizes during project activities

It is basically claimed that the less availability of an activity to its required resource, the more possibility of prolongation in its execution time. Therefore, it is more likely that the activity will need more safety time. Accordingly, there is a direct relationship between buffer size and resource compression. In this paper, it is assumed that there is no constraint concerning accessibility to the resource of equipment and materials. If MR_j denotes the maximum ratio of the resource to the available resource for the *j*-th activity, its value can be obtained from the equation below:

$$MR_j = max\left(\left(\frac{r_L(j)}{R_L(j)}\right), \left(\frac{r_{NL}(j)}{R_{NL}(j)}\right)\right) \qquad (7)$$

In the equation above, the variables $r_L(j)$ and $R_L(j)$ denote the values of the required resource and the available resource of manpower type for the *j*-th activity, respectively. The variables $r_{NL}(j)$ and $R_{NL}(j)$ indicate the values of the needed resource and the available resource of machinery (i.e., non-manpower) type for the *j*-th activity, respectively. To study the rate of resource compression and its effect on the size of feeding and project buffers, the membership function of the resource compression rate, that is, $\mu(MR_j)$ is used as follows:

$$\mu(MR_j) = \begin{cases} 0 & , 0 \le MR_j \le n \\ \dfrac{MR_j - n}{m - n} & , n \le MR_j \le m \\ 1 & , MR_j \ge m \end{cases} \qquad (8)$$

In Eq. 8, if $MR_j \le n$, the ratio of the accessible human resources and machinery to the required ones for the *i*-th activity is considerable and we may no longer face resource compression. In other words, the possibility of the activity delay is rated as zero due to resource compression. In case that $n \le MR_j \le m$ resource compression is to some extent present and the possibility of the *j*-th activity may be variable. When $MR_j \ge m$ the activity is faced with resource compression and there may be the least flexibility to protect against it without increasing the time. In this situation, the values of *m* and *n* are determined (in mind) by the project manager considering the existing conditions. According to the experienced project manager's views, $n = 0.1$ and $m = 0.6$ in this paper.

4. Estimating the effect of activities network complexity on buffer sizes

It is essentially believed that the more precedence a project activity has, the more likely one of them lags leading to some delays in the same activity. Hence, there is a positive relationship between an activity's precedence and delay probability [20, 21]. To estimate the complexity of the critical activities networks, equation (9) is used [22]:

$$C_{Cj} = 1 + \left(\frac{P_{Cj} - 1}{P_C} \right) \quad (9)$$

where C_{Cj} denotes the complexity rate of the *j*-th critical activity's network, P_{Cj} reflects the total number of the *j*-th activity's precedence relations, and P_C shows the total number of the activities on the critical chain related to the *j*-th activity. Moreover, equation (10) is used to estimate the complexity of the non-critical activities network:

$$C_{NCj} = 1 + \left(\frac{P_{NCj} - 1}{P_{NC}} \right) \quad (10)$$

where C_{NCj} shows the complexity rate of the *j*-th critical activity's network, P_{NCj} denotes the total number of the *j*-th activity's precedence relations, and P_{NC} reflects the total number of the activities on the critical chain related to the *j*-th activity.

Based upon the equations above, we notice that if the total number of precedence relations of critical and non-critical activities equals one, network complexity will also be equal to one.

5. Estimating the effect of external environment's factors on buffer sizes

External factors such as political, economical, social, technological, and environmental (PESTE) rules are also one of the variables influencing buffer size and project duration. In this research, PESTE model is used for analyzing the effect of external factors on the size of buffers. To prepare the PESTE model for the foregoing project, the researcher held some meetings with the manager and the supervisor of the project who were also present at its executive process. As a result, she obtains a list of the most significant external environment sub-factors having the highest effect on the activity duration, project completion time and buffer sizes. Then, through interviewing them, she considers a weight from 0 to 1 and a ranking from 1 to 4 (i.e., 1 or 2 or 3 or 4) for each sub-factor based upon its significance. Supposing the parameter ε_j denotes the effect rate of all the external environment factors on the *j*-th activity of the project and μ_i reflects the sum of the scores of all the sub-factors related to the *i*-th external factor, the rate of effects exercised by all the external environment factors on the *j*-th activity of the project may be roughly obtained through the equation below [23]:

$$\varepsilon_j = \begin{cases} 1 & , \sum_i \mu_i \geq 3 \\ 0.75 & , 2.5 \leq \sum_i \mu_i \leq 3 \\ 0.5 & , 2 \leq \sum_i \mu_i \leq 2.5 \\ 0.25 & , \sum_i \mu_i \leq 2 \qquad , i = 1, 2, \ldots, 5 \end{cases} \quad (11)$$

In this research, taking into account the PESTE model compiled for the project, the sum of all scores of the sub-factors influencing the project activities is 3.60; therefore, the value of ε_j is considered as 1.

6. The proposed formula to estimate the size of project and feeding buffers

As stated earlier, such parameters as the (experienced) project manager's risk-taking level, resource compression rate, network complexity, and the external environment factors affecting project activities are all directly related to buffer sizes. The product of these four parameters offers the rate of the improved safety. Zhao *et al.* (2010), in their paper, indicated that the square root of the sum of the squares of safety times might prevent buffer sizes from getting too long or too short. The viewpoint taken from Newbold's proposed method is used in this research to obtain desirable results. Thus, the extracted proposed equations (12) and (13), to determine the size of project and feeding buffers, may be as follows:

$$FBS = \sqrt{\sum_{j=1}^{n} (St_j * \mu(MR_j) * C_{Ncj} * \varepsilon_j)^2} \quad (12)$$

$$PBS = \sqrt{\sum_{j=1}^{n} (St_j * \mu(MR_j) * C_{Cj} * \varepsilon_j)^2} \quad (13)$$

III. Result

At this stage, considering the data obtained from the implementation, the values of such parameters as St_j, $\mu(MR_j)$, C_{Cj}, C_{NCj}, and ε_j are determined for each of the project activities through the calculations done on the project during its previous stages. With these values at hand, and using equations (12) and (13), the size of the project buffer using the proposed quantitative model was estimated as 13 days and those of the feeding buffers as 2, 2, and 1 day, respectively. The obtained buffers have to be applied in the network of activities now, so that the project buffer can be added to the end of the critical chain and the feeding buffers to the end of the noncritical semi-chains introduced into the critical activities.

Based upon the proposed algorithm of FCCM, it is required that resource leveling be exercised before and after using the buffers. The task was conducted prior to applying the buffers into the network, through one of the resource leveling methods (i.e., increasing the manpower resource) proportional to the project conditions. Moreover, following the application of buffers into the project network, there was no resource interference. Moreover, analyzing the results from FCCM method by MSP 2010 Software, it may reduce the project's planned duration to 198 days. On the other hand, the experts of project planning for constructing the electrical and control unit at Lorestan Petrochemical Company used CPM technique for project scheduling. Based upon their scheduling by means of the CPM method, a planned duration of 270 days is obtained for the project. In this method, the activities duration is considered by the project manager with regard to uncertainties and unexpected factors. Generally, in this method, upper limit estimation of activity duration as well as float in non-critical activities, are the main reasons for emerging the deterrent human factors and reducing the productivity of working resources in the project. On the other hand, to determine the activities duration and buffer sizes in

Goldratt's method, the data obtained through CPM method are used. Then, we may add the mean execution time of critical activities as project buffer to the end of the critical chain, and that of non-critical activities as feeding buffer to the end of the non-critical chains. Ultimately, it is observed that the scheduling by Goldratt's CCM determines the project buffer size as 74 days, and those of feeding buffers as 6.25, 2.75 and 1 day, respectively. As it was predicted, based upon the experience of using the CCM method in real projects, the planned duration of project buffer is a large number; therefore, the project's planned duration is obtained as 216 days.

IV. Conclusion

Considering the baseline programs compiled for the project by means of MSP 2010 Software and using CPM, CCM and FCCM methods, the results indicate that the projects' planned duration is obtained as 198 days through the proposed FCCM, being lower compared to those of the other two methods. In principle, differences between the results obtained through CCM and the proposed method, compared to the CPM, are due to the deterrent human factors in determining the duration of activities. Determining the duration more than that required for project activities may reduce the productivity of human resources. In other words, it may elongate the task leading to an undesired increase in project duration. Although Goldratt's CCM method , compared to CPM, has decreased the project's planed duration from 270 days to 216 days due to removing the deterrent human factors, its wrong approach to estimate the duration of activities and buffer sizes has left some parts of the problems unresolved. Application of the proposed FCCM, while involving fuzzy logic in the estimation of activities duration and buffer sizes, may eliminate the overestimations of the CCM method, decreasing the project's planned duration to 198 days.

We now deal with studying the potentials of the proposed model to determine buffer sizing compared to both C&PM and RESM methods. Here, for a better comparison of the three methods, fuzzy durations of the activities involved in the construction project of electrical and control unit of Lorestan Petrochemical Company are used. In C&PM, we may require a 50-percent estimation. However, in RESM, it is supposed that we could obtain the estimation of the safety time with a certainty level of 90 percent. Table (3) shows the results of the three methods. As you see, C&PM method offers very large buffer sizes based upon previous predictions. Application of the proposed quantitative model leads to eliminating the drawbacks in both methods and producing more acceptable results.

Table 3. Feeding and project buffer sizes in the construction of the electrical and control unit at Lorestan Petrochemical Company based upon C&PM and RESM methods and the proposed quantitative model

	C&PM method	RESM method	Proposed Quantitative method
Project buffer	49.266	15.631	13
Feeding buffer 1	5	1.5	2
Feeding buffer 2	2.25	1.5	2
Feeding buffer 3	0.734	0.5	1

Generally, the results showed that the proposed model might produce a smaller buffer size compared to Goldratt's and Newbold's recognized methods, leading to decrease the execution duration of the project. It should be noted that, in FCCM method, 50-percent estimations are no longer needed; therefore, individuals offer more real estimations for the execution duration of activities and may not be worried about reducing their estimations by the project manager. Another advantage of the proposed method is that, during the project execution while controlling the rate of buffer consumption, the manager is warned to take corrective actions and better control the activities execution process in case of needed to prevent more delays. On the other hand, any decrease in project execution duration by FCCM method may tend to reduce the direct and indirect costs of the project. Thus, application of the proposed FCCM is more logical than other two methods due to being economical with time and cost, and may be a suitable alternative for project planning and execution.

Acknowledgement

The authors would like to thank the hardworking personnel of Lorestan Petrochemical Company, in general, and Mr. Reza Mohammadi, expert of planning, in particular. Moreover, we wish to express special thanks to Mr. Hossein Varezardi for translating the paper into English. Our cordial thanks must also go to Mrs. Hadis Soleimaninia for her putting the paper into the standard format set by the IJER.

References

i. *Kouchaki, S. (2010). A new approach to determine the buffer size of the project management of the critical chain in high-risk environment. Unpublished master's thesis, Tarbiat Modarres. University, Iran.*

ii. *Project Management Institute. (2009). A developed guide for project management (Z. Ashtiani , Trans.) (2nd ed.). Iran: Adineh Publishing House.*

iii. *Long, L. D., & Ohsato, A. (2008). Fuzzy critical chain method for project scheduling under resource constraints and uncertainty. International Journal of Project Management, 26, 688–698.*

iv. *Ashtiani, B., Aryannejad, M., Moghadam, B. (2007). Applying the standard deviation of activities to determine buffer sizes in the critical chain. Third International Conference on Project Management, Iran.*

v. *Jafarnejad, A. (2006). Production management and modern Operations. Iran: Management Faculty Press.*

vi. *Cohen, I., Mandelahum, A., & Shtub, A. (2004). Multi-project scheduling and control: A process-based comparative study of the critical chain methodology and some alternatives. Project Management Journal, 35-39 .*

vii. *Newbold, R. C. (1998). Project management in the fast lane: Applying the Theory of Constraints. New York: Lucie Press.*

viii. *Steyn, H. (2002). Project management applications of the theory of constraints beyond critical chain scheduling. International Journal of Information Sciences, 20, 78- 80.*

ix. *Maylor, H. (2000, June 4-7). Another silver bullet? A review of the TOC approach to project management. In: Proceedings of the Paper Presented at the 7th International Annual Euroma Conference,Ghent.*

x. *McKay, K. N., & Morton, T. E. (1998). Book reviews- critical chain. Journal of IIE Transactions, 30, 759–763.*

xi. *Raz, T., Brans, T., et al. (2003). A critical look at critical chain project management. Project Management Journal, 34(4), 24-32.*

xii. *Leach, L. P. (2000). Critical Chain Project Management. Boston: Artech House.*

xiii. *Golberson, S. (2000). PMBOK and the critical chain PM network, 14(5), 63-66.*

xiv. *Herroelen, W., Leus, R. (2001). On the merits and pitfalls of critical chain scheduling. Journal of Operations Management, 19, 559-577.*

xv. *Lixi, Y., Shiqi, L., Xiabao, H., & tao, P. (2009). A buffer sizing approach in critical chain scheduling with attributes dependent. Journal of Industrial Engineering and Management, 4, 11-14.*

xvi. *Chen, M. K., & Hsu, S. P. (2004). Fuzzy-Critical-Chain-based Project Management. Journal of the Chinese institute of industrial engineers, 21(2), 167-176.*

xvii. *Li, K., & Chen, Y. X. (2007). Applying critical chain in project scheduling and estimating buffer size based on fuzzy technique. IEEE International Conference on Industrial Engineering Management, 1068-1072.*

xviii. *Pappis, C. P., Karacapilidis, N. I. (1993).A comparative assessment of measures of similarity of fuzzy values: Fuzzy sets and systems, 56, 171-174.*

xix. *Zhen, Y. Z., Wei, Y. Y., & Qian, L. L. (2008). Applications of fuzzy critical chain method in project scheduling. Fourth International Conference on Natural Computation, 5(3), 473-477.*

xx. *Tukel, O. I., Walter, O. R., & Eksioglu, S. D. (2006). An investigation of buffer sizing techniques in critical chain scheduling. European Journal of Operational Research, 172, 401– 416.*

xxi. *Chao, C. C. (2008). Buffer sizing and critical chain project management. Journal of Computer Integrated Manufacturing, 14(5), 1029-1035.*

xxii. *Shi, Q., Gong, T. (2009). An improved project buffer sizing approach to critical chain management under resources constraints and fuzzy uncertainty. Journal of IEEE Computer Society, 5, 486-490.*

xxiii. *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. Journal of Science and Technology, 4, 566-569.*

xxxviii. *Zhao, Z. Y., Yang You, W., & Zuo, J. (2010). Application of innovative critical chain method for project planning and control under resource constraints and uncertainty. Journal of Construction Engineering and Management, 5, 1056*-1060.