LONTAR KOMPUTER VOL. 16, NO. 1 APRIL 2025 p-ISSN 2088-1541
DOI : 10.24843/LKJITI.2025.v16.i01.p05 e-ISSN 2541-5832
Accredited Sinta 2 by RISTEKDIKTI Decree No. 158/E/KPT/2021

Maintenance Scheduling for Buildings Using Fuzzy Logic Application

I Nyoman Dita Pahang Putra[a1], I Gede Susrama Mas Diyasa[b2], Anak Agung Diah Parami Dewi[c3], Bambang Trigunarsyah[d4]

[a]Civil Engineering Department, Universitas Pembangunan Nasional Veteran Jawa Timur
Raya Rungkut Madya Street - Surabaya, Indonesia
[1]putra_indp.ts@upnjatim.ac.id (Corresponding author)

[b]Magister Information Technology, Universitas Pembangunan Nasional Veteran Jawa Timur
Raya Rungkut Madya Street - Surabaya, Indonesia
[2]gsusrama.if@upnjatim.ac.id

[c]Civil Engineering Department, Universitas Udayana
Kampus Bukit Jimbaran Street – Badung, Indonesia
[3]anakagungdewi@unud.ac.id

[d]School of Property, Construction and Project Management, RMIT University
360 Swanston Street – Melbourne, Australia
[4]bambang.trigunarsyah@rmit.edu.au

Abstract

This research proposes an innovative approach to building maintenance scheduling using fuzzy logic. Fuzzy logic addresses uncertainty and complexity in decision-making processes concerning prioritizing and scheduling maintenance tasks. This study aims to enhance the efficiency of maintenance scheduling, reduce maintenance costs, and consider the variability in building conditions. Traditional methods, such as PERT (Program Evaluation and Review Technique) and CPM (Critical Path Method), have limitations in accurately predicting scheduling times. At the same time, fuzzy logic offers a more precise approach to overcoming uncertainty. Implementing a maintenance scheduling model based on fuzzy logic is expected to yield a more adaptive and responsive maintenance plan in response to changes in building conditions. The results of this research are expected to contribute positively to building maintenance management by leveraging the advantages of fuzzy logic in addressing the challenges of complexity and uncertainty in building maintenance management. By applying fuzzy logic-based maintenance scheduling, it is hoped that precise and efficient building maintenance scheduling can be achieved, thereby minimizing project completion time and assisting project managers. The fuzzy logic method can be employed for construction project scheduling according to the schedule determined by the contractor. This allows the contractor to use it as a consideration for the total duration, along with detailed timing in the project proposal. For the owner, it provides insights into the potential project completion time.

Keywords: *Maintenance Scheduling, Buildings, Fuzzy Logic*

1. Introduction

Building maintenance often involves several variables that are difficult to measure precisely [1]. Physical building conditions, usage levels, and functional priorities can vary dynamically. The scheduling phase indicates whether a building's maintenance management is successful or not [2]. This is because the scheduling phase has dependencies between activities that build the entire project. In the scheduling phase, it must also be able to predict whether a project can be completed or not, taking into account several parameters, including the project completion deadline. In conventional project management, document recording is often done with separate

Excel files or paper documents. Therefore, it will be tough to assess, analyze, or predict the success of a project.

Hence, using information systems in building project management is essential for user convenience in project organizing. In analyzing project management, several methods are available, including PERT (Program Evaluation and Review Technique) and CPM (Critical Path Method), which focus on project completion time[3]. PERT is probabilistic, and CPM is deterministic [4], [5]. Both CPM and PERT methods have low accuracy in predicting the scheduling time of building maintenance management[6]. In this scenario, traditional methods in maintenance scheduling could be more effective due to inherent uncertainty. Fuzzy logic offers a more precise approach to address this uncertainty[7]. By modeling variables as fuzzy sets, we can describe building conditions more realistically. Therefore, maintenance scheduling based on fuzzy logic can provide a more adaptive and customizable plan for dynamic condition changes to determine the success of maintenance scheduling by measuring parameters in the scheduling phase[8], [9]. An application for building maintenance scheduling will also be developed to facilitate the organization and management of documents resulting from building maintenance management planning.

This research is expected to help facilitate building maintenance management, scheduling, and analysis. Alternative method of construction project scheduling using the Fuzzy Set theory by implementing the Program Evaluation Review Technique (PERT) [10]. PERT, as one method, determines the duration of uncertain activities. In the PERT method, the value of the probability density function of the duration of the activity is determined based on the results of the beta distribution [11]. Then, simplification is done using the values of the beta distribution parameters. The average duration is used to determine the critical path, and the total duration probability is calculated from the critical path. In some instances, this simplification causes errors and contradictions. Therefore, this study aims to develop a building maintenance scheduling model that utilizes the advantages of fuzzy logic. Applying this approach is expected to increase maintenance efficiency (Optimize maintenance schedules to minimize building downtime and maximize productivity). Reduce Maintenance Costs (Creating timely and effective maintenance schedules to avoid severe damage that requires major repairs). Consider Variability of Conditions (adjusting maintenance schedules to dynamic changes in building conditions, considering fuzzy factors), with a significant contribution to the development of more innovative and adaptive maintenance scheduling strategies. Through the application of fuzzy logic, we strive to improve responsiveness and decision accuracy in building maintenance management.

2. Research Methods

Figure 1 is a block diagram of the system created for building repair scheduling using fuzzy logic. Figure 1 illustrates the main steps in the fuzzy logic-based building maintenance system. Inputs, consisting of building conditions and maintenance criteria, are fed into the fuzzy logic process, which consists of three main stages: fuzzification, rule evaluation, and defuzzification[12].

a. The Fuzzification Stage transforms the input into fuzzy sets with appropriate membership functions. Fuzzification is responsible for handling uncertainty and complexity in the input.
b. Rule Evaluation Stage: This stage utilizes predefined fuzzy rules to evaluate the fuzzy sets generated from the fuzzification stage. Fuzzy rules produce fuzzy output based on building conditions and maintenance criteria.
c. Defuzzification Stage: This stage converts the fuzzy output into crisp values and provides maintenance recommendations based on the resulting crisp values.

Each stage in this Fuzzy Logic system collaborates to offer maintenance recommendations based on building conditions and criteria. The system utilizes Fuzzy Logic to address uncertainty and complexity in the decision-making process for building repair scheduling.

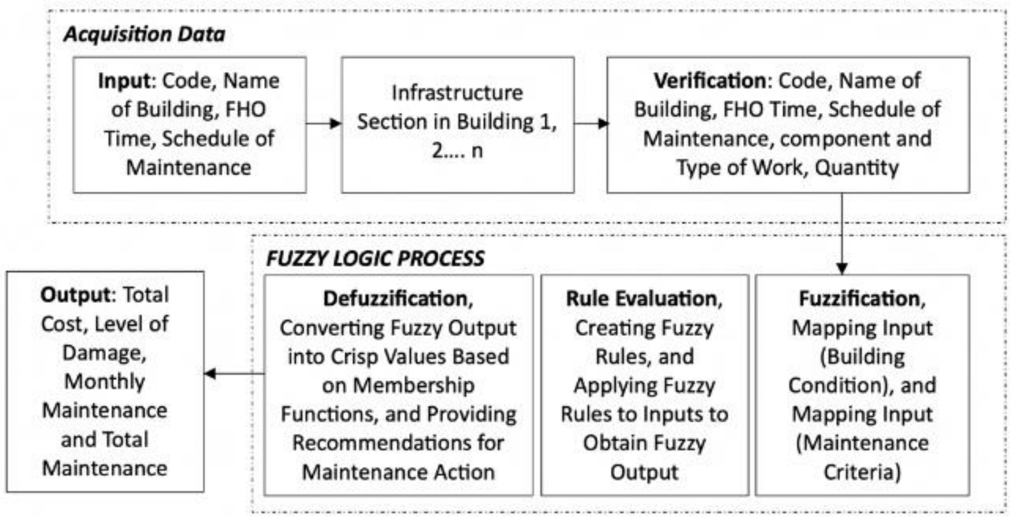

Figure 1. Block Diagram of Building Damage Scheduling System Using Fuzzy Logic

2.1. Data Acquisition for Building Maintenance Scheduling Management

Data acquisition in building maintenance scheduling involves collecting the necessary information to determine a maintenance plan, where the data is extracted from various building maintenance schedules from one of the companies undertaking such work. In this context, data acquisition includes several parameters used in fuzzy logic implementation, as follows:

a. Coding: Unique code or identification for each building, facilitating data organization and grouping.
b. Building Name: Identification of the building that will undergo maintenance.
c. FHO Time (Final Handover): The time or date of the final handover from building construction serves as the starting point for maintenance calculations.
d. Maintenance Period: The period during which maintenance is scheduled or planned to be performed.
e. Components and Types of Work: Identification of building components requiring maintenance, along with the types of work to be carried out.
f. Quantity: Quantity of a specific type of work to be performed during the maintenance period.
g. Unit Cost: Cost per unit for each type of work performed.
h. Development Cost: Development cost involves calculating the total cost based on quantity and unit cost.

The infrastructure department will verify these eight elements. The application can produce outputs such as total cost, monthly damage and maintenance levels, and total maintenance costs for each building. The damage level is based on the Ministry of Public Works Regulation Number 24/PRT/M/2008 regarding Guidelines for Building Maintenance[13], which will be applied to fuzzy logic. Applying fuzzy logic in building maintenance guidelines involves assessing the level of damage and maintenance needs[14], [15]. Some criteria that can be used include:

a. Minor Damage: Indicates minor-scale damage requiring minimal maintenance.
b. Medium Damage: Indicates damage requiring moderate maintenance and may involve several components.
c. Major Damage: Indicates significant damage requiring intensive and extensive maintenance.
d. Special Maintenance: Indicates the need for special maintenance or repair projects not included in the ordinary damage category.

This acquisition data is then used in the fuzzy logic process to evaluate the damage level and recommend appropriate maintenance actions. Building maintenance management can be carried out more adaptively and effectively by considering these factors. The Head of the Regional Working Unit oversees the decision-making process for implementing building maintenance. The decisions made by the Head of the Regional Working Unit are expected to represent the priority scale of building maintenance that the Regional Working Unit must carry out.

Based on the results of observations and interviews, the components and types of work that frequently and very frequently require maintenance are explained in Table 1. The table illustrates that maintenance often occurs in building elements, including architectural, structural, mechanical, electrical, and exterior spatial planning. Various types of work can be found in Table 1.

Table 1. Component and Type of Work

Component	Type of Work (ToW)	Component	Type of Work (ToW)	Component	Type of Work (ToW)
Architecture	Glass Wall/tempered glass	Mechanical	Sewer	Outdoor Layout	Roof covering (zinc roof, metal tile, concrete, ceramic tile, fiberglass)
	Ceramic/Mosaic Wall		Clean water line		List-plank wood
	Marble wall		Sanitary equipment (sink, toilet seat, and/or squat seat)		List of glass fiber cement
	Wall with Cladding Aluminium Composite Cover		Water faucet	Structure	Foundation
	Triplex Ceiling		Dish sink		Steel structure (trusses, roof construction, pillars, or other auxiliary parts)
	Acoustic Ceiling		Air conditioning system		Concrete structure (floor slabs, beams, columns)
	Gypsum Ceiling		Vertical transportation system		Red brick wall or Block
	Wooden Ceiling		Fire protection system (Sprinkler, Hydrant, etc.)		River stone wall
	Metal Ceiling		Plumbing and pump system		Concrete wall
	Locks, latches, and hinges	Electrical	Electrical systems (Electric panels, generators, transformers, etc.)		Wooden wall
	Sliding door, rolling door, folding door		Electronic systems (fire alarm, telephone, computer network/internet, CCTV, etc.)		
	Aluminium Frame	Outdoor Layout	Septic Tank		
	Wooden Frame		The gutter is upright and flat		
	Plastic Frames and Iron Frames		Floor drain		
	Door Closer		Exterior paint		

2.2. Fuzzy Logic Membership

In the building repair scheduling system using fuzzy logic, we can implement a fuzzy model to depict the relationship between input variables (coding, building name, FHO time, maintenance period, components and types of work, quantity, unit cost, and development cost) and specific repair criteria (1. Minor damage, 2. Moderate damage, 3. Severe damage, 4. Special maintenance). The following are the steps and components of the fuzzy model:

a. Fuzzification: Input Variables: Coding, FHO Time, Maintenance Period, Quantity: Each of these variables can be transformed into fuzzy sets with appropriate membership functions. For example, FHO time can have sets like "long," "medium," or "short." Unit Cost and Development Cost: Similar to the variables above, these two variables can also be transformed into fuzzy sets. Membership Functions: Each fuzzy set needs to have a membership function. Example: "Long" is a triangular membership function (low, medium, high).
b. Rule Evaluation: Creating fuzzy rules that connect input variables with repair criteria. Rules: "If FHO time is short and development cost is high, then severe damage." Each rule is given a weight indicating its level of importance.
c. Inference: Applying fuzzy rules to input variables to generate fuzzy output. The combination of regulations and their weights determines the level of repair needs.
d. Defuzzification: Converting fuzzy output into concrete values that can be used to make repair decisions. This involves determining a concrete solution based on the membership level within the fuzzy set.
e. Recommendation for Repair Actions: Based on the defuzzification results, the system provides recommendations for repair actions required for the building. These recommendations may include a repair schedule, required types of work, and cost estimates.

This fuzzy model enables the system to address uncertainty in building conditions and provide more adaptive and responsive repair recommendations to dynamic changes in input variables. Such fuzzy models can be developed and customized according to the specific needs of the building repair scheduling system under construction.

2.3. Fuzzy Logic Application for Scheduling

Fuzzy logic can be applied to CPM in terms of the Activity on Arrow (AOA) diagram and its calculations, except for the characteristics of its durations [16], [17]. The duration of activity i-j is expressed in three different values: the lower limit, the most likely, and the upper limit. Since fuzzy assumes that triangular fuzzy numbers represent the duration of activities [16], [17]. These three values are denoted as 1, m, and u or Di-j (l, m, u). For node i, Early Start (Ei) and Latest Start (Li) are also fuzzy numbers, but they do not necessarily have to be triangular fuzzy numbers [18]. The duration of activities is expressed as TFN (Triangular Fuzzy Number) [16], [19], [20], [21], [22], as seen in Figure 2. From this figure, it can be observed that the membership function of the triangular curve is as follows [19], [20], [21], [22].

$$\mu_x = \begin{cases} 0 & , x \leq l \\ (x-l)/(m-l), & l < x \leq m \\ (u-x)/(u-m), & m < x \leq u \\ 0 & , x > u \end{cases} \tag{1}$$

Where:
$x =$ input variable (e.g., damage level, building age),
$l, m, u =$ lower bound, most likely value, and upper bound,
$\mu A(x) =$ membership degree of x in fuzzy set A.

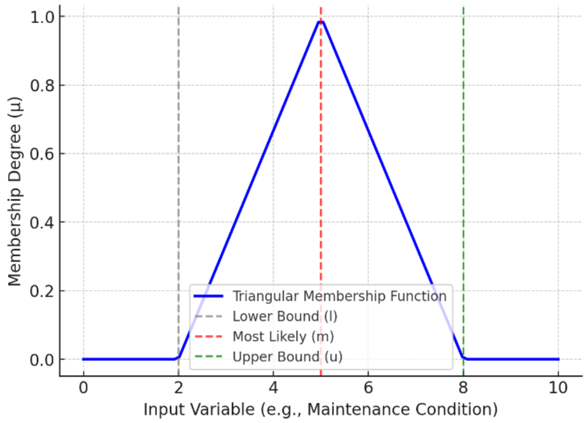

Figure 2. Triangular Fuzzy Membership Function Representation

In Figure 2, the X-axis in the diagram represents the input variable, which can be factors related to building maintenance conditions, such as the severity of damage, the age of the building, or the urgency of maintenance needs. Meanwhile, the Y-axis illustrates the degree of membership (μ) within the fuzzy set, ranging from 0 to 1, indicating how strongly an input value belongs to a particular fuzzy category.

The blue triangular curve represents the fuzzy membership function, which defines how a specific input value is categorized into a fuzzy set. The shape of this function helps determine the degree of belonging of an input value within different maintenance condition categories. This ensures that the system can handle uncertainty and imprecision in decision-making.

To provide further clarity, dashed lines in different colors highlight critical points within the fuzzy set:

a. Lower Bound (l) (Gray): Represents the starting point of the fuzzy membership function, where the input value begins to have a slight association with the category.
b. Most Likely (m) (Red): Denotes the peak of the membership function where the input value has full membership (μ = 1) in the fuzzy category.
c. Upper Bound (u) (Green): Marks the end of the fuzzy membership function, beyond which the input value no longer belongs to the category.

Values that fall between l and u will have a membership degree between 0 and 1, meaning they partially belong to a fuzzy category. If the input value is exactly m, it holds full membership (μ = 1) within the fuzzy category.

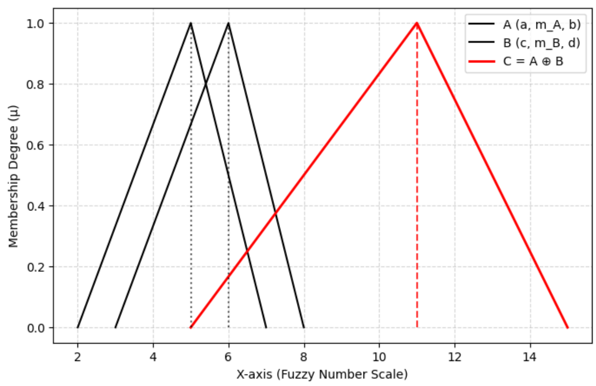

Figure 3. Addition of Two Triangular Fuzzy Numbers

This graph visually represents the addition of two Triangular Fuzzy Numbers (TFNs), A and B, to produce a new fuzzy number C = A ⊕ B.

The addition of two TFNs follows the equation:

$$A(a, m_A, b) \oplus B(c, m_B, d) = C(\alpha + c, m_A + m_B, b + d) \quad (2)$$

Where:
$A = (a, m_A, b)$ represents the first fuzzy number.
$B = (c, m_B, d)$ represents the second fuzzy number.
The resulting fuzzy number C is computed as:

a. Left Bound: $\alpha + c$
b. Peak Value: $m_A + m_B$
c. Right Bound: $b + d$

2.4. Forward Pass Calculation

The search for critical paths and activity time parameters begins with the forward pass process, which calculates FES and FEF from the beginning to the end of the activities. FES and FEF are calculated using the following formulas [23].

$$FES_x = \max(FEF_p) \quad (3)$$
$$FEP_x = FEF_p(+)FD_x \quad (4)$$

FESx = fuzzy start time of activity x, FESx = fuzzy start time of activity x, p = fastest activity preceding, p = fastest activity preceding, FEF = fastest finish time in a fuzzy form, FEF = fastest finish time in a fuzzy form, FDX = duration of activity x. FDX = duration of activity x.

2.5. Backward Pass Calculation

The backward pass process is conducted to find FLS and FLF, starting from the last activity and continuing to the first. Suppose some activities are preceded by more than one activity. In that case, the membership function of each predecessor activity is calculated first, and the minimum value is chosen to determine the next activity[24].

$$FLP_x = \min(FLS_s) \quad (5)$$
$$FLS_x = FLF_x(+)FD_x \quad (6)$$

FLSx = latest time activity x can start, FLSx = latest time activity x can start, FLFx = latest time activity x can finish, FLFx = latest time activity x can finish, FDX = duration of activity x. FDX = duration of activity x.

2.6. Float Times

Float time is the amount of time available in an activity that allows the activity to be delayed without causing an increase in the total project duration. There are three types of float times: total float (TF), free float (FF), and independent float (IF) [25], [26].

$$TF_x = FLF_x - FD_x - FES_x \quad (7)$$
$$FF_x = FEF_x - FD_x - FES_x \quad (8)$$
$$IF_x = FES_x - FD_x - FLS_x \quad (9)$$

The centroid (C) of a fuzzy set (a, b, c) can be calculated using the formula[27].

3. Results And Discussion

This study is descriptive, explaining how fuzzy theory is applied in analyzing a construction project schedule that contains elements of uncertain duration. The calculations are performed using the fuzzy logic application. The calculations are carried out in three stages: forward pass calculation (early start), backward pass calculation (latest start), and float calculation. The forward pass calculation is done by summation and fuzzy max, while the backward pass and float calculations are performed by subtraction and fuzzy min. The results obtained from the data calculation, through both forward and backward pass calculations, include the potential time required to complete the project, including optimistic time, pessimistic time, most likely time, and float time, which encompasses total float time, free float time, and independent float time. These threshold values indicate the critical path of the observed project. Furthermore, based on the comparison of minimum and maximum durations obtained with the normal duration, calculations are performed to get the minimum and maximum project costs.

3.1. Scheduling Duration of Building Maintenance with Fuzzy

In addition to data on the relationships between activities, the duration of each activity must also be known when preparing this network. Unlike CPM, in fuzzy, the duration is expressed in FN (Fuzzy Number) obtained from interview data. Thus, each job has three types of durations: optimistic, normal, and pessimistic times. These three durations are then referred to as FDx or Fuzzy Duration for job x (Table 2).

For example, the Glass Wall/tempered glass (A) job is preceded by the Door Closer (M) job with a fuzzy duration of an optimistic time of 4 days, an average time of 6 days, and a pessimistic time of 7 days. The network of architectural work completion in the building maintenance scheduling project for the elementary school is shown in Figure 3. This network will facilitate providing an overview of overlapping activities, enabling the calculation of AOA (Activity on Arrow) network requirements. This can be seen in Figure 4.

In this case, the fuzzy membership function limit is not 1 but the α-cut value. This is because the average project delay factor has reduced to 1. In other words, this α-cut value indicates the likelihood of completing the project on time for each job.

Table 2. Optimistic (O), Normal (N), and Pessimistic (P) Durations for Each Job

Work	Code	Duration		
		O	N	P
Glass Wall/tempered glass	A	4	6	7
Ceramic/Mosaic Wall	B	2	4	3
Marble wall	C	1	3	2
Wall with Cladding Aluminum Composite Cover	D	4	5	7
Triplex Ceiling	E	3	5	6
Acoustic Ceiling	F	5	3	5
Gypsum Ceiling	G	6	4	5
Wooden Ceiling	H	4	3	5
Metal Ceiling	I	4	7	11
Locks, latches, and hinges	J	3	4	6
Sliding door, rolling door, folding door	K	7	6	8
Aluminum Frame	L	5	7	8
Wooden Frame	M	3	4	3
Plastic Frames and Iron Frames	N	7	4	3
Door Closer	0	4	4	5

3.2. Forward Calculation

Forward calculation is a calculation that starts from the initial node and moves to the end to calculate Fuzzy Early Start (FES) and Fuzzy Early Finish (FEF). From the above network, forward calculations can be performed for each job. The FES value for code A (Glass Wall/tempered glass) is (0,0,0) as it is the first job to be performed. Therefore, its FES value is as shown in Figure 5.

The x value is the crisp output value of the fuzzy membership function. This calculation process is interpreted as the defuzzification process. At an α level, in this case, the α-cut value for code A is 73.13%, so that x will produce two different values for the minimum and maximum states. The x values are:

$$X1 = 6\,\alpha + 4$$
$$= 6\,(0{,}7313) + 4 = 8{,}5 \text{ days}$$
$$X2 = 7 - 3\alpha$$
$$= 7 - 3\,(0{,}7313) = 5 \text{ days}$$

LONTAR KOMPUTER VOL. 16, NO. 1 APRIL 2025
DOI : 10.24843/LKJITI.2025.v16.i01.p05
Accredited Sinta 2 by RISTEKDIKTI Decree No. 158/E/KPT/2021
p-ISSN 2088-1541
e-ISSN 2541-5832

The results of this calculation imply that code A1 can be completed in a minimum of 5 days and a maximum of 8,5 days. Similarly, FES and FEF values are obtained for the following jobs.

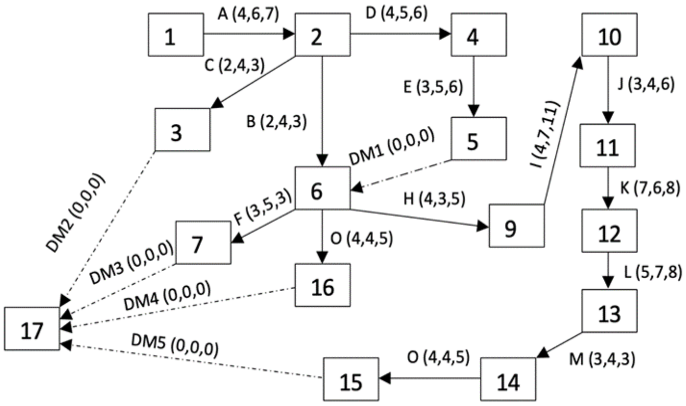

Figure 4. AOA Project work for Elementary School building maintenance scheduling.

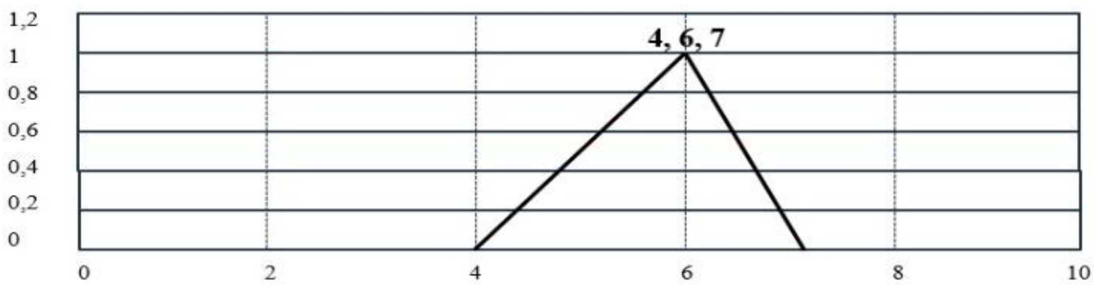

Figure 5. FEF Graph for Job A

3.3. Backward Calculation

Similar to scheduling with CPM, backward calculation is also carried out. It is performed to calculate Fuzzy Latest Start (FLS) and Fuzzy Earliest Finish (FEF) and begins from the last activity to the first. In this case, subtraction is applied to calculate the values of FLS and FEF. As the name suggests, the calculation starts from the end (or the last activity), assuming that the FLF value for the previous job, Door Closer (O), is the same as its FLS value. Thus, the calculation can be performed to find its FLS value as follows.
FLSS = FLPS (-) FDS
FLSS = FLPS (-) FDS

3.4. Float Calculation

Float time in fuzzy logic aims to determine critical points. For example, based on the data for job A (Glass Wall/tempered glass), the values of TF, FF, and IF are calculated as follows.
TFA1 = FLFA1-FDA1-FESA1
= (-7,11,15) - (5,1,4) - (0,0,0)
= (-7-11-0), (5-1-0), (5–1–0)
= (-11,0,11)

FFA1 = FEFA1 - FDA1 - FESA1
= (5,1,4) – (5,1,4) – (0,0,0)
= (5-4-0), (1-1-0), (4-5-0)
= (-4,0,2)

DOI : 10.24843/LKJITI.2025.v16.i01.p05 **e-ISSN 2541-5832**
Accredited Sinta 2 by RISTEKDIKTI Decree No. 158/E/KPT/2021

IFA1 = FEFA1 – FDA1 - FLSA1
= (5,1,4) – (5,1,4) – (0,0,0)
= (5-4-0), (1-1-0), (4-5-(0))
= (-4,0,8)

Using the same calculation, values for TF, FF, and IF are obtained for all Elementary School building maintenance scheduling jobs. The critical path, in this case, is indicated by the centroid value on Total Float, which is less than or equal to 0 (C ≤ 0). This suggests that attention must be given to this job to avoid delays because there is no float time. The critical path for the bridge project's structural jobs is (A-B-H-I-J-K-L-M-N-O), visualized in Figure 6 with a thick arrow path.

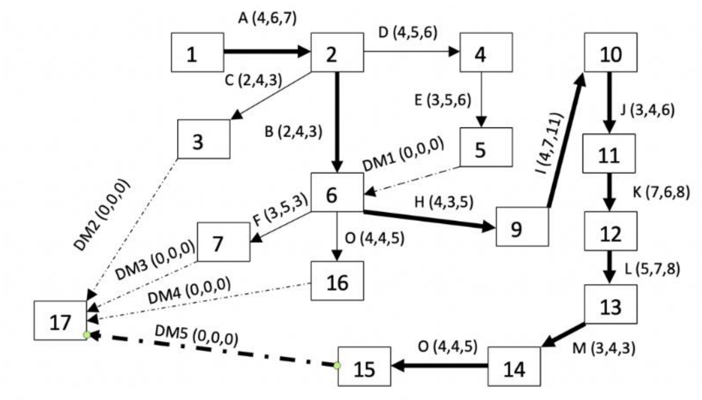

Figure 6. Critical Path in AOA Elementary School Building Maintenance Jobs

3.5. Cost Calculation

Scheduling is closely related to the costs incurred. Therefore, with changes in scheduling, there are also changes in costs. Costs related to time as non-fixed expenses include labor and equipment rental costs, while material costs do not change in this case.

4. Conclusion

The application of the fuzzy logic method in creating construction project scheduling has similarities with CPM for Activity on Arrow (AOA) diagrams and the calculation process, except for the nature of its durations. The duration of activities is composed of fuzzy numbers consisting of two bounds, namely the lower bound and upper bound. After that, a forward calculation analysis is performed using the addition of fuzzy numbers and fuzzy max, and a backward calculation analysis is performed using the subtraction of fuzzy numbers and fuzzy min.

When using CPM, the critical path is identified, and the final result is a single total duration value. In contrast, the fuzzy logic method cannot be used to find the critical path, and its final result is a total duration value in the form of fuzzy numbers, along with the likelihood of when the project can be completed.

The fuzzy logic method can be employed for construction project scheduling according to the schedule determined by the contractor. This allows the contractor to use it as a consideration for the total duration, along with detailed timing in the project proposal. For the owner, it provides insights into the potential project completion time.

The initial plan for the duration of the Architecture work (Division 7) in the elementary school building maintenance project is 154 days. After scheduling with the fuzzy logic application, the fastest duration obtained is 148 days, and the slowest is 162 days.

References

[1] G. A. T. d. Morais and A. C. L. Júnior, "Building maintenance management activities in a public institution," *Engineering, Construction and Architectural Management,* vol. 26, no. 1, pp. 85-103, 2019, doi: https://doi.org/10.1108/ECAM-01-2018-0024.

[2] C. Drent, S. Kapodistria, and J. A. C. Resing, "Condition-based maintenance policies under imperfect maintenance at scheduled and unscheduled opportunities," *Queueing Systems,* vol. 93, pp. 269–308, 2019, doi: https://doi.org/10.1007/s11134-019-09627-w.

[3] A. Maulana and F. Kurniawan, "Time optimization using CPM, PERT and PDM methods in the social and department of Kelautan building development project Gresik district," *IJTI International Journal of Transportation and Infrastructure eISSN 2597-4769 pISSN 2597-4734,* vol. 2, no. 2, pp. 57-66, 2019, doi: https://doi.org/10.29138/ijti.v2i2.784.

[4] Y. Huo, D. Delahaye, and M. Sbihi, "A probabilistic model based optimization for aircraft scheduling in terminal area under uncertainty," *Transportation Research Part C: Emerging Technologies,* vol. 132, 2021, doi: https://doi.org/10.1016/j.trc.2021.103374.

[5] S. Salvatori, V. Introna, V. Cesarotti, and I. Baffo, "Engineer-to-order Project Schedule Planning through a probabilistic simplified approach: a case study," *Journal of Modern Project Management,* vol. 7, no. 3, pp. 190-214, 2019, doi: https://doi.org/10.19255/JMPM02108.

[6] J. Sobieraj and D. Metelski, "Project Risk in the Context of Construction Schedules—Combined Monte Carlo Simulation and Time at Risk (TaR) Approach: Insights from the Fort Bema Housing Estate Complex," *Applied Sciences,* vol. 12, no. 3, p. 1044, 2022, doi: https://doi.org/10.3390/app12031044.

[7] Z. K. Nemaa and G. K. Aswed, "Forecasting construction time for road projects and infrastructure using the fuzzy PERT method," in *IOP conference series: materials science and engineering*, 2021, vol. 1076, no. 1: IOP Publishing, p. 012123, doi: https://doi.org/10.1088/1757-899X/1076/1/012123.

[8] S. Park, N. Kwon, and Y. Ahn, "Forecasting repair schedule for building components based on case-based reasoning and fuzzy-AHP," *Sustainability,* vol. 11, no. 24, p. 7181, 2019, doi: https://doi.org/10.3390/su11247181.

[9] M. Gallab, H. Bouloiz, Y. L. Alaoui, and M. Tkiouat, "Risk assessment of maintenance activities using fuzzy logic," *Procedia computer science,* vol. 148, pp. 226-235, 2019, doi: https://doi.org/10.1016/j.procs.2019.01.065.

[10] N. Dayoub, A. Stashevskiy, S. M. Elroba, and M. R. Elshahate, "Application of Fuzzy theory in project scheduling," in *International Conference on Engineering Systems 2020*, Moscow, 2020: IOP Publishing, doi: https://doi.org/10.1088/1742-6596/1687/1/012011.

[11] E. Akan and S. Bayar, "Interval type-2 fuzzy program evaluation and review technique for project management in shipbuilding," *Ships and Offshore Structures,* vol. 17, no. 8, pp. 1-19, 2021, doi: https://doi.org/10.1080/17445302.2021.1950350.

[12] V. B. Watkar, "Fuzzy Inference Systems: Types & Applications," *Journal of Emerging Technologies and Innovative Research,* vol. 9, no. 12, 2022. [Online]. Available: https://www.jetir.org/papers/JETIR2212653.pdf.

[13] D. P. Umum, "Peraturan Menteri Pekerjaan Umum Nomor 24 Tahun 2008 tentang Pedoman Pemeliharaan dan Perawatan Bangunan Gedung," *Kementerian Pekerjaan Umum. Jakarta,* 2008. [Online]. Available: https://peraturan.bpk.go.id/Details/104476/permen-pupr-no-24prtm2008-tahun-2008.

[14] F. Klashanov and A. Swan, "Application of fuzzy logic methods for controlling buildings HVAC equipment," in *IOP Conference Series: Materials Science and Engineering*, 2020, vol. 869, no. 2: IOP Publishing, p. 022010, doi: https://doi.org/10.1088/1757-899X/869/2/022010.

[15] A. Taneva, D. Atanasova, and A. Daskalov, "Fuzzy Logic Control in Building Automation Application," *Engineering Proceedings,* vol. 41, no. 1, p. 14, 2023, doi: https://doi.org/10.3390/engproc2023041014.

[16] A. Khalim, H. U. Ghifarsyam, N. Rozy, and F. Ma'arif, "Scheduling design of Jakarta-Cikampek II elevated toll road project (P. 186–P. 187)," *Journal of Engineering and Applied Technology,* vol. 1, no. 2, 2020, doi: https://doi.org/10.21831/jeatech.v1i2.34957.

[17] W. W. Yudiarti and F. A. Razi, "Application of Critical Path Method and Fuzzy Logic in Optimizing Bottled Drinking Water Production," *InPrime: Indonesian Journal of Pure and*

Applied Mathematics, vol. 3, no. 1, pp. 53-62, 2021, doi: https://doi.org/10.15408/inprime.v3i1.19646.
[18] A. Wibowo, "Alternatif Metoda Penjadwalan Proyek Konstruksi Menggunakan Teori Set Samar," *Civil Engineering Dimension,* vol. 3, no. 1, pp. 1-8, 2001, doi: https://doi.org/10.9744/ced.3.1.pp.%201-8.
[19] H. Gharib and G. Kovács, "Implementation and Possibilities of Fuzzy Logic for Optimal Operation and Maintenance of Marine Diesel Engines," *Machines,* vol. 12, no. 6, pp. 1-16, 2024, doi: https://doi.org/10.3390/machines12060425.
[20] T. Sudha and G. Jayalalitha, "Fuzzy triangular numbers in-Sierpinski triangle and right angle triangle," in *Journal of Physics: Conference Series*, 2020, vol. 1597, no. 1: IOP Publishing, p. 012022, doi: https://doi.org/10.1088/1742-6596/1597/1/012022.
[21] E. Natarajan, F. Augustin, M. K. Kaabar, C. R. Kenneth, and K. Yenoke, "Various defuzzification and ranking techniques for the heptagonal fuzzy number to prioritize the vulnerable countries of stroke disease," *Results in Control and Optimization,* vol. 12, p. 100248, 2023, doi: https://doi.org/10.1016/j.rico.2023.100248.
[22] Q. Liu and H. Yang, "Incorporating variability in lean manufacturing: a fuzzy value stream mapping approach," *Mathematical Problems in Engineering,* vol. 2020, pp. 1-17, 2020, doi: https://doi.org/10.1155/2020/1347054.
[23] Ö. Ökmen and A. Öztaş, "A CPM-based scheduling method for construction projects with fuzzy sets and fuzzy operations," *Journal of the South African Institution of Civil Engineering,* vol. 56, no. 2, pp. 2-8, 2014, doi: https://hdl.handle.net/10520/EJC158382.
[24] D. Kurnia and W. Aulia, "Simulasi Penjadwalan Kegiatan Fisik Nagari Berbasis Metode Fuzzy Logic Application For Schedulling," *Jurnal Sains dan Informatika: Research of Science and Informatic,* vol. 5, no. 2, pp. 70-77, 2019, doi: https://doi.org/10.22216/jsi.v5i2.4771.
[25] A. Francis and S. Morin-Pepin, "The concept of float calculation based on the site occupation using the chronographical logic," in *Creative Construction Conference*, Primosten, Croatia, 2017, vol. 196: Procedia Engineering, ScienceDirect, Elsevier Ltd, pp. 690-697, doi: https://doi.org/10.1016/j.proeng.2017.07.235.
[26] J. Nisar and S. Halim, "The effect of critical activity on critical path and project duration in Precedence Diagram Method," *International Journal of Structural and Construction Engineering,* vol. 12, no. 9, pp. 837-843, 2018, doi: https://doi.org/10.5281/zenodo.1474541.
[27] V. Shankar, A. Venkatesh, C. Hofacker, and P. Naik, "Mobile marketing in the retailing environment: current insights and future research avenues," *Journal of Interactive Marketing,* vol. 24, no. 2, pp. 111-120, 2010, doi: https://doi.org/10.1016/j.intmar.2010.02.006.