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ESTIMATING HOUSE CONSTRUCTION COMPLETION TIME WITH PROBABILISTIC ACTIVITIES DURATION USING THE PROGRAM EVALUATION AND REVIEW TECHNIQUE (PERT) METHOD

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Abstract

Construction housing projects involve many risks and uncertainties that can affect their completion time. To ensure a construction housing project is completed on time, accurate duration estimates are required for each activity. Deterministic duration methods, such as the Critical Path Method (CPM), are commonly used in project scheduling for construction projects. However, this method may not always produce a realistic schedule as it uses only a single duration estimation for each activity. As an alternative, this study uses the Program Evaluation and Review Technique (PERT) which utilizes three duration estimates namely optimistic duration, most likely duration, and pessimistic duration. A house construction project with 23 activities was analyzed using CPM to find the critical activities which produced 59 days of completion time. The critical path durations were then analyzed using PERT. PERT calculations found that there was only a 15% probability to complete the project in 59 days, and the project needed 66 days of completion time with a 95% level of confidence. The findings of this study indicate that PERT can assist project managers in creating a more realistic project schedule by considering the risks and uncertainties in estimating the duration of its activities.

Keywords: PERT, Scheduling, CPM, Construction Project, Probabilistic Duration

Abstrak

Proyek konstruksi perumahan memiliki banyak risiko dan ketidakpastian yang dapat mempengaruhi waktu penyelesaiannya. Untuk memastikan proyek konstruksi perumahan dapat diselesaikan tepat waktu, diperlukan estimasi durasi yang akurat untuk setiap aktivitasnya. Metode durasi deterministik, seperti Critical Path Method (CPM), adalah metode yang umum digunakan dalam penjadwalan proyek konstruksi. Namun, metode ini tidak selalu menghasilkan jadwal yang realistis karena hanya menggunakan satu perkiraan durasi untuk setiap aktivitas. Sebagai alternatif, studi ini menggunakan Program Evaluation and Review Technique (PERT) yang memeiliki tiga estimasi durasi, yaitu durasi optimistis, durasi paling mungkin, dan durasi pesimistis. Sebuah proyek konstruksi rumah dengan 23 aktivitas dianalisis dengan menggunakan metode CPM untuk menentukan aktivitas-aktivitas kritisnya dan didapatkan waktu penyelesaian 59 hari. Durasi jalur kritis kemudian dianalisis menggunakan metode PERT. Perhitungan PERT menemukan bahwa hanya ada 15% probabilitas untuk menyelesaikan proyek tersebut dalam waktu 59 hari, dan proyek membutuhkan 66 hari untuk selesai dengan tingkat kepercayaan 95%. Hasil penelitian ini menunjukkan bahwa PERT dapat membantu manajer proyek dalam membuat jadwal proyek yang yang lebih realistis dengan cara mempertimbangkan risiko dan ketidakpastian dalam penentuan durasi aktivitas-aktivitasnya.

Kata kunci: PERT, Scheduling, CPM, Construction Project, Probabilistic Duration

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1. Introduction

Construction projects have many risk and uncertainty factors that can affect the completion time of a project (Goh et al., 2013). Housing construction projects are one part of the construction industry with complex construction processes that involve many activities, each with its risks and uncertainties.

For a housing construction project to be completed on time, accurate duration estimates are needed for each activity. Typically, scheduling a construction project uses deterministic duration methods for each activity, where each activity is scheduled using a single duration without taking into account duration variability (Ballesteros-Pérez et al., 2020) which is too optimistic and unrealistic for real projects (Ballesteros-Pérez et al., 2018; Barrientos-Orellana et al., 2021). Therefore, construction projects often exceed their planned duration (González-Cruz et al., 2022) which is a widely known problem in the construction industry (Budayan et al., 2018; Fan et al., 2021; Mohammed & Bello, 2022; Sweis, 2013)

The weakness of deterministic duration methods is that they do not always produce realistic scheduling that takes into account the risks and uncertainties present in a construction project (González-Cruz et al., 2022; Zidane & Andersen, 2018). An alternative method that can be used is the probabilistic duration method. Probabilistic duration methods are scheduling methods that take into account the risks and uncertainties in determining the duration of each activity in a construction project (Lu & AbouRizk, 2000), which in turn will produce more realistic project duration estimates.

This study aims to investigate the use of probabilistic duration methods in scheduling housing construction projects. It is hoped that the results of this study will help the construction industry in general and the housing industry in particular to improve their scheduling accuracy.

2. Material and Methods

2.1. Study Location

The study was carried out in one of the housing construction locations in Palu City, the capital of Central Sulawesi Province, Indonesia.

2.2. Data

Data of typical house type 36 construction activities were collected during field works and interviews with the housing developer site engineers, as shown in Table 1. The picture of a typical house type 36 is shown in Figure 1.

Table 1 House Type 36 Construction Activity Duration and Logical Relationship

No	Activity	Immediately Preceding Activities	Duration (days)		
			Optimistic	Most Likely	Pessimistic
1.	Site clearance	-	1	2	4
2.	Stake out	Site clearance	1	2	4
3.	Footing excavation	Stake out	1	2	3
4.	Footing	Footing excavation	1	2	4

Diterima 12 Januari 2023, Direvisi 9 Februari 2023, Diterima untuk publikasi 20 April 2023

5.	Plumbing	Footing	0.5	1	2
6.	Footing backfills	Plumbing	1	2	4
7.	Steel fabrication	Footing	2	3	5
8.	Lower tie beam	Steel fabrication	1	2	4
9.	Wall, column, window, and door frame	Footing backfills, Lower tie beam	6	7	9
10.	Upper tie beam	Wall, window, and door frame	1	2	5
11.	Brick rafter	Upper tie beam and column	2	3	5
12.	Steel Roof	Brick rafter	1	2	3
13.	Electrical rough-in	Steel Roof	1	2	3
14.	Wall plaster	Electrical rough-in	7	10	15
15.	Bathroom and toilet fixtures	Wall plaster	1	2	3
16.	Floor	Bathroom and toilet fixtures	3	4	7
17.	Septic tank	Floor	1	2	3
18.	Carport	Septic tank	1	2	3
19.	Ceiling	Floor	2	3	4
20.	Doors and windows installation	Ceiling	2	3	5
21.	Painting	Doors and windows installation	3	4	6
22.	Electrical fitting	Painting	1	2	3
23.	Cleaning	Electrical fitting, Carport	1	2	3

Figure 1 Typical House Type 36

Diterima 12 Januari 2023, Direvisi 9 Februari 2023, Diterima untuk publikasi 20 April 2023

2.3. Literature Review

2.3.1. Deterministic Scheduling Method

The Critical Path Method (CPM) is a deterministic scheduling method commonly used in construction project scheduling (Rama et al., 2017). The advantage of CPM in project scheduling is that the calculation process to determine the completion time of a project is relatively easy (González-Cruz et al., 2022). However, because the duration of each activity is deterministic, in other words, there is only one duration value for each activity, the CPM analysis results on the overall completion time of a project will also produce a single value (Kerzner, 2003; Mubarak, 2010; Turner, 2009), where the uncertainty factor that always exists in every construction project is not taken into account.

2.3.2. Probabilistic Scheduling Method

Program Evaluation and Review Technique (PERT) is a method that can be used to analyze the duration of each activity in a construction project probabilistically.

The PERT method uses three duration estimates based on the practical conditions and situations of the construction project being analyzed (Kerzner, 2003). These three duration estimates are optimistic duration, most likely duration, and pessimistic duration (Ballesteros-Pérez et al., 2020). Based on these three duration estimates, PERT uses the central limit theorem, which treats the average duration of each activity as a normal distribution used in calculating the expected duration, variance, and standard deviation of a construction project (Mubarak, 2010). The PERT method allows project management to determine the probability of the total duration of a project with a desired level of confidence.

The use of the PERT method in construction project scheduling can be seen in many works of literature, for example, in Aja & Chukwu (2017) and Lu & AbouRizk (2000). Comparative studies between the use of CPM and PERT methods in construction projects (Agyei, 2015; Cynthia, 2020) found that the PERT method is more realistic for project completion time estimation as it takes into account risk and uncertainty factors that are common in construction projects.

2.4. Methods

2.4.1. Precedence Diagrams Network Development and CPM Calculation

Data in Table 1 were used to develop a network using the precedence diagrams method with the most likely durations serving as a deterministic duration for each activity. The network of precedence diagrams and CPM calculation results is presented in Figure 2 where the critical activities are depicted in bold lined nodes. As can be seen in Figure 2, the completion time for one house type 36 is 59 days.

Diterima 12 Januari 2023, Direvisi 9 Februari 2023, Diterima untuk publikasi 20 April 2023

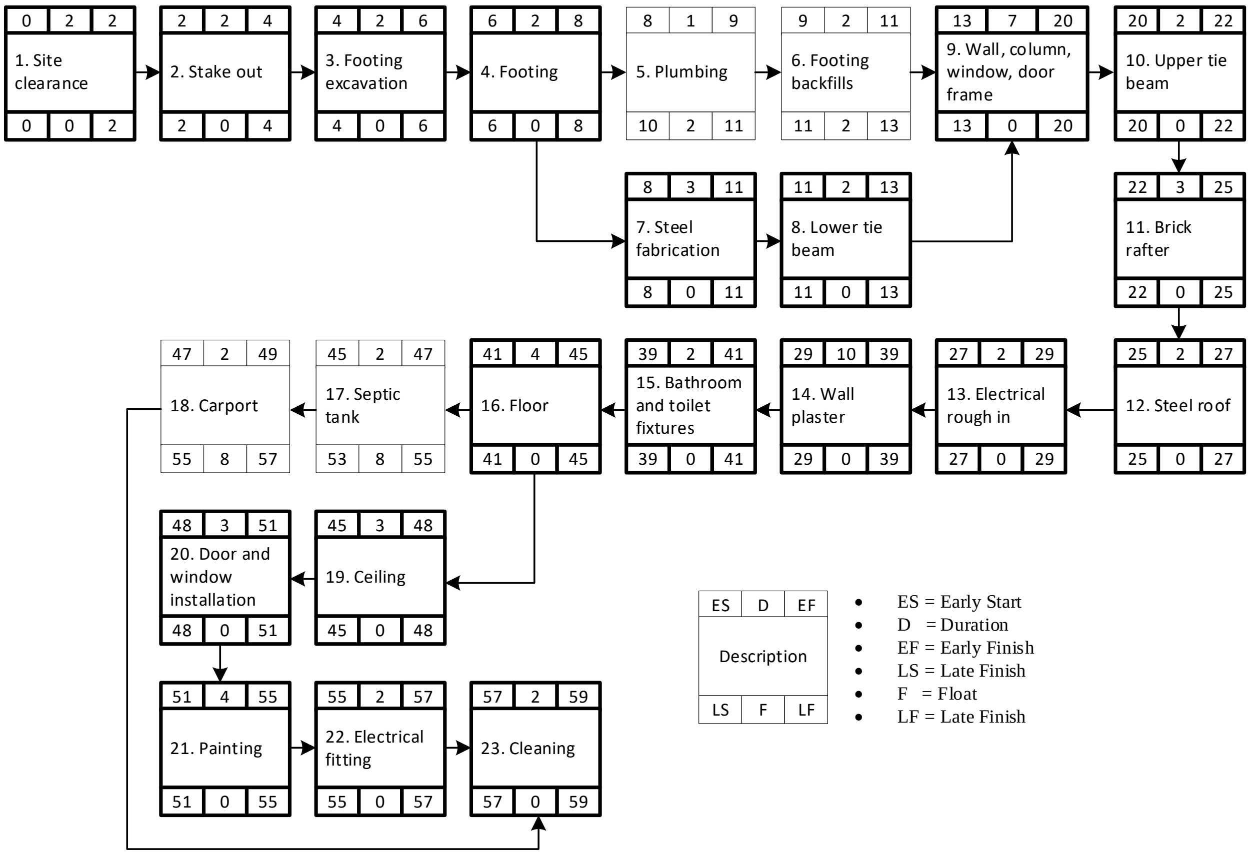

Figure 2 Precedence Diagrams and CPM Calculation Results

2.4.2. Program Evaluation and Review Technique Calculations (PERT)

In PERT, for each critical activity, three durations must be calculated namely:

T_o: optimistic duration

T_m: most likely duration

T_p: pessimistic duration

Program Evaluation and Review Technique (PERT) calculations (Mubarak, 2010) adhere to the following steps.

1. Calculate each activity's expected duration (T_e) using Equation 1.

$$T_e = \frac{T_o + 4T_m + T_p}{6} \quad (1)$$

2. Determine the standard deviation for the expected duration (σ_e) using Equation 2.

$$\sigma_e = \frac{T_p - T_o}{6} \quad (2)$$

3. Calculate the variance (V_e) of the expected duration with Equation 3.

$$V_e = \sigma_e^2 \quad (3)$$

4. Determine the expected duration for all critical activities (T_E) using Equation 4.

Diterima 12 Januari 2023, Direvisi 9 Februari 2023, Diterima untuk publikasi 20 April 2023

$$T_E = \sum_{i=1}^{n} (T_e)_i \tag{4}$$

5. The variance for the critical path (V_E) is determined using Equation 5.

$$V_E = \sum_{i=1}^{n} (\sigma_e^2)_i \tag{5}$$

6. The standard deviation for the critical path (σ_E) is calculated using Equation 6.

$$\sigma_E = \sqrt{V_E} \tag{6}$$

3. Results and Discussion

PERT calculation results are shown in Table 2 as follows.

Table 2 PERT Calculation Results

No	Activity	Duration (days)			Expected Duration (T_e)	Standard Deviation (σ_e)	Variance (V_e)
		Optimistic (T_o)	Most Likely (T_m)	Pessimistic (T_p)			
1.	Site clearance	1	2	4	2.17*	0.500	0.250
2.	Stake out	1	2	4	2.17*	0.500	0.250
3.	Footing excavation	1	2	3	2*	0.333	0.111
4.	Footing	1	2	4	2.17*	0.500	0.250
5.	Plumbing	0.5	1	2	1.08	0.250	0.063
6.	Footing backfills	1	2	4	2.17	0.500	0.250
7.	Steel fabrication	2	3	5	3.17*	0.500	0.250
8.	Lower tie beam	1	2	4	2.17*	0.500	0.250
9.	Wall, column, window, and door frame	6	7	9	7.17*	0.500	0.250
10.	Upper tie beam	1	2	5	2.33*	0.667	0.444
11.	Brick rafter	2	3	5	3.17*	0.500	0.250
12.	Steel Roof	1	2	3	2*	0.333	0.111
13.	Electrical rough-in	1	2	3	2*	0.333	0.111
14.	Wall plaster	7	10	15	10.33*	1.333	1.778
15.	Bathroom and toilet fixtures	1	2	3	2*	0.333	0.111
16.	Floor	3	4	7	4.33*	0.667	0.444
17.	Septic tank	1	2	3	2	0.333	0.111
18.	Carport	1	2	3	2	0.333	0.111
19.	Ceiling	2	3	4	3*	0.333	0.111
20.	Doors and windows installation	2	3	5	3.17*	0.500	0.250
21.	Painting	3	4	6	4.17*	0.500	0.250
22.	Electrical fitting	1	2	3	2*	0.333	0.111
23.	Cleaning	1	2	3	2*	0.333	0.111

*Critical activity

PERT assumes that the project completion time equals the sum of all its critical activities (Khamooshi & Cioffi, 2013; Nelson et al., 2016), therefore, the following calculations were only carried out on the critical activities shown in Table 2.

Diterima 12 Januari 2023, Direvisi 9 Februari 2023, Diterima untuk publikasi 20 April 2023

The expected duration for all critical activities (T_E), the variance for the critical path (V_E), and the standard deviation for the critical path (σ_E) are then calculated using Equation 4, Equation 5, and Equation 6 respectively. Therefore, T_E = 61.50, V_E = 5.69, and σ_E = 2.39.

It is now possible to calculate the probability of completion time on a certain day by using the normal distribution formula as follows.

$$Z = \frac{T_S - T_E}{\sigma_E} \quad (7)$$

Using Equation 7 and Table 3 (Taha, 2017), the probability of the project completion is 59 days as in the CPM calculation in Figure 2, is calculated as follows.

$Z = \frac{T_S - T_E}{\sigma_E} = (59 - 61.50)/2.39 = -1.05$. Since Z < 0, take the probability of the positive value Z, then subtract it from 1.0 (100%). Therefore, the probability of T_S equals 59 days = 1 – 0.8485 = 0.152 = 15%. In other words, the probability of completing the project in 59 days, as in the CPM calculation in Figure 2, is only 15%.

Using Table 3 and Equation 7 it is also possible to calculate the estimated project completion time with a certain level of confidence.

$$T_s = \sigma_E * Z + T_E \quad (7)$$

Thus, the estimated project completion time with a 95% level of confidence is as follows.

$T_s = \sigma_E * Z + T_E$ = 2.39*1.65 + 61.50 = 65.44 ≈ 66 days which is 7 days longer that the completion time of 59 days as calculated by CPM in Figure 2.

Table 3 Z-score Cumulative Probability of the Standard Normal Distribution

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
0.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
0.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
0.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	0..6443	.6480	.6517
0.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
0.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
0.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
0.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
0.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
0.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830

Diterima 12 Januari 2023, Direvisi 9 Februari 2023, Diterima untuk publikasi 20 April 2023

1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.3	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.4	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.0	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990

4. Conclusion

The study indicates that PERT can assist project managers in creating a more realistic schedule that factors in risks and uncertainties by using probabilistic activity duration. Despite its effectiveness, PERT's precision is determined by the input variables and the project model or network being analyzed. PERT's accuracy may be compromised if the project model is inadequate, or if the project activity durations are not properly estimated.

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