Optimizing House Renovation Projects Using Industrial Engineering-Based Approaches

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***Abstract*—The persistent challenge of project delays poses significant issues with the escalating demand for house renovations. The company in Kedah, Malaysia, faces frequent project delays due to ineffective project management, leading to substantial liquidated damages. This study aims to minimise project delays and ensure timely completion within budget constraints, focusing on both the entire house renovation project and the kitchen renovation project. This study employed the Program Evaluation and Review Technique to illustrate the project network and utilised the Critical Path Method to identify the critical path while implementing project crashing with linear programming to optimise activity duration reduction and minimise costs. The PERT method results in an illustrative network diagram that aids subsequent analysis. The completion time for the entire house renovation project is determined to be 58 days using CPM, with a 96.8% probability of completion within 60 days. In contrast, for the kitchen renovation project, the completion time is identified as 38 days, with a 0% probability of meeting the 30-day deadline. Therefore, linear programming was successfully applied, shortening the kitchen project to 30 days at a total cost of RM 18,517.50, further reduced to 20 days with a cost of RM 20,980. Both scenarios remained below the total penalty cost of RM 21,780. The finding enables the company to make informed decisions on resource allocation to accelerate project duration and avoid delays. Future research should delve into realistic models, considering labour allocation and indirect costs, for a more comprehensive evaluation of project crashing strategies and their financial impacts.**

Keywords—House renovation; Program Evaluation and Review Technique (PERT); Critical Path Method (CPM); project crashing techniques; construction project management; linear programming optimisation

I. Introduction

In any generation, houses serve as essential shelter, playing an important role in people's lives. House renovation has become a common phenomenon in recent years as the quality of life improves and people focus more on creating a comfortable and safer home environment. Simultaneously, the growing trend of renovating kitchens underscores this space's unique role as the hub and heart of the home. Homeowners are increasingly investing in both entire house and kitchen renovation projects, driven by a desire to enhance functionality, increase property value, and create inviting spaces for family gatherings and social events. These renovations, offering customisation within budget constraints, also pose challenges with project deadlines. Delays often arise from factors such as ineffective planning, material and labour shortages, adverse weather, and equipment failures [1]. In addition, as project complexity increases, improper management can lead to cost overruns and schedule delays. To mitigate these challenges, this study aims to minimise project delays and ensure timely completion within budget by employing effective project management tools and techniques. This study was conducted on two cases, an entire house and a kitchen renovation, by a renovation company in Kedah, Malaysia.

According to a study [2], the construction industry historically faces challenges like delays, exceeding budgeted costs, and substandard quality. Similar causes of delays, such as inadequate planning and scheduling and insufficient site management, have been emphasised in studies by [1], [3], [4], and [5]. Besides that, the ever-changing nature of project development poses challenges for construction companies lacking adequate project management skills [6]. Therefore, as [7] emphasises, efficient project management has several advantages, including cost, time, and quality assurance. According to study [8], project management is characterised by using knowledge, skills, tools, and techniques to manage project activities and meet specific requirements effectively. Similarly, [9] proposes that utilising project management tools can alleviate challenges in planning, organising, and managing diverse sets of resources. [10] and [11] emphasise that effective project planning and scheduling are essential for successful construction projects, ensuring timely completion within budget and meeting quality standards. However, project planning and scheduling represent one of the most difficult tasks faced by managers, requiring a deep understanding of the planned work [12], especially for complex construction projects where careful consideration of project scheduling and cost planning is essential [13].

The Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) are proven approaches that aid in planning, scheduling, and controlling construction projects [14]. Studies by [15], [16], and [17] highlight the effectiveness of CPM and PERT in identifying the critical path, allowing for better control and acceleration of activities to ensure timely project completion. Project crashing is a strategy for utilising additional resources to expedite critical activities and meet deadlines [18] and [19]. [20] assert that delays can be mitigated by implementing project crashing strategies while considering the cost factor simultaneously. Additionally, [21] and [22] apply linear programming, which results in a cost increase but significantly shortens the project duration. However, the study in [23] stated that combining linear programming with project crashing can minimise project overruns. These methods have proven helpful in project management, allowing for proper planning and scheduling of projects and effective control of costs.

In this study, two crucial components of project management, PERT and CPM, will be utilised to illustrate the project network, identify critical paths, and estimate the probability of completion time for both the entire house and kitchen renovation projects. Subsequently, linear programming will be applied for project crashing in the kitchen renovation project. Finally, the performance of the project crash results will be compared with the current project cost and completion time for the kitchen renovation project. This study will help various renovation companies understand the importance of applying project management principles to their projects.

II. Materials and Methods

A. Data Description

The data obtained from a private renovation company in Kedah, Malaysia, consists of two case studies: the entire house and the kitchen renovation projects. This deliberate selection aims to evaluate the applicability of various project management tools to datasets of different sizes. The entire house renovation dataset, representing a large-scale project with a 60-day deadline, includes the duration of each activity and the corresponding total renovation cost for each project scope. In contrast, the kitchen renovation dataset reflects a smaller-scale project with a 30-day deadline. This dataset provides comprehensive information on the duration and cost associated with each renovation step within the kitchen. This dual-dataset approach enables a comprehensive assessment of project management tools across varying project complexities. A one-week delay resulted in a penalty of approximately RM4,000 for these projects.

B. PERT

The PERT methodology facilitates a comprehensive analysis of project completion time by incorporating a three-point time estimate, addressing uncertainties in activity duration. It employs three different time estimates: optimistic (a), most likely (m), and pessimistic (b) to account for variability [24]. The optimistic estimate signifies the minimum activity duration; the most likely estimate reflects the duration expected to occur most frequently; and the pessimistic estimate represents the maximum expected duration. To calculate the expected time (Te) and variance (V) of each activity duration, specific formulas are utilised. Eq. (1) estimates the average duration, while Eq. (2) quantifies the level of uncertainty associated with each activity [25].

$$Te = \frac{(a + 4m + b)}{6} \tag{1}$$

$$V = \left[\frac{b - a}{6}\right]^2 \tag{2}$$

C. CPM

Using a network-based approach, the CPM identifies time-sensitive activities crucial for project success, considering parameters such as earliest start (ES), earliest finish (EF), latest start (LS), latest finish (LF), and slack time (S) [26]. Eq. (3) and (4) determine the earliest start and finish times, while Eq. (5) and (6) establish late start and finish times [27]. These calculations indirectly yield slack time, defined as the maximum allowable delay for an activity without affecting project completion. The critical path, characterised by zero slack, represents the path with the longest duration in the network [28], with the formula for slack time outlined in Eq. (7). Determining the critical path is vital for guiding completion time, coordinating activities, developing schedules, and monitoring project planning [29].

$$ES(j) = maximum\,\{EF(i)\}, j = 1,2,3,\dots,n \tag{3}$$

$$ES(j) = ES(j) + Duration \tag{4}$$

$$LF(i) = minimum\,\{LS(j)\}, i + n - 1, n - 2, \dots, 0 \tag{5}$$

$$LS(i) = LF(i) - Duration \tag{6}$$

$$S = LS - ES = LF - EF \tag{7}$$

Furthermore, the variations in activities along the critical path can significantly impact the overall project completion. Assessing the variances of critical path activities contributes to a more comprehensive understanding of project uncertainty. The standard normal (Z) can be obtained from Eq. (8), thus referring to the normal distribution table to find the probability. A higher calculated probability, approaching 100%, signifies a greater likelihood of meeting the project deadline, whereas a lower probability, nearing 0%, suggests a reduced likelihood of achieving the project duration [30].

$$Z = \frac{\text{Due date} - \sum \text{Expected date of completion}}{\sum \sqrt{\text{All the variance of critical activities}}} \tag{8}$$

D. Project Crashing

Project crashing involves minimising a project's remaining duration by reducing the time required for critical activities, resulting in additional costs, known as crash costs, due to the increased allocation of resources to ensure timely completion [31]. The methodology includes identifying the normal critical path and its critical activities. Following this, the crash cost per period for various activities is computed using Eq. (9). Next, the critical path activity with the lowest crash cost per period is identified and accelerated to the maximum extent possible or until the desired deadline. The process is iteratively checked to ensure the critical path remains unchanged. This iterative approach continues until the optimal solution is attained and the project reaches its desired completion date [32].

$$\text{Crash cost per time period} = \frac{\text{Crash cost} - \text{Normal cost}}{\text{Normal time} - \text{Crash time}} \tag{9}$$

E. Linear Programming

Linear programming serves as an alternative approach to optimising project crashing schedules, involving three key components: decision variables, an objective function, and constraints. The objective is to minimise the cost of crashing the entire project. Therefore, the objective function can be defined based on Eq. (10) [32]. The objective function is subject to several constraints, such as the maximum reduction constraint, the start time constraint, the project duration constraint, and non-negativity constraints [14]. The maximum reduction constraint ensures each activity does not crash more than the maximum crashing time. In a project, activities are interconnected, and the beginning of certain activities relies on the completion of others. To ensure a smooth flow of work, the sequence of activities needs to be established by setting start time constraints. The project duration constraint is determined at the last activity before the project deadline.

$$\text{Minimise crash cost, } z = \sum_{i=1}^{n} C_i Y_i, i = 1, 2, 3, \ldots, n \qquad (10)$$

Subject to:

- Maximum reduction constraint, $y_i \leq$ Allowable crashing time for activity i measured in terms of days
- Start time constraint, $X_i \geq X_{\text{Predecessor}} + (t - Y_i)$
- Project duration constraint, $X_{\text{Finish}} \leq$ The completion project time at the last activity
- Non – negativity constraint, $x_i, y_i \geq 0$

Where X_i represents the time when the event i will occur, measured since the beginning of the project; Y_i represents the number of time activity will be crashed, where $i = (1, 2, 3, \ldots, n)$; X_{Start} represents the start time for the project (usually 0); X_{Finish} represents the earliest finish time of the project; C_i represents the crash cost per unit of time for activity i.

III. Result and Discussion

This section explores two case studies: the entire house renovation project and the kitchen renovation project.

A. Case Study 1: Entire House Renovation Project

Illustrating the project network, identifying the critical path and activities, and estimating the probability of completing the overall project are the key objectives for this case study.

1) Project network for case study 1: For the entire house renovation project, there are a total of 31 activities.

Fig. 1 displays the PERT network diagram, which starts with activity A and ends with activity AF. Notably, activities E and F have the highest number of predecessors, with three dependents each, originating from activities B, C, and D. Following this, the second-highest number of predecessors is found in activities G, M, P, W, X, Y, and AE, each having two dependents.

2) Critical path and activities for case study 1: Fig. 2 clearly shows the duration, earliest start (ES) time, earliest finish (EF) time, latest start (LS) time, latest finish (LF) time, and slack time for each activity in the entire house renovation project.

The yellow path in Fig. 2 represents the critical path, which is characterised by zero slack and represents the critical activities in case study 1. Notably, there are two critical paths in the project, totalling 58 days.

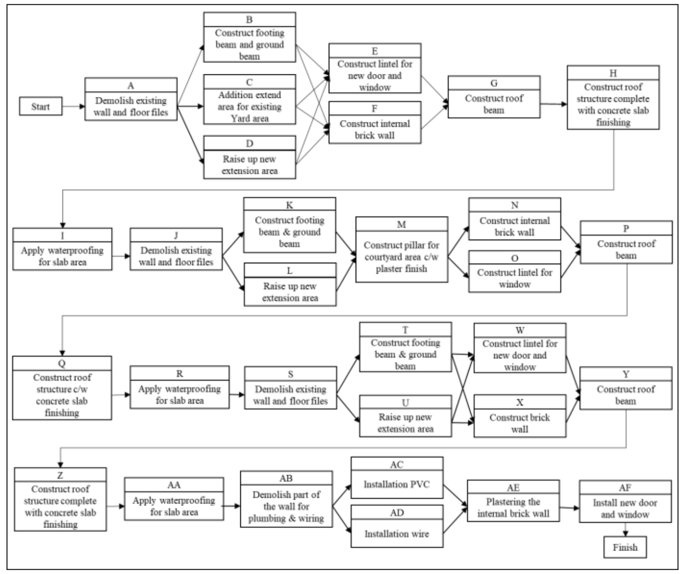

Fig. 1. PERT network diagram for case study 1.

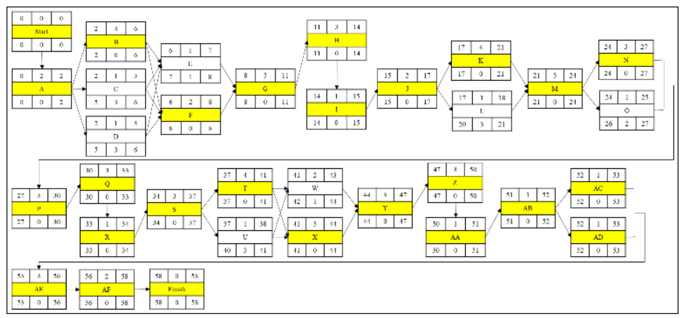

Fig. 2. CPM network diagram for case study 1.

3) Probability of completion time for case study 1: The PERT method employs three-time estimates, which are optimistic time (a), most likely time (m), and pessimistic time (b). Using Eq. (1) and Eq. (2), the PERT method calculates the expected time and variances. The results are presented in Table I.

The deadline for this project is 60 days, and the expected date of completion is 58 days. So, the z value can be obtained using Eq. (8):

$$Z = \frac{60 - 58}{\sqrt{1.167}} = 1.8514$$

Then, this z value can be seen in the standard normal distribution table. The z-value of 1.8514 obtained from the standard normal distribution table corresponds to a probability of 0.9679, which is expressed as a percentage of approximately 96.8%. This high probability suggests a strong likelihood that the project will be completed on schedule in less than or equal to 60 days. Given this higher probability and the absence of a risk of penalties for project delay, the application of linear programming for project crashing was deemed unnecessary. Implementing project crashing would typically involve additional costs to expedite critical activities, and in this context, the substantial likelihood of on-time completion rendered the incurring of extra expenses unnecessary.

TABLE I. PROJECT VARIANCE FOR EACH ACTIVITY IN CASE STUDY 1

Activity Code	Estimation Time (day)			Expected time, Te	Variance, V
	a	***m***	***b***		
A	1.5	2	3	2.083	0.063
B	3	4	5	4.000	0.111
C	0.5	1	1	0.917	0.007
D	0.5	0.5	1	0.583	0.007
E	0.5	1	2	1.083	0.063
F	2	2.5	3	2.500	0.028
G	2	3	3	2.833	0.028
H	2	3	4	3.000	0.111
I	0.5	0.5	1	0.583	0.007
J	1.5	2	3	2.083	0.063
K	3	4	5	4.000	0.111
L	0.5	0.5	1	0.583	0.007
M	2	3	3	2.833	0.028
N	2	2.5	3	2.500	0.028
O	0.5	0.5	1	0.583	0.007
P	2	3	3	2.833	0.028
Q	2	3	4	3.000	0.111
R	0.5	0.5	1	0.583	0.007
S	1.5	2	3	2.083	0.063
T	3	4	5	4.000	0.111
U	0.5	0.5	1	0.583	0.007
W	0.5	1	2	1.083	0.063
X	2	2.5	3	2.500	0.028
Y	2	3	3	2.833	0.028
Z	2	3	4	3.000	0.111
AA	0.5	0.5	1	0.583	0.007
AB	1	1	2	1.167	0.028
AC	0.5	1	1	0.917	0.007
AD	0.5	1	1	0.917	0.007
AE	2	3	3	2.833	0.028
AF	1	1.5	2	1.500	0.028

B. Case Study 2: Kitchen Renovation Project

The process for case study 2 involves illustrating the project network, identifying the critical path and activities, estimating the probability of completion time, utilising linear programming for resource allocation to accelerate the schedule, and finally, comparing the project crash results with the current cost and completion time of the kitchen renovation project.

1) Project network for case study 2: For the kitchen renovation project, there are a total of 18 activities.

Fig. 3 illustrates the PERT network diagram, starting with activities A and B. It is worth noting that both activities L and M have the highest number of predecessors, with each having four dependent activities from activities H, I, J, and K, respectively. Then, activities C, N, and Q each have two dependent activities.

2) Critical path and activities for case study 2: Fig. 4 clearly shows the duration, earliest start (ES) time, earliest finish (EF) time, latest start (LS) time, latest finish (LF) time, and slack time for each activity in the kitchen renovation project.

In Fig. 4, the yellow path represents the critical path with zero slack, indicating the critical activities in case study 2. It is evident that in the kitchen renovation project, there are eight critical paths, amounting to 38 days in total.

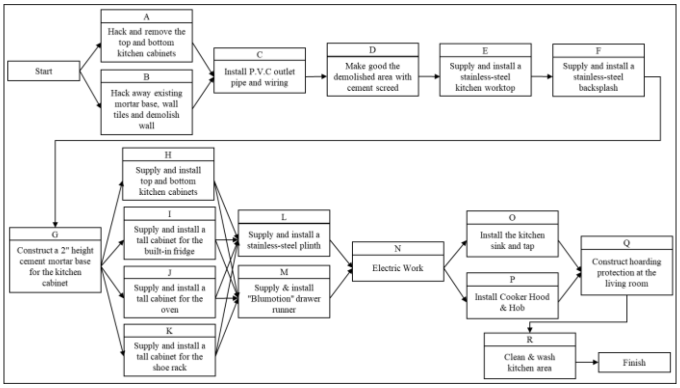

Fig. 3. PERT network diagram for case study 2.

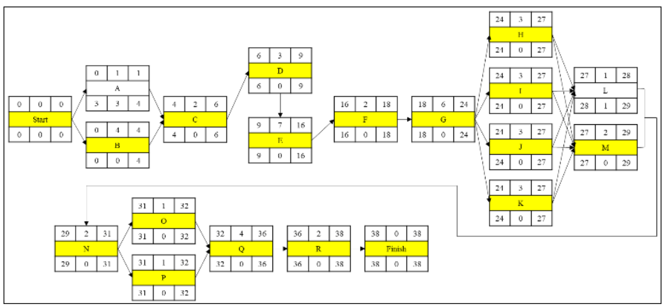

Fig. 4. CPM network diagram for case study 2.

3) Probability of completion time for case study 2: The expected time and variance of the PERT method were calculated by applying Eq. (1) and Eq. (2), as detailed in Table II.

TABLE II. PROJECT VARIANCE FOR EACH ACTIVITY IN CASE STUDY 2

Activity Code	Estimation Time (day)			Expected time, Te	Variance, V
	a	*m*	*b*		
A	0.5	1	1	0.917	0.007
B	3	3.5	4	3.500	0.028
C	1	1.5	2	1.500	0.028
D	2	3	4	3.000	0.111
E	6	7	8	7.000	0.111
F	1	1.5	2	1.500	0.028
G	4	6	7	5.833	0.250
H	2.5	3	4	3.083	0.063
I	2	2.5	3	2.500	0.028
J	2	2.5	3	2.500	0.028
K	2	2.5	3	2.500	0.028
L	0.5	1	1	0.917	0.007
M	1	1.5	2	1.500	0.028
N	1	1.5	2	1.500	0.028
O	0.5	1	1	0.917	0.007
P	0.5	1	1	0.917	0.007
Q	2	4	5	3.833	0.250
R	1	1.5	2	1.500	0.028

The deadline for this project is 30 days, and the expected date of completion is 38 days. So the z value obtained is:

$$Z = \frac{30 - 38}{\sqrt{1.049}} = -7.8109$$

Next, the z value of -7.8109 corresponds to a probability value of 0. When expressed as a percentage, this indicates a 0% probability of completing the project in 30 days or less, signifying that completing the duration is unlikely. Faced with this challenge, the implementation of the project crashing became critical. By accelerating critical activities through project crashing, the likelihood of completing the project within the 30-day deadline significantly increased.

4) Apply linear programming method for project crashing in case study 2: The linear programming method for project crashing is being applied to achieve the shortest possible duration at the least cost. Table III shows the cost-time slope of the kitchen renovation project, including the additional costs incurred resulting from the time reduction, with the crash cost per time calculated using Eq. (9).

TABLE III. COST-TIME SLOPE OF CASE STUDY 2

	Activity description	Normal Time (Days)	Crash Time (Days)	Normal Cost (RM)	Crash Cost (RM)	Crash cost per time
A	Hack and remove the top and bottom kitchen cabinets	1	0.5	350	450	200
B	Hack away existing mortar base, wall tiles and demolish wall	4	2	1000	1450	225
C	Install P.V.C outlet pipe and wiring for kitchen & washing machine	2	0.5	450	600	100
D	Make good the demolished area with cement screed	3	2	1000	1150	150
E	Supply and install a stainless-steel kitchen worktop	7	4	2200	3000	266.67
F	Supply and install a stainless-steel backsplash	2	0.5	800	900	66.67
G	Construct a 2" height cement mortar base for the	6	4	450	770	160

	kitchen cabinet					
H	Supply and install top and bottom kitchen cabinets	3	2	3380	3560	180
I	Supply and install a tall cabinet for the built-in fridge	3	2	780	880	100
J	Supply and install a tall cabinet for the oven	3	2	780	880	100
K	Supply and install a tall cabinet for the shoe rack	3	2	780	880	100
L	Supply and install a stainless-steel plinth.	1	1	3370	3370	0.00
M	Supply & install "Blumotion" drawer runner	2	1	480	580	100
N	Electric Work	2	0.5	800	900	66.67
O	Install the kitchen sink and tap	1	0.5	80	180	200
P	Install Cooker Hood & Hob	1	0.5	100	200	200
Q	Construct hoarding protection at the living room	4	2	700	950	125
R	Clean & wash kitchen area	2	1	280	380	100
Total		50	28	17780	21080	2440

After formulating the objective function and constraints, the linear programming model is applied using Excel Solver. The results of the model solution reduced to 30 days are presented in Table IV.

TABLE IV. SOLUTION OF THE LP PROBLEM USING EXCEL SOLVER FOR 30 DAYS

Objective Value	Final Value
Min Z	RM 737.50
$X_A, X_B, X_D, X_E, X_G, X_H, X_I, X_J, X_K, X_L, X_O, X_P$	0
X_C, X_F, X_N, X_Q	1.5
X_M, X_R	1

In order to meet the desired project completion time of 30 days, specific activities required acceleration. Critical activities identified for crashing were C, F, N, and Q, each requiring a reduction of 1.5 days. Additionally, activities M and R were expedited by 1 day each to align with the targeted project timeline. Initially, the linear programming method was utilised to ensure the completion of the kitchen renovation project within the 30-day deadline by allocating additional resources to accelerate specific tasks. The total cost incurred for crashing these activities amounts to RM737.50.

Subsequently, considering a further reduction in the project duration to 20 days, a detailed analysis was conducted. The application of linear programming successfully achieved the goal of shortening the project duration. The results of the model solution for the 20-day timeline are presented in Table V.

TABLE V. SOLUTION OF THE LP PROBLEM USING EXCEL SOLVER FOR 20 DAYS

Objective Value	Final Value
Min Z	RM 3200
X_A, X_L	0
X_B, X_G, X_Q	2
X_C, X_F, X_N	1.5
$X_D, X_H, X_I, X_J, X_K, X_M, X_R$	1
X_E	3
X_O, X_P	0.5

To meet the project completion time of 20 days, specific adjustments were made to various activities. Activities B, G, and Q were reduced by two days, while activities C, F, and N were accelerated by 1.5 days. Additionally, activities D, H, I, J, K, M, and R were shortened by 1 day each. Further improvements included a 3-day acceleration for activity E and a 0.5-day acceleration for activities O and P. The total cost of crashing these activities into 20 days is RM3,200. Thus, the final project cost, determined through the linear programming method, is RM20,980.

5) Compare the performance of project crashing result with the current project cost and completion time for case study 2: Table VI shows the results of project crashing for the kitchen renovation project in comparison to the current project cost and completion time.

TABLE VI. COMPARISON TABLE IN PROJECT COST AND COMPLETION TIME

	Time	Cost	Penalty	Total Cost
Normal	38 days	RM 17,780	RM4,000	RM 21,780.00
Crash	30 days	RM 737.50	-	**RM 18517.50**
Crash	20 days	RM3200.00	-	**RM 20980.00**

Table VI displays the total direct cost for completing the project within the normal 38-day duration, amounting to RM 17,780, with a penalty of RM 4,000 for a one-week delay. The cost, including the penalty, for completing the project without activity crashing is RM 21,780. Additionally, crashing for 30 days is RM 18,517.50, and for 20 days, it is RM 20,980. Despite the increased cost for shorter durations due to additional resources, both remain below the total cost without crashing. Therefore, the company can decide to add additional resources for crashing the activities to accelerate the project duration. This analysis affirms that the project crashing strategy is cost-effective, helping meet deadlines and avoid penalties.

IV. Conclusion

In conclusion, the application of Program Evaluation and Review Techniques and the Critical Path Method has successfully managed and evaluated two distinct renovation projects: an entire house renovation and a kitchen renovation. This study achieved its first and second objectives by illustrating project networks, estimating completion probabilities, and identifying critical paths and activities for both cases.

For the entire house renovation, the PERT method was employed to construct network diagrams and determine expected times and variances. Critical activities were identified using the Critical Path Method, resulting in a high likelihood of project completion within the 60-day deadline.

In contrast, the kitchen renovation presented challenges with a 30-day deadline and a calculated 38-day completion time using CPM, indicating potential delays. The application of linear programming for project crashing successfully reduced the duration to 30 days, incurring an additional cost of RM737.50. A further reduction to 20 days was achieved, incurring an additional cost of RM3,200. The comparison with the original cost structure confirmed the feasibility of completing the project within the specified time and at a lower cost.

This study contributes significantly to house renovation project management by addressing two projects and providing valuable insights for future research. It effectively tackles persistent project delays through the strategic use of tools like CPM, PERT, and linear programming. The findings emphasise the crucial role of acquiring skills for efficient tool application. The practical implications extend to the industry, aiding renovation companies in improving project management practices for timely and cost-effective outcomes. In summary, this research advances academic understanding and offers actionable strategies for enhancing efficiency and cost-effectiveness in house renovation projects.

However, limitations include challenges in linear programming for projects with complex dependencies and a lack of detailed information on worker allocation and indirect costs. Future research should explore real-world models, consider resource availability, and analyse the impact of worker allocation on project costs and completion time. Additionally, including detailed information on indirect costs would provide a more comprehensive evaluation of project crashing financial impacts. Furthermore, to mitigate delays caused by a lack of project management expertise, it is recommended that companies hire professional project managers. This can enhance planning, scheduling, and overall project efficiency, reducing the likelihood of delays in future house renovation projects.

References

[1] M. Sambasivan, and Y. W. Soon, "Causes and effects of delays in Malaysian construction industry," International Journal of project management, vol. 25, no. 5, pp. 517-526, July. 2007, doi:10.1016/j.ijproman.2006.11.007.

[2] J. K. Larsen, G. Q. Shen, S. M. Lindhard, and T. D. Brunoe, "Factors affecting schedule delay, cost overrun, and quality level in public construction projects," Journal of management in engineering, vol. 32, no. 1, pp. 04015032, Jan. 2016, doi: 10.1061/(asce)me.1943-5479.0000391.

[3] M. Haseeb, Xinhai-Lu, A. Bibi, Maloof-ud-Dyian, and W. Rabbani, "Problems of projects and effects of delays in the construction industry of Pakistan," Australian Journal of Business and Management Research, vol. 1, no. 5, pp. 41–50, Sep. 2011.

[4] H. Doloi, A. Sawhney, K. C. Iyer, and S. Rentala, "Analysing factors affecting delays in Indian construction projects," International journal of project management, vol. 30, no. 4, pp. 479-489, May. 2012, doi: 10.1016/j.ijproman.2011.10.004.

[5] J. B. H. Yap, P. L. Goay, Y. B. Woon, and M. Skitmore, "Revisiting critical delay factors for construction: Analysing projects in Malaysia," Alexandria Engineering Journal, vol. 60, no. 1, pp. 1717-1729, Feb. 2021, https://doi.org/10.1016/j.aej.2020.11.021.

[6] A. Serpell, and H. Rubio, "Evaluating project management (PM) readiness in construction companies: cases from Chile," Procedia Computer Science, vol. 219, pp. 1642-1649, 2023, doi: 10.1016/j.procs.2023.01.457.

[7] Q. Shi, "Rethinking the implementation of project management: A Value Adding Path Map approach," International Journal of Project Management, vol. 29, no. 3, pp. 295–302, Apr. 2011, doi:10.1016/j.ijproman.2010.03.007.

[8] Project Management Institute, "A guide to the Project Management Body of Knowledge (PMBOK guide) (6th ed.)," Project Management Institute, 2017.

[9] M. Clemente, and L. Domingues, "Analysis of Project Management Tools to support Knowledge Management," Procedia Computer Science, vol. 219, pp. 1769–1776, 2023, doi: 10.1016/j.procs.2023.01.472.

[10] C. Chowdeswari, D. S. Chandra, and S. Asadi, "Optimal planning and scheduling of high rise buildings," Int. J. Civ. Eng. Technol, vol. 8, pp. 312-324, Jan. 2017.

[11] S. Gaur, "Understanding the importance of project planning and scheduling in Indian construction projects," Journal of Positive School Psychology, vol. 6, no. 3, pp. 3535-3544, 2022.

[12] Z. K. Nemaa, and G. K. Aswed, "Forecasting construction time for road projects and infrastructure using the fuzzy PERT method," IOP Conference Series: Materials Science and Engineering, vol. 1076, no. 1, pp. 012123, 2021, doi:10.1088/1757-899X/1076/1/012123.

[13] F. Habibi, O. T. Birgani, H. Koppelaar, and S. Radenović, "Using fuzzy logic to improve the project time and cost estimation based on Project Evaluation and Review Technique (PERT)," Journal of Project Management, vol. 3, no. 4, pp. 183–196, 2018, doi: 10.5267/j.jpm.2018.4.002.

[14] W. Agyei, "Project planning and scheduling using PERT and CPM techniques with linear programming: case study," International journal of scientific & technology research, vol. 4, no. 8, pp. 222-227, Aug. 2015.

[15] M. Kholil, B. N. Alfa, and M. Hariadi, "Scheduling of house development projects with CPM and PERT method for time efficiency (Case study: House type 36)," IOP Conference Series: Earth and Environmental Science, vol. 140, no. 1, pp. 012010, 2018, doi: 10.1088/1755-1315/140/1/012010.

[16] N. Nahendra, I. N. Daulay, and A. Paramitha, "The optimization of Gebe Airport project using PERT and CPM method," Operations Management and Information System Studies, vol. 2, no. 4, pp. 208-218, 2022, https://doi.org/10.24036/omiss.v2i4.

[17] M. Simion, G. Vasile, C. Dinu and R. E. Scutariu, "CPM and PERT techniques for small-scale R&D projects," National Research and Development Institute for Industrial Ecology, INCD-ECOIND, pp. 166-174, Sep. 2019, DOI:10.21698/simi.2019.fp22.

[18] M. R. Feylizadeh, A. Mahmoudi, M. Bagherpour and D. -F. Li, "Project crashing using a fuzzy multi-objective model considering time, cost, quality and risk under fast tracking technique: A case study," Journal of Intelligent & Fuzzy Systems, vol. 35, no. 3, pp. 3615-3631, 2018, doi: 10.3233/jifs-18171.

[19] Y. Li, Z. Cui, H. Shen, and L. Zhang, "Target-based project crashing problem by adaptive distributionally robust optimization.," Computers & Industrial Engineering, vol. 157, pp. 107160, 2021, doi:10.1016/j.cie.2021.107160.

[20] Andiyan, R. M. Putra, G. D. Rembulan, and H. Tannady, "Construction project evaluation using CPM-Crashing, CPM-PERT and CCPM for minimize project delays," Journal of Physics: Conference Series, vol. 1933, no. 1, pp. 012096, 2021, doi:10.1088/1742-6596/1933/1/012096.

[21] C. L. Karmaker, and P. Halder, "Scheduling project crashing time using linear programming approach: Case study," International Journal of Research in Industrial Engineering, vol. 6, no. 4, pp. 283-292, 2017, DOI: 10.22105/riej.2017.96572.1010.

[22] S. Sharma, N. Bedi, and V. K. Sukhwani, "Optimization of Time and Cost for a Research Project by Project Crashing Method," IOP Conference Series: Materials Science and Engineering, vol. 998, no. 1, pp. 012057, 2020, doi: 10.1088/1757-899x/998/1/012057.

[23] R. J. Gade, "A proposed solution to the problem of construction industry overruns: lean construction techniques and linear programming," Indian Journal of Science and Technology, vol. 9, no. 25, pp. 1-12, Jul. 2016, doi: 10.17485/ijst/2016/v9i25/91929.

[24] Q.-T. Huynh, and N.-T. Nguyen, "Probabilistic Method for Managing Common Risks in Software Project Scheduling Based on Program Evaluation Review Technique," International Journal of Information Technology Project Management, vol. 11, no. 3, pp. 77–94, 2020, doi: 10.4018/ijitpm.2020070105.

[25] O. U. Cynthia, "Implementation of Project Evaluation and Review Technique (PERT) and Critical Path Method (CPM): A Comparative Study," International Journal of Industrial and Operations Research, vol. 3, no. 004, Mar. 2020, doi: 10.35840/2633-8947/6504.

[26] I. A. Kusumadarma, D. Pratami, I. P. Yasa, and W. Tripiawan, "Developing project schedule in telecommunication projects using critical path method (CPM)," International Journal of Integrated Engineering, vol. 12, no. 3, pp. 60–67, 2020.

[27] S. Zareei, "Project scheduling for constructing biogas plant using critical path method," Renewable and Sustainable Energy Reviews, vol. 81, pp. 756-759, Jan. 2018, https://doi.org/10.1016/j.rser.2017.08.025.

[28] P. Tamrakar, "Analysis and improvement by the application of network analysis (Pert/Cpm)," The International Journal of Engineering and Science, vol. 2, no. 1, pp. 154-159, Jan. 2013.

[29] Y. Takakura, T. Yajima, Y. Kawajiri, and S. Hashizume, "Application of critical path method to stochastic processes with historical operation data," Chemical Engineering Research and Design, vol. 149, pp. 195-208, Sep. 2019, https://doi.org/10.1016/j.cherd.2019.06.027.

[30] Y. Farida, and L. P. Anenda, "Network Planning Analysis on Road Construction Projects by CV. X Using Evaluation Review Technique (PERT)-Critical Path Method (CPM) and Crashing Method," International Journal of Integrated Engineering, vol. 14, no. 4, pp. 377-390, 2022.

[31] Y. E. P. R. Waliulu, and T. J. W. Adi, "A system dynamic thinking for modeling infrastructure project duration acceleration," Procedia Computer Science, vol. 197, pp. 420-427, 2022, https://doi.org/10.1016/j.procs.2021.12.181.

[32] M. N. Islam, M. B. Rana, S. Rafique and T. Aziza, "Crashing project time with least cost: A linear programming approach," Journal of Business Research, vol. 6, 2004, doi: 10.2139/ssrn.1012525.