Sustainable Green City Development Project Analysis using the Critical Path Method (CPM) and the Crashing Project Method on Time and Cost Optimization

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ABSTRACT

Due to the increase in population all over the world, the term city development has emerged using the method of sustainable green cities, which are cities designed taking into account the environmental impact to reduce the required input from energy, water, and food production. This study discusses this topic with three main objectives; the first is to analyze the project work network of the Sustainable Green City Development Project, the second is to investigate the impact of speeding up the project on network planning, and the third is to determine the cost differences before and after acceleration. The Critical Path Method (CPM) is valuable for managing complex projects if the activity durations are known. However, in reality, the projected durations may vary in the course of a project due to multiple factors, such as equipment breakdowns, human errors, and material shortages. This study used the CPM and crashing methods to determine the optimal project turnaround time using critical path optimization techniques. Analysis using CPM showed that the initial project duration was 1205 weeks but can be reduced to 1197 weeks. However, with acceleration, there is a slight difference, corresponding to a 0.67% decrease in the duration and approximately 8 weeks. The study showed that the total cost of the project work is US $55M at the normal duration and became US $59M after acceleration, which is a slight increase.

Keywords-Critical Path Method (CPM); crashing method; network planning; optimal duration; optimal cost

I. INTRODUCTION

Project scheduling involves determining the timeline, resources, labor, and materials required for each project activity [1]. It is important to ensure that the implementation of a project follows the schedule plan, which is achieved by selecting the most appropriate planning game. The game practice provides certainty in the completion of the project, minimizing delays and negative impacts on quality, cost, and time [2]. The optimal scheduling of a home energy system has a significant effect on its operating cost [3]. In the current competitive business landscape, completing projects quickly and cost-effectively is crucial for successful project management. Effective planning and timely completion of projects provide a significant advantage in terms of cost, time, and customer satisfaction. Consequently, there is an increasing interest in project management methods to ensure timely delivery success. Project planning is a crucial step in project management and employs various methods. Critical Path Method (CPM) is one of the most preferred methods due to its effectiveness. CPM identifies the critical path, which is the path from the beginning to the end of the project, where all slack times are zero [4]. This method also helps to identify critical activities on the critical path, allowing for resource concentration to reduce project length. Furthermore, CPM can also identify bottlenecks in the project [5].

When it comes to real-life applications, it can be difficult to determine the exact duration of the activities of projects. Expert opinions and estimates are used to determine activity durations, but different experts may provide different estimations for the same project [6]. CPM is a valuable approach for determining the project completion time by considering the priority relationships among activities. In real-life scenarios, CPM is an effective tool for planning and managing intricate projects [7]. The project network diagram always starts with an event marking the project's beginning and concludes with an event indicating its completion [8]. A project can contain multiple paths or routes from the initial event to the final [9]. "Crashing Project" refers to the process of accelerating the period of a project [10-11], reducing its overall duration by shortening the activities while minimizing the associated costs. The goal of crashing is to expedite the project schedule without causing a significant increase in cost. This can be achieved by identifying

critical activities that are hindering the project's progress and allocating additional resources. Crashing ensures that the project is completed on time or ahead of schedule while maintaining quality standards and meeting all requirements.

This study aimed to address the issue of delayed completion time in the Sustainable Green City Development Project by effectively planning and scheduling project activities and sub-activities. To achieve this goal, CPM was used to design network planning that takes into account the priority relations between project activities. The implementation of effective network planning can provide a more organized work schedule, resulting in optimized time and cost management. The crashing method was also used to expedite the project timeline without cost increases, further ensuring that project completion occurs within the stipulated time.

II. METHODS

A. *Critical Path Method (CPM)*

CPM is a scheduling technique that is used to manage a series of activities that depend on each other in terms of their start and end times. These times converge eventually to arrive at the expected outcome of the project. The goal of this method is to identify the critical path that must be followed to reach the project endpoint within the given time and explore different options that may arise in case the durations of activities change [12]. To understand CPM, it is important to understand some basic concepts. A project network refers to a graphical representation of activities and their prioritized relationships within the project. Activity is any work that contributes to the completion of the project. A predecessor refers to an activity that must be completed before another, known as a successor, can begin. The Earliest Start (ES) of an activity is the earliest time it can begin once all preceding activities have been finished. The Earliest Finish (EF) is the time obtained by adding the duration of the activity to the ES of the activity. The Latest Start (LS) is calculated by subtracting the activity completion time from the Latest Finish (LF). LF is determined by adding the activity duration to LS. Slack (S) is the time available between the ES and LS or LF and EF times for an activity. The critical path refers to the sequence of activities that have no slack time [13-14]. Any delay in these critical activities will delay the overall project. Therefore, it is essential to manage the project efficiently to avoid delays in these activities [15-17].

Critical Chain Project Management (CCPM) is a TOC tool used for planning and project management. It can be used in one- and multi-project structures, where resources are used in several projects simultaneously [18-19]. Table I provides definitions of the activities and sub-activities for the Sustainable Green City Development Project, which will be planned and scheduled using CPM to optimize time and cost and minimize delays. Table I also shows the activities and sub-activities of the project. The sub-activities are given an alphabetical code, and Figure 1 shows a Gantt chart of the sub-activities. Figure 1 shows that the critical path of the project passes by the sub-activities A, D, I, J, K, and L. It can also be noted that the total project duration is 25 years, based on the approximate timing of each of the critical sub-activities described in Figure 1.

TABLE I. ACTIVITIES AND SUB-ACTIVITIES OF THE SUSTAINABLE GREEN CITY DEVELOPMENT PROJECT

No	Activity	Sub-Activity	Code
1	Reduce carbon emissions	Investing in renewable energy sources	A
2	Supporting the tourism sector	Creating new tourism products and experiences that showcase the local culture and environment	B
3	Increase green areas	Promote local tourist attractions	C
		Planting trees in public parks	D
		Preserving natural areas	E
4	Improving public facilities and services	Developing programs to support small businesses and entrepreneurs	F
		Attracting investors from outside the region	G
5	Improving healthcare and physical fitness	Develop programs to promote healthy eating and lifestyle	H
		Providing mental health support services	I
6	Improve transportation services	Implementation of bicycle and pedestrian paths	J
		Encouraging the use of alternative means of transportation to reduce carbon emissions	K
7	Improving cultural and entertainment services	Hosting international sports events	L

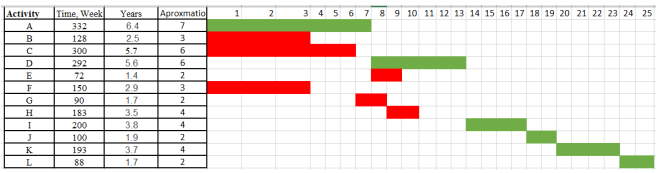

Fig. 1. Gantt chart of the sustainable green city development project.

Table II shows a comparison of the normal schedule cost and duration compared to the crash, mentioning the sub-activity precedence. This Table shows that shortening the duration of an activity will cause its cost to increase. For example, shortening the duration of activity A by 2 weeks will increase the cost by $1M. This observation applies to all the activities mentioned in Table II.

TABLE II. ANALYSIS RESULTS ACCORDING TO POSSIBLE VALUES

Activity	ES	EF	LS	LF	Slack LS-ES	On critical path
A	0	332	0	332	0	Yes
B	0	128	523	651	523	No
C	0	300	351	651	351	No
D	332	624	332	624	0	Yes
E	332	404	552	624	220	No
F	0	150	591	741	591	No
G	300	390	65	741	351	No
H	390	573	741	924	351	No
I	624	824	624	824	0	Yes
J	824	924	824	924	0	Yes
K	924	1117	924	1117	0	Yes
L	1117	1205	1117	1205	0	Yes

Table III shows the results of optimizing project time and cost. The total cost of the project based on the normal schedule

was \$55M and will last 1205 weeks. Shortening an activity by one week will increase its cost by \$0.5M. This indicates that shortening the overall project duration from 1205 to 1197 weeks will increase the overall cost of the project from \$55M to \$59M. Figure 3 shows the variation of the project cost with its duration. It can be noted that the relationship between duration and cost is a linear relationship with a negative slope. At 1205 weeks duration, the cost is \$55M. As the duration shortens, the cost increases by \$0.5M/week. Table IV shows the same results differently.

TABLE III. RESULTS OF TIME AND COST OPTIMIZATION USING CRASHING METHODS

Cycle	Activity	Time	Cost	Total Cost	Duration
0	-			55,000,000	1205
1	A	2	500,000	56,000,000	1203
2	D	2	500,000	57,000,000	1201
3	K	1	500,000	57,500,000	1200
4	L	3	500,000	59,000,000	1197

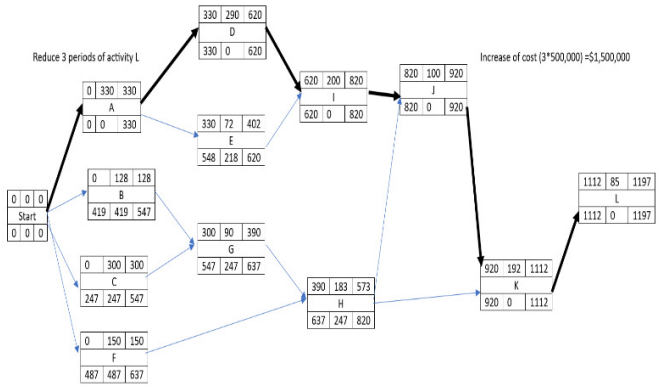

Fig. 2. The activity-on-mode network diagram of optimizing time using crashing methods.

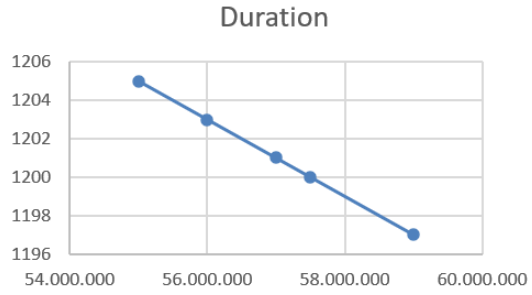

Fig. 3. Reduction of the project's duration from 1205 to 1197 weeks with cost increasing to \$59M.

B. Optimization using the Crashing Method

This is a structured and logical approach to reduce the time required for a project [20]. The goal of this method is to optimize the duration of the project activities in a cost-efficient manner. The method involves a trade-off between time and cost, which means that a reduction in the duration of the project activities is achieved at an additional cost. This cost incurs due to the increase in work efficiency to reduce the project's overall duration. The use of the crashing method can significantly impact project delays by decreasing the time allocated to activities on the critical path. This method applies a cost slope, which refers to the additional cost when the time required for project completion is reduced.

C. Experimental Analysis

CPM involves several steps, such as the identification of individual activities, the determination of their sequence, the organization of the network diagram, the estimation of the completion time for each activity, and the definition of the critical path [6]. Table IV provides a list of activities, their predecessors, and their expected normal and crash durations and costs, which are essential to estimate the overall duration of a project. Additionally, the Table illustrates the project's network diagram, which highlights the relationships between the project activities and their dependencies.

TABLE IV. DATA OF THE SUSTAINABLE GREEN CITY DEVELOPMENT PROJECT

Activity	Precedence	Normal		Crash	
		Time (weeks)	Cost (\$)	Time (weeks)	Cost (\$)
A	-	332	5,000,000	330	6,000,000
B	-	128	1,000,000	127	1,500,000
C	-	300	2,500,000	299	3,000,000
D	A	292	3,000,000	290	4,000,000
E	A	72	500,000	71	1,000,000
F	-	150	9,000,000	148	10,000,000
G	B, C	90	13,000,000	90	13,000,000
H	G, F	183	4,000,000	180	5,500,000
I	D, E	200	3,500,000	200	3,500,000
J	H, I	100	7,000,000	100	7,000,000
K	H, J	193	2,000,000	192	2,500,000
L	K, J	88	4,500,000	85	6,000,000

Figure 4 shows the Activity-On-Mode (AON) network diagram for the normal schedule. The figure also shows the critical path, which is A, D, I, J, K, and L. It can also be observed that the total project duration is 1205 working weeks. Table III also shows the earliest start, latest finish, earliest finish, latest start, slack, and the presence of the activities on the critical path. It can be seen that all critical activities that lie on the critical path have zero slack. Figure 4 also shows the AON network diagram for the crash schedule. The crash schedule can be shortened to 1197 weeks, but this shortening will increase the overall cost of the project.

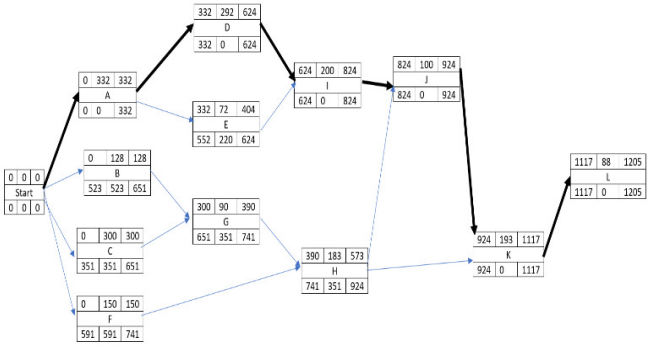

Fig. 4. The AON network diagram of the project.

III. OBSERVATIONS AND DISCUSSION

The process of determining the time needed to complete a project and identifying the critical path involves using the expected durations of the activities and establishing sequential relationships among them. Based on these observations, the results were presented in Table II, indicating that the duration of this particular project was estimated to be 1205 weeks, while the critical path was A, D, I, J, K, and L. So, any delay in completing any of the activities in the critical path will directly impact the overall project duration. Therefore, the project manager should focus on these critical activities to ensure the project's timely completion.

Accelerating activities in the critical path increases the total cost by US $4M. A time shortening of 8 weeks can be obtained by adopting CPM to optimize resources and manage the critical path. This means that the project can be completed 8 weeks earlier than the expected time of 1205 weeks. The time efficiency gained by using the CPM methodology was (1205-1197)/1197×100%=0.67%. This shows that the CPM method can help project managers significantly reduce the time required to complete a project, optimize project resources, and deliver the project within the expected timeline.

A. Using Crashing Methods to Optimize Time and Cost

The crashing method was used to optimize project completion time while minimizing costs. The method involved adding extra labor, such as US $500 per person per week, in critical activities to speed up project completion. By deploying additional labor, activities on the critical path can be completed quicker, resulting in the overall project's time and cost optimization.

B. Trade-Off Analysis (Time and Cost)

Reduction stage with maximum crashing duration:

- Cost slope = US $0.5M/week
- Time Normal = 1205 weeks
- Crashing Time = 1197 weeks
- Total crashing = 8 weeks
- Total project duration = 1197 weeks
- Direct costs = Normal direct costs + cost slope = $55M + (0.5M *8)= $59M.

IV. CONCLUSION

Effective project management is crucial for the success and future of any enterprise in modern days. Due to the high competitiveness in the business environment, the ability to complete projects within stipulated time and cost is becoming increasingly important. This study focused on the Sustainable Green City Development Project, and the results showed that CPM is an effective tool for project management. Using CPM, the critical path for the project was determined as A, D, I, J, K, and L, with a duration of 1205 weeks. The study also demonstrated the use of the crashing method to optimize the project completion time while minimizing costs. By accelerating the duration of critical activities, the project completion time was reduced to 1197 weeks, with a total cost of US $59M. The time efficiency gained by using CPM was 0.67%. These findings show the importance of using project management tools, such as CPM and the crashing method, to optimize project completion time, reduce costs, and ensure project success.

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