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Implementation Of The Critical Path Method In Optimizing The Orthodox Black Tea Processing

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ABSTRACT

PTPN IV Regional 4 plays a strategic role in black tea production, particularly through orthodox black tea processing methods. As a producer of high-quality tea, PTPN IV Regional 4 faces challenges in ensuring operational efficiency at every stage of production, from tea leaf withering to sorting and packing. In an effort to optimize the tea processing process, many methods can be used, one of which is the Critical Path Method (CPM). Critical Path Method (CPM) is a technique used to determine the most important (most critical) set of activities in a project or job, which determines the overall project completion time. Based on the analysis that has been done, the optimal time of the Orthodox black tea processing process obtained is 3,665 minutes or 61 hours 5 minutes with the critical path obtained, namely at the 1-2-3-4-5-6-7-8-12-15-16-17 event or at the A-B-C-D-E-F-G-K-N-O-P activity. Activities that are on the critical path include weighing fresh shoots (A), analyzing the quality of fresh shoots (B), WT distribution (C), shaking (D), withering (E), withering test (F), OTR rolling (G), powder fermentation I (K), drying (N), sorting (O), and packing (P).

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1. INTRODUCTION

PT Perkebunan Nusantara IV Regional 4 is a company under the auspices of a State-Owned Enterprise (BUMN) engaged in plantations. During the internship, the author was placed in the Engineering and Processing section in charge of providing technical and operational support for each business unit. PT Perkebunan Nusantara IV Regional 4 holds control over oil palm, coffee, and tea plantations. PTPN IV Regional 4 plays a strategic role in black tea production, particularly through the orthodox black tea processing method. As a producer of high-quality tea, PTPN IV Regional 4 faces challenges in ensuring operational efficiency at every stage of production, from tea leaf withering to sorting and packing. These challenges include optimally managing time and resources to meet growing market demand without compromising product quality. One of the main obstacles that often arises is the occurrence of bottlenecks at certain stages, which causes the production process to be less efficient and has an impact on high operational costs.

In an effort to optimize the tea processing process, many methods can be used, one of which is the Critical Path Method (CPM). Critical Path Method (CPM) is a technique used to determine the most important (most critical) set of activities in a project or job, which determines the overall project completion time [1]. CPM is a time-oriented method, where time scheduling is the main factor in determining its effectiveness [2]. As the name implies, this method focuses on determining the critical path, which is the path that includes a series of activities with the longest total duration and the fastest-

-project completion time. The critical path includes important activities that must be carefully managed from the beginning to the end of the path [3].

The implementation of CPM at PTPN IV Regional 4 has great potential to identify critical stages in the orthodox black tea processing process. By understanding the critical path, companies can focus resources and attention on activities that determine the total duration of the production process. This can help reduce frequent bottlenecks, optimize production time, and increase productivity and efficiency.

Through this research, the application of Critical Path Method (CPM) is expected to provide a practical solution for PTPN IV Regional 4 in managing the orthodox black tea production process. In addition, this study also aims to show how this method can be used to improve the company's competitiveness, both in domestic and international markets, by producing high-quality products in a timely and efficient manner.

2. RESEARCH METHOD

2.1 Network Analysis

Network analysis is a method that involves analytically examining the trajectory of activities in a network. Through the application of network analysis, the planning process can become more efficient and effective [4]. By identifying the critical path, which is the set of activities that if performed late will cause delays to the entire project, network analysis allows project managers to focus on the most crucial activities or activities. In addition, by taking into account dependencies between activities, this method helps in optimizing the allocation of resources such as labor, equipment, and raw materials.

According to [5] the use of network analysis in a project aims to monitor all project elements in a master plan, build a work model for the completion of a project in such a way that an efficient time is taken to complete work or activities, reduce costs, minimize risks, use resources more economically, obtain or develop optimal scheduling, facilitate revision or correction of deviations that occur. Network analysis can also help solve complex problems to be simpler by presenting these problems in a network diagram.

[4] added that planning a project that usually utilizes network analysis includes 1) Construction of houses, roads, bridges, buildings, and others 2) The production process in a company and so on. By using network analysis, project managers can visualize workflows, identify dependencies between activities, and optimize resource allocation to achieve the desired results efficiently. This helps solve problems that may arise during project execution and improves the ability to make necessary adjustments.

According to [6] in network analysis there are several symbols used, including:

1. Arrow, in the form of an arrow that represents an activity / activity, namely a job or task where completion requires a certain duration (period of time) and resources (labor, equipment, material and cost).
2. Node/event, in the form of a circle that represents an event or occurrence, namely the beginning or end of one or more activities.
3. Double arrow, parallel arrows that represent activities on the critical path.
4. Dummy, in the form of a discontinuous arrow that represents a pseudo-activity or pseudo-activity that is not an activity/activity but is considered an activity/activity, only it does not require a certain duration and resources.

The figure below shows the form of a network analysis diagram.

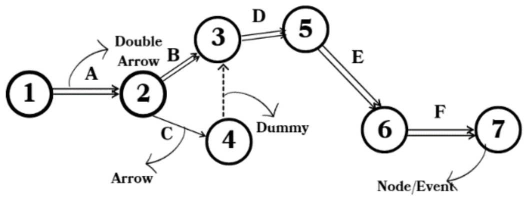

Figure 1. Example of a Network Diagram

Based on the figure above, it can be observed that there are 6 activities consisting of activities A, B, C, D, E, F, and G. Activity A precedes activities B and C, activity D is preceded by activity B and indirectly preceded by activity C, activity E is preceded by activity D, and activity F is preceded by activity E. There are 7 nodes that start and end each vertex. Double Arrow indicates activities on the critical path. While the dummy shows the indirect relationship between activities B and C.

1. The preparation of the network analysis is done through the following steps.
2. Determine all activities required in a project or process.
3. Determine the time duration for each activity.
4. Arrange the sequence of activities based on logical dependencies.
5. Create a network diagram that illustrates the sequence of activities.
6. Determine the critical path that determines the total duration of the project.

2.2 Activity on Arrow Method

The Activity on Arrow (AOA) method is a technique in network analysis that describes the relationship between activities in a project using arrows and circles. In an AOA diagram, each arrow represents an activity to be performed, while nodes depict events or points where the activity starts or finishes. This diagram starts with an initial node that marks the beginning of the project, followed by an arrow that shows the sequence of activities, and ends with an end node that marks the completion of the project. [7] stated that there are three terminologies in the AOA method, as follows:

1. An activity is a part of a project that involves a specific job or task.
2. Event is a significant point in the project, such as when an activity is completed or when all activities are completed.
3. Dummy activities are activities that take no time and are only used to show how other activities depend on each other.

2.3 Critical Path Method (CPM)

The Critical Path Method (CPM) was first developed in the late 1950s by two engineers, Morgan R. Walker of DuPont and James E. Kelley Jr. Of Remington Rand. The method was designed to assist in the planning and management of complex construction and engineering projects. The critical path method is a commonly used method for solving network analysis problems to rank the most important or most critical activities. This method is useful for identifying the critical path, which is a series of activities that must be completed on time so that the project is not delayed as a whole. With the CPM method, the estimated time required to complete each stage in a project is considered to be determined with certainty, as well as the relationship between the resources used and the duration required to complete the project [8].

Critical Path Method (CPM) plays an important role in project management, especially in the context of projects that involve many interrelated activities. In its application, this method allows project managers to map each activity in a logical sequence and determine which activities are part of the critical path. This critical path consists of activities that, if delayed, will cause delays to the overall project, so project management must focus attention on supervising and controlling activities on the critical path so that the project is completed on time.

[9] argues that the purpose of using the critical path method as well as network planning in project implementation is to complete the project within the specified time according to the network diagram provided. This is not always possible, so implementation can still be delayed. There are many types of work that have a delay limit, but there are also jobs that do not have a delay limit, so that delays in completion will affect the duration of project completion. Activities that do not have a delay limit are called critical activities.

2.4 Determining Project Completion Duration

used. There are several terms that need to be understood in forward and backward pass. [7] in their book Project Management, state that the terms to consider include:

1. Early Start (ES): The earliest time a task can begin after the preceding task is completed. If the operation time is expressed in hours, ES is the first moment the activity can start.
2. Late Start (LS): The latest time a task can begin without delaying the project's planned completion. This is the maximum time limit for starting an activity to ensure the project is completed on schedule.
3. Early Finish (EF): The earliest time a task can be completed if started at its Early Start and completed within the designated duration. If there is only one preceding activity, EF is the completion time of that activity, while ES is the start time of the next activity.
4. Late Finish (LF): The latest time a task can be completed without delaying the project's completion. LF is the maximum time limit for completing an activity without affecting the project's final schedule.

The diagram below illustrates a portion of the project network diagram, showing the placement of ES, LS, EF, and LF.

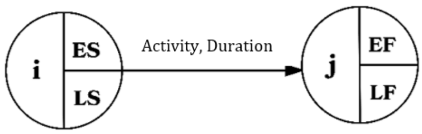

Figure 2. Example of Network Analysis Diagram

As previously mentioned, determining project duration involves two calculations: forward pass and backward pass. The explanations of these calculations are as follows.

1. Forward Pass

   Forward pass starts from point 1 (initial event) and ends at point n (final event). [10] states that the rules to consider in forward pass are as follows:
   - An activity can only start if its preceding activity has been completed, except for the initial activity.
   - The initial time for an activity is 0.

- If an activity has only one direct predecessor, then its Early Start (ES) is equal to the Early Finish (EF) of the predecessor.
- If an activity has more than one direct predecessor, its ES is the maximum value of all EF values of its predecessors, expressed as:

$$\mathrm{ES} = \max\{\mathrm{EF}_1, \mathrm{EF}_2, \dots, \mathrm{EF}_n\} \tag{1}$$

- The Early Finish (EF) is equal to the Early Start (ES) plus the activity duration, expressed as:

$$\mathrm{EF} = \mathrm{ES} + \text{waktu kegiatan} \tag{2}$$

- The forward pass method is considered complete when all ES and EF values have been determined.

2. Backward Pass

The purpose of backward pass is to determine the latest possible time an activity can start and finish without affecting the overall project deadline, which has been set by the forward pass [7]. The rules for backward pass are as follows:

- Backward pass starts from the last event or the final event.
- If an activity is the direct predecessor of only one activity, its Late Finish (LF) is equal to the Late Start (LS) of the activity that directly follows it.
- If an activity is the direct predecessor of more than one activity, its LF is the minimum value of all LS values of the succeeding activities, expressed as:

$$\mathrm{LF} = \min\{\mathrm{LS}_1, \mathrm{LS}_2, \dots, \mathrm{LS}_n\} \tag{3}$$

- The Late Start (LS) is calculated as the difference between LF and the activity duration, expressed as:

$$\mathrm{LS} = \mathrm{LF} - \text{durasi aktivitas} \tag{4}$$

- The backward pass method is complete when all LS and LF values have been determined.

2.5 Critical Path Identification

Critical path identification is based on two approaches: the event-based approach and the activity-based approach.

1. Event-Based Approach

The event-based approach in project management uses slack time (S), which focuses on the amount of time that can be saved or the additional time available for an activity without affecting the schedule of other activities. Slack time represents the flexibility in the project schedule. If the slack time (S) for an activity is 0, it indicates that the activity is on the critical path, as there is no extra time available without delaying the entire project. Slack time is calculated as:

$$S = \text{late time} - \text{early time} \tag{5}$$

2. Activity-Based Approach

The activity-based approach uses total float (TF) to measure the amount of time that can be saved or the flexibility available for each activity within the project. Total float represents the difference between the latest possible start time and the earliest possible finish time of an activity. If the total float (TF) for an activity is 0, the activity is part of the critical path, meaning that any delay in this activity will directly impact the project's overall duration. However, if total float (TF) is greater than 0, it indicates a time buffer, meaning that some activities can be delayed without postponing the project's completion. Total float is calculated as:

$$\mathrm{TF} = \text{late time} - \text{early time} - \text{activity duration} \tag{6}$$

3. RESULT AND ANALYSIS

PT Perkebunan Nusantara IV Regional IV operates two tea factories with a production capacity of 125 tons of fresh leaves per day. The Orthodox black tea processing method produces three different grades of black tea: Grade I (BOP. I, BOP, BOPF, PF, DUST), Grade II (PF. II, DUST. II, BP. II, BT. II, DUST. III), dan Grade III (BM, PLUFF). The data in this study is secondary data obtained from PT Perkebunan Nusantara IV Regional IV regarding the Orthodox black tea processing method. The Orthodox black tea processing steps can be represented in the following table:

Table 1. Activity Components in Orthodox Black Tea Processing

No	Activities	Completion Time (Minutes)
1	Fresh Leaf Weighing	30
2	Fresh Leaf Quality Analysis	15
3	WT Distribution	5
4	Withering Trough Loading	5
5	Withering	1080
6	Withering Test	60
7	Rolling (OTR)	50

8	Rolling (ITR)	5
9	Rolling (First RV)	10
10	Rolling (Second RV)	10
11	Fermentation of Powder I	50
12	Fermentation of Powder II	25
13	Fermentation of Powder III	5
14	Drying	30
15	Sorting	Uncertain
16	Packaging	1920

Based on the data obtained above, it can be observed that the sorting process in Orthodox black tea processing has an uncertain duration. This is because sorting depends heavily on the quality of the tea powder produced from the drying process. The higher the level of impurities left after drying, the longer the sorting process will take. Therefore, the sorting duration is assumed to be 7 hours (420 minutes), based on [11], who stated that the working hours for sorting activities are 8 hours with a 1-hour break. The following is the newly obtained data:

Table 2. Process Activities in Orthodox Black Tea Processing

No	Activities	Completion Time (Minutes)
1	Fresh Leaf Weighing	30
2	Fresh Leaf Quality Analysis	15
3	WT Distribution	5
4	Withering Trough Loading	5
5	Withering	1080
6	Withering Test	60
7	Rolling (OTR)	50
8	Rolling (ITR)	5
9	Rolling (First RV)	10
10	Rolling (Second RV)	10
11	Fermentation of Powder I	50
12	Fermentation of Powder II	25
13	Fermentation of Powder III	5
14	Drying	30
15	Sorting	420
16	Packaging	1920

Solution Using the Critical Path Method

The steps to apply the Critical Path Method (CPM) to optimize the Orthodox black tea processing at PT Perkebunan Nusantara IV Regional IV are as follows:

1. Identify all activities involved in the Orthodox black tea processing.
2. Determine the sequence of each activity.
3. Create a network diagram to visualize the workflow.
4. Calculate the earliest start and latest finish times for each process using forward and backward pass.
5. Determine the critical path using two approaches: Event-based approach (using slack time) and Activity-based approach (using total float).
6. Identify which activities are part of the critical path.

All activities in the Orthodox black tea processing—as shown in Table 2—will be arranged in the correct sequence. The sequence of each activity is presented in Table 3 below.

Table 3. Sequence of Activities in Orthodox Black Tea Processing

No	Activities	Activities Code	Preceding Activities	Completion Time (Minutes)
1	Fresh Leaf Weighing	A	-	30
2	Fresh Leaf Quality Analysis	B	A	15
3	WT Distribution	C	B	5
4	Withering Trough Loading	D	C	5
5	Withering	E	D	1080

6	Withering Test	F	E	60
7	Rolling (OTR)	G	F	50
8	Rolling (ITR)	H	G	5
9	Rolling (First RV)	I	H	10
10	Rolling (Second RV)	J	I	10
11	Fermentation of Powder I	K	G	50
12	Fermentation of Powder II	L	H	25
13	Fermentation of Powder III	M	I	5
14	Drying	N	J, K, L, M	30
15	Sorting	O	N	420
16	Packaging	P	P	1920

After sequencing each activity in the Orthodox black tea processing, the next step is to create a network diagram, which is shown in Figure 4. Each node containing a number in Figure 4 represents an event sequence, marking the beginning or end of an activity.

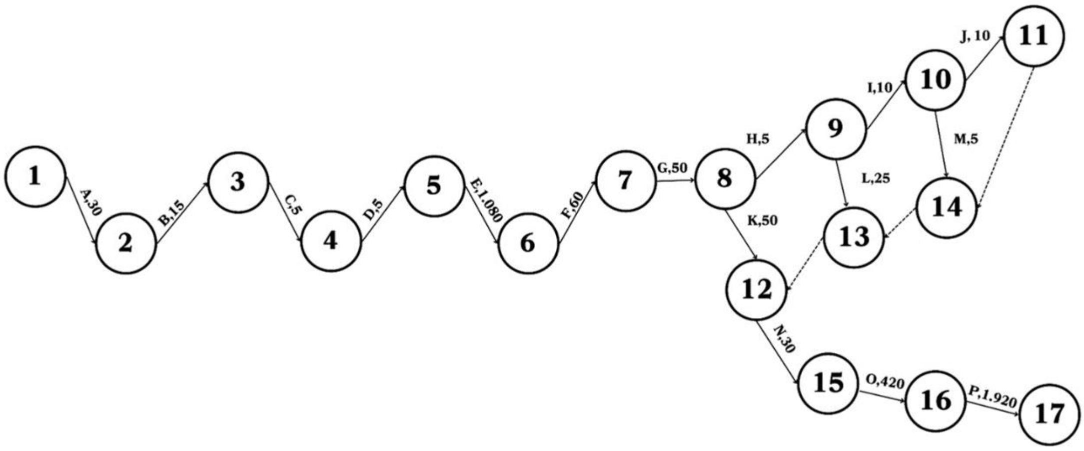

Figure 3. Network Diagram for Orthodox Black Tea Processing

The earliest start time (ES) and latest finish time (LF) for the Orthodox black tea processing are determined using forward and backward pass. The forward pass results are presented in Table 4 below.

Table 4. Forward Pass

Events	Previous Events	Early Time + Activity Duration	Early Start
1	-	-	0
2	1	0+30=30	30
3	2	30+15=45	45
4	3	45+5=50	50
5	4	50+5=55	55
6	5	55+1.080=1.135	1.135
7	6	1.135+60=1.195	1.195
8	7	1.195+50=1.245	1.245
9	8	1.245+5=1.250	1.250
10	9	1.250+10=1.260	1.260
11	10	1.260+10=1.270	1.270
12	8	1.245+50=1.295	1.295
13	9	1.250+25=1.275	1.275
14	10	1.260+5=1.265	1.265
15	11	1.270+30=1.305	1.325
	12	1.295+30=1.325	
	13	1.275+30=1.305	
	14	1.265+30=1.295	

16	15	1.325+420=1.745	1.745
17	17	1.745+1920=3.665	3.665

After completing the forward pass, the next step is to perform the backward pass, which is presented in Table 5.

Table 5. Backward Pass

Events	Next Event	Late Time – Activity Duration	Late Finish
17	-	-	3.665
16	17	3.665-1.920=1.745	1.745
15	16	1.745-420=1.325	1.325
14	15	1.325-30=1.295	1.295
13	15	1.325-30=1.295	1.295
12	15	1.325-30=1.295	1.295
11	15	1.325-30=1.295	1.295
10	14	1.295-5=1.290	1.285
	11	1.295-10=1.285	
9	13	1.295-25=1.270	1.270
	10	1.285-10=1.275	
8	12	1.295-50=1.245	1.245
	9	1.275-5=1.270	
7	8	1.245-50=1.195	1.195
6	7	1.195-60=1.135	1.135
5	6	1.135-1.080=55	55
4	5	55-5=50	50
3	4	50-5=45	45
2	3	45-15=30	30
1	2	30-30=0	0

The earliest start (ES) and latest finish (LF) times in the Orthodox black tea processing can also be visualized in the network diagram shown in Figure 4.

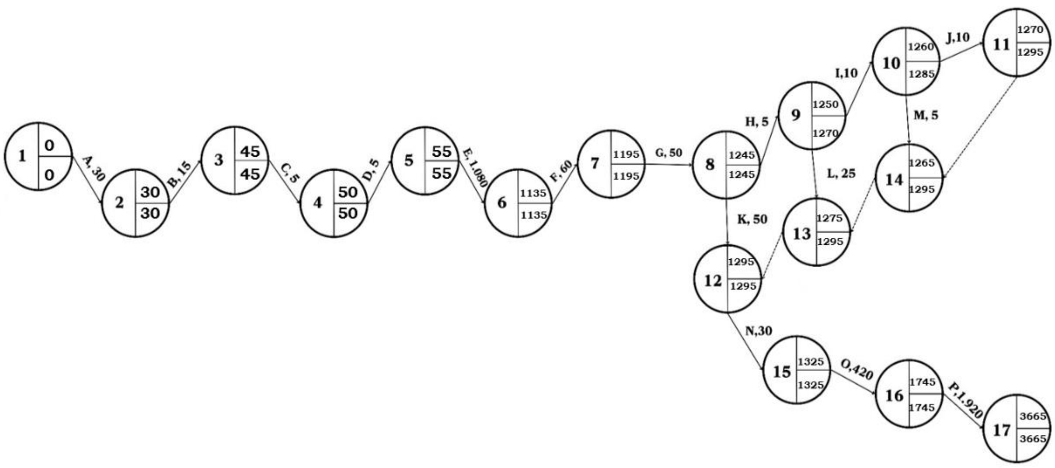

Figure 4. Forward and Backward Pass Diagram

The next step after determining the earliest and latest times in the Orthodox black tea processing is to identify the critical path. This path consists of highly sensitive activities, where any delay in these activities will affect the overall project duration (in this case, the tea processing). The critical path can be determined using two approaches: the event-based approach and the activity-based approach. The identification of the critical path for each approach is shown in the table below.

1. Event-Based Approach

The critical path identification using the event-based approach is determined by calculating the slack value, which is the difference between the latest time and the earliest time. When the resulting slack value is zero, the activity is considered to be on the critical path. The slack calculation results for each event are shown in the following table.

Table 6. Event-Based Approach

Events	*Slack*	Critical Events
1	0-0=0	*
2	30-30=0	*
3	45-45=0	*
4	50-50=0	*
5	55-55=0	*
6	1.135-1.135=0	*
7	1.195-1.195=0	*
8	1.245-1.245=0	*
9	1.275-1.250=25	
10	1.285-1.260=25	
11	1.295-1.270=25	
12	1.295-1.295=0	*
13	1.295-1.275=20	
14	1.295-1.265=30	
15	1.325-1.325=0	*
16	1.745-1.745=0	*
17	3.665-3.665=0	*

The events marked with an asterisk in Table 6 indicate critical events. Thus, the critical path identified using the event-based approach is: 1-2-3-4-5-6-7-8-12-15-16-17.

2. Activity-Based Approach

Unlike the event-based approach, which uses slack to identify the critical path, the activity-based approach determines it by calculating the total float. Total float represents the difference between the latest time, the earliest time, and the duration of the activity. If the total float is zero, the activity is part of the critical path. However, if the total float is greater than zero, it indicates a time-saving equivalent to that value. The total float calculation results for each activity are as follows.

Table 7. Activity-Based Approach

Activities	Total Float	Critical Activities
A	30-0-30=0	*
B	45-30-15=0	*
C	50-45-5=0	*
D	55-50-5=0	*
E	1.135-55-1.080=0	*
F	1.195-1.135-60=0	*
G	1.245-1.195-50=0	*
H	1.270-1.245-5=20	
I	1.285-1.250-10=25	
J	1.295-1.260-10=25	
K	1.295-1.245-50=0	*
L	1.295-1.250-25=20	
M	1.295-1.260-5=30	
N	1.325-1.295-30=0	*
O	1.745-1.325-420=0	*

P	3.665-1.745-1925=0	*

The activities A, B, C, D, E, F, G, K, N, O, and P are considered critical activities because their total float (TF) is zero.

After determining the critical path using both approaches, it can be concluded that the optimal completion time for the Orthodox black tea processing is 3,665 minutes or 61 hours 5 minutes. The network diagram below shows the critical path that has been identified. The critical path in the network diagram is marked with parallel arrows: 1-2-3-4-5-6-7-8-12-15-16-17 or A-B-C-D-E-F-G-K-N-O-P.

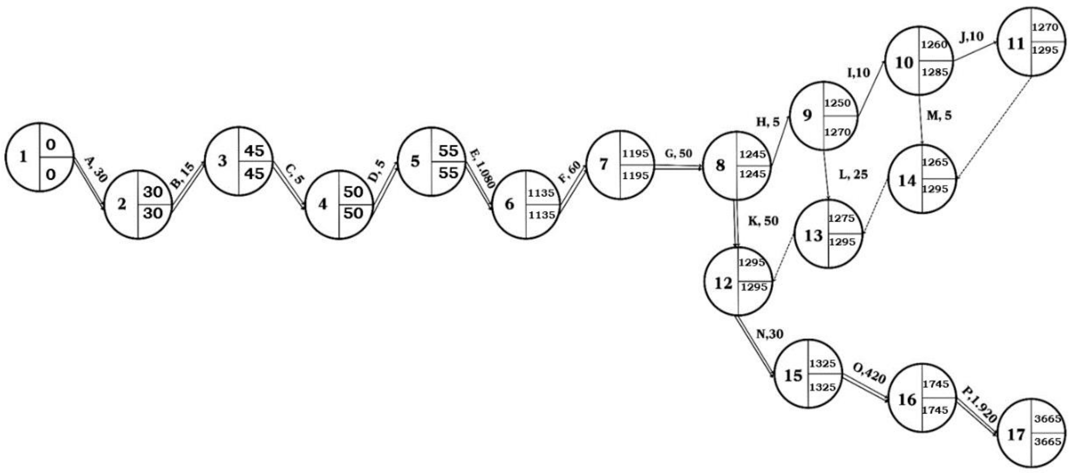

Figure 5. Critical Path in Orthodox Black Tea Processing

The network diagram above shows the activities that are on the critical path, including the weighing of fresh tea leaves (A), quality analysis of fresh leaves (B), WT distribution (C), withering (D), withering test (E), rolling OTR (F), fermentation of Grade I (G), drying (N), sorting (O), and packing (P). These stages play a significant role in determining the overall production time, meaning that any delay in any of these stages will directly impact the overall production completion time.

The critical path identified using the Critical Path Method (CPM) is closely related to first-grade powder, one of the highest-grade Orthodox black tea products. First-grade powder produces Grade I tea, such as BOP I, BOP, BOPF, PF, and Dust, which hold the highest economic value for the company. Therefore, the company must ensure that the entire process runs smoothly to maintain the high quality of Grade I tea while minimizing the risk of production delays that could disrupt distribution and profitability.

4. CONCLUSION

The process of Orthodox black tea production involves several complex stages, ranging from withering, rolling, fermentation, drying, sorting, to packing. There are numerous methods available to optimize the process of Orthodox black tea production. In this study, the author chose to apply the Critical Path Method (CPM), a technique used to identify the most important (critical) activities within a project or task, which directly impacts the overall time required for its completion. Based on the calculations using the Critical Path Method (CPM), the time required to complete the Orthodox tea processing is 3,665 minutes or 61 hours 5 minutes. The critical path identified is A-B-C-D-E-F-G-K-N-O-P or 1-2-3-4-5-6-7-8-12-15-16-17.

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