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# Developing Schedule With Linear Programming (Case Study: STTF II Project Komplek Sukamukti Banjaran)

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ABSTRACT

Shift to The Front II Komplek Sukamukti Banjaran Project is one of the projects implemented by one of the companies engaged in telecommunications. In its implementation, each project including Shift to The Front II Komplek Sukamukti Banjaran has a time limit specified in the contract. Project scheduling is an important role in predicting both the cost and time in a project. Every project should be able to complete the project before or just in the time specified in the contract. Delay in a project can be anticipated by accelerating the duration of completion by using the crashing method with the application of linear programming. Linear programming will help iteration in the calculation of crashing because if linear programming not used, iteration will be repeated. The objective function in this scheduling is to minimize the cost. This study aims to find a trade-off between the costs and the minimum time expected to complete this project. The acceleration of the duration of this study was carried out using the addition of 4 hours of overtime work, 3 hours of overtime work, 2 hours of overtime work, and 1 hour of overtime work. The normal time for this project is 35 days with a service fee of Rp. 52,335,690. From the results of the crashing analysis, the alternative chosen is to add 1 hour of overtime to 34 days with a total service cost of Rp. 52,375,492. This acceleration will affect the entire project because there are 33 different locations worked on Shift to The Front II and if all these locations can be accelerated then the duration of completion of the entire project will be effective

## 1. Introduction

Types of delays can be divided into three types namely excusable delay (ED), compensable delay (CD), and non-excusable delay (NED). Excusable delay is a delay that can be forgiven or tolerated, while the compensable delay is a delay that deserves compensation and non-excusable delay is an unforgivable delay [1]. The type of delay that is ranked first according to Table 1 is a non-excusable delay. This delay problem should be able to be a concern of the project manager to prevent delays in a project.

**Table 1 - Ranking of The Delay Category[2]**

| Rank | Category |
|---|---|
| 1 | Non-Excusable Delay (NED) |
| 2 | Compensable Delay (CD) |
| 3 | Excusable Delay (CD) |

Scheduling is one of the parameters of the success of a project, therefore scheduling needs to be considered to define the duration and sequence of activities so that the schedule can be carried out [3]. Therefore, the existence of project management and how a project is managed and project scheduling is very important [4]. Because project scheduling is an important thing, the project manager wants to compress the schedule to get the fastest duration. To compressing the schedule, it can usually be done by reducing the duration of projects that are on the critical path. Reducing the duration of a project can be done by adding more resources to an activity that can lead to increased costs for the entire project.

**Table 2 - Ranking of Cause of Delay (Management Aspect)[2]**

| Rank | Cause of Delay (Management Aspect) |
|---|---|
| 1 | Resource preparation |
| 2 | Work planning and scheduling |
| 3 | Organizational, coordination and communication systems |
| 4 | Scope and work documents |
| 5 | Inspection, control and evaluation system |
| 6 | etc. |

Based on Table 2, there are six aspects of management that cause delays. These six aspects are resources preparation; work planning and scheduling; organizational, coordination and communication systems; scope and work documents; inspection, control and evaluation system; and others. Of the six aspects, which in the top rank in the management aspects of the delay are resources preparation and work scheduling planning. Therefore, to prevent delays in the project can be done by planning an accelerated work scheduling. This accelerated schedule is expected to produce the shortest duration and has a minimum cost.

PT XYZ is a company engaged in telecommunications. This company is one of the companies in Indonesia that builds fiber optic networks and provides internet services directly to the customer's house. Until now PT XYZ has built a fiber optic network of more than 8,500 km. In March 2020, PT XYZ carried out another fiber optic construction project. This project is called the Shift to The Front (STTF) project. The Shift to The Front project has been carried out from previous years. For 2020, the Shift to The Front project has arrived in the second batch. The Shift to The Front II project is a fiber optic development project in 33 locations.

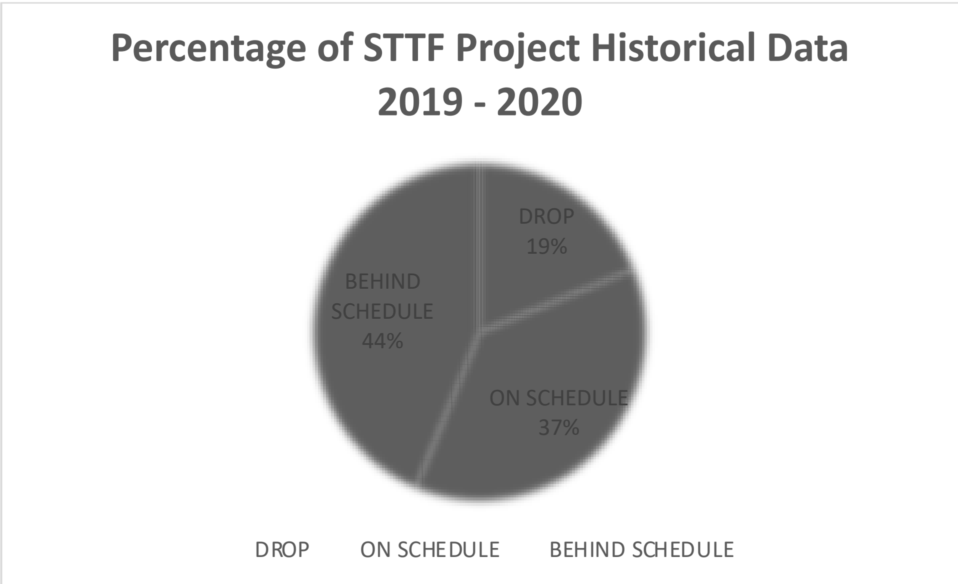


**Fig. 1 - Historical Data of STTF Project**

Until the first quarter of 2020, the Shift to The Front project has worked on 238 locations for the construction of fiber optic networks. Figure 1 is the percentage of Shift to The Front projects from 2019 to 2020. From Figure 1 it can be seen that the number of fiber optic construction sites is delayed by up to 44%. This 44% Figure is a very large number. Therefore, the project scheduling design is needed and also compressing the duration of the project to minimize the possibility of delays in this Shift to The Front II project.

From the background description above, the formulation of the problem that will be discussed in this study is to find out what activities are included in the critical path, what is the time and cost needed to compress the duration of the completion of the Shift to The Front II Komplek Sukamukti Banjaran project and how to compare the time and cost needed between a schedule that has been accelerated and a schedule that has not been accelerated. The main objective of this research is to compress the duration of the project. The alternative used to accelerate the project by adding overtime hours by simulating alternative overtime hours 1, 2, 3, and 4 hours. This schedule compression will help project manager to complete this project as quick as possible.

## 2. Literature Review

Project management is a temporary and unique effort to create a product or result[5]. Project management is planning, organizing, leading, and controlling company resources to achieve short-term goals that have been determined[6]. Project management is a field of science that can be useful to help carry out project activities and complete projects under the costs and schedules that have been previously planned. There are 10 Knowledge Areas in project management. These 10 Knowledge Areas will be integrated to support the project. One of the 10 Knowledge Areas is Project Schedule Management. Project Schedule Management includes the processes needed to manage project completion on time[5].

Project Scheduling is a detailed plan that represents how and when the project will provide the final results of the project[5]. Scheduling will also be used as a means for delivering information to stakeholders. In a project, scheduling will determine when the project is complete and will also determine whether the project is experiencing delays or not. To create a project schedule several methods can be used. Based on PMBOK, one method that can be used to create a schedule is to use the Critical Path Method.

Critical Path Method (CPM) is a technique that can help project managers evaluate the earliest time and latest time, calculate slack time, define important activities, and evaluate the impact of changes in duration[7]. The earliest start and latest finish that is generated is not certain of the initial and final schedule of a project but shows the time in which the activity can be executed. A Critical path is a sequence of activities that represent the longest path in a project's activities and are used to calculate the critical path and the number of floats in each activity[5]. Critical path method can be used to define a critical activity. This critical activity should be prioritized because if critical activity is delayed, then the entire project will be delayed [8].

When developing schedules, project managers often face problems because they have to shorten the scheduled completion time to speed up project implementation[7]. Reducing the project duration can be achieved by adding more resources, adding overtime hours, or by assigning additional labour. But the decision will increase the overall cost of the project. The concept of project management which involves investing extra budget to minimize the duration to meet the targeted date is known as crashing[5].

The problem of compressing the schedules and minimizing costs was the concern of project managers in the late 1950s, so the idea came to solve this problem using mathematical models such as linear programming[4]. Linear programming is one of the techniques of operations research to solve an optimization problem (maximization or minimization) by using linear equations and inequalities to find optimal solutions by taking into account existing constraints[9]. The goal of minimization from linear programming can help managing a project to determine the schedule to get the fastest schedule and minimal costs. The relationship between cost and time is linear, which means that when an activity is accelerated by adding resources, the costs increase linearly per unit time[10].

## 3. Methodology

The data needed to conduct this research are the details of activities on the project along with the sequence of activities of each activity, the duration of time required for each activity, and the budget for each activity. These data were obtained from the Shift to The Front II project manager and then data will be used to calculate crash duration, crash cost, and cost slope. There are several stages to making a schedule with linear programming. These stages are illustrated in Figure 2.

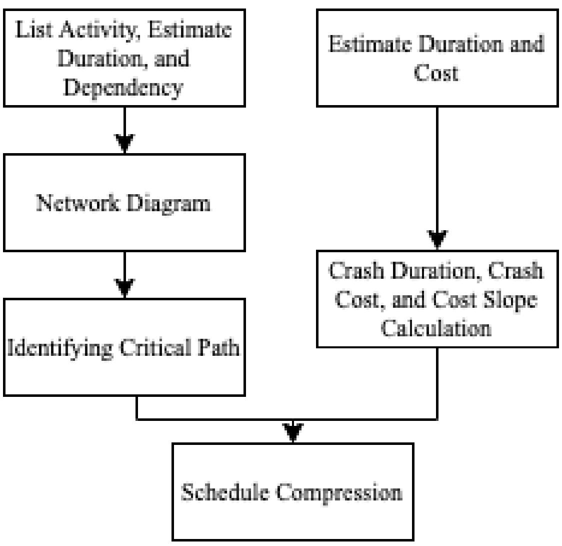


**Fig. 2 - Research Step**

The first stage in this research is to identify the critical path on the network diagram. This critical path is a path that has the longest duration on the network diagram. The duration of the activities on this critical path will be compressed. Activities that are not on the critical path are not compressed because they will not make changes. The schedule compression can be done by adding overtime hours or by adding additional resources. Before compressing the schedule, some data must be known in advance. The data are crash duration, crash cost, and cost slope. Calculation the compression of the duration of completion of an activity that is on a critical path can be calculated in the following way[11]:

$$\text{Productivity per day} = \frac{\text{Volume}}{\text{Estimate Duration}} \quad (1)$$

$$\text{Productivity per hour} = \frac{\text{Productivity per Day}}{\text{Working Hours per Day}} \quad (2)$$

Productivity after crashing per hour = (Working Hours per Day × Productivity per Hour) + (Addition of Overtime Hours × Coefficient of Declining Productivity × Productivity per Hour) (3)

$$\text{Crash duration} = \frac{\text{Volume}}{\text{Productivity After Crashing per Day}} \quad (4)$$

After knowing the crash duration, the next calculation is to calculate the crash cost. The compression of the duration of each activity will cause an increase in the cost of paying overtime labor or commonly called a crash cost. The value of the crash cost will be different for each additional working hour overtime. Logically, the longer the addition of overtime hours carried out, the greater the crash cost needed. After calculating the crash cost, the next step is to calculate the cost slope. Slope is additional crashing costs per day. Crash cost and cost slope calculation can be calculated as follows[11]:

$$\text{Normal wage per day} = \frac{\text{Total Wage for Worker}}{\text{Estimate Duration}} \quad (5)$$

$$\text{Normal wage per hour} = \frac{\text{Normal Wage per Day}}{\text{Normal Working Hours}} \quad (6)$$

Overtime wage per day = (1,5 × Normal Wage per Hour) + [2 × (Addition of Overtime Hours – 1 Hour) × Normal Wage per Hour] (7)

Crash cost per day = (Normal Working Hours × Normal Wage per Hour) + Overtime Wage per Day (8)

Crash cost total = Crash Cost per Day × Crash Duration (9)

$$\text{Cost Slope} = \frac{\text{Crash Cost - Normal Cost}}{\text{Normal Duration - Crash Duration}} \quad (10)$$

After knowing the data needed to schedule compression, the next step is compressing the schedule. Compressing the schedule is done by compressing the duration of activities that are on the critical path. This stage is carried out repeatedly until no more activity that can't be compressed. To simplify this stage, it can be done by using linear programming. Linear programming is a mathematical model technique for solving problems that aim to maximize or minimize something that is limited by certain limitations[9]. There are three steps in modeling linear programming formulation[12], namely:

a. Determine the decision variables then described in the algebra symbol.
b. Determine the objective function (maximization or minimization).
c. Determine the constraints then described in the equation or inequality.

## 4. Result and Discussion

The project to be examined in this study is the Shift to The Front II project for Komplek Sukamukti Banjaran. This project is one of the projects being carried out by PT XYZ. The duration of this project takes 35 days with a material cost of Rp. 45,013,490 and service fees of Rp. 52,335,690. In this study, the schedule compression will be done using 4 alternatives. The alternatives are by adding 4 hours of overtime, adding 3 hours of overtime, adding 2 hours of overtime, and adding 1 hour of overtime.

The Shift to The Front II project is a fiber optic cable construction project in 33 different locations. One of the locations being worked on is Komplek Sukamukti Banjaran. This research was conducted at the Komplek Sukamukti Banjaran location because this location has complete activity. To make a schedule in a network diagram, it will need an estimate of how much time must be needed to complete activities in a normal way. This estimated time was obtained from the Shift to The Front II project manager. Table 3 shows the sequence of activities in the Shift to The Front II project. This project starts from Activity A to Activity W.

**Table 3 - Activity List**

| Activity Code | Activity Name | Duration | Predecessors | Volume |
|---|---|---|---|---|
| | Preparation | | | |
| A | Design Review Meeting | 1 | START | 1 |
| B | Permission | 3 | A | 1 |
| C | Site Acquisition | 3 | B | 1 |
| | Warehouse | | | |
| D | Aerial Cable and Connecting Devices Procurement | 2 | C | 1972 |
| E | Easy to Split Cable Procurement | 2 | C | 1778 |
| F | Pole Procurement | 2 | C | 82 |
| G | Pole Accessories Procurement | 2 | C | 11 |
| H | Optical Distribution Point (ODP) Procurement | 1 | C | 10 |
| I | Splitter Procurement | 1 | C | 3 |
| | Installation | | | |
| | Feeder | | | |
| J | Aerial Cable Withdrawal | 5 | D | 1972 |
| K | Connecting Devices Installation | 3 | J | 1 |
| L | Optic Cable Connection | 2 | J | 24 |
| M | Optical Distribution Cabinet (ODC) Installation | 3 | K, L | 1 |
| N | Jumper Patch Cord | 1 | M | 57 |
| | Distribution | | | |
| O | Pole Installation | 10 | F | 82 |
| P | Pole Accessories Installation | 14 | G | 11 |
| Q | Easy to Split Cable Withdrawal | 10 | E | 1778 |
| R | Optic Cable Connection | 3 | Q | 58 |
| S | Splitter Installation | 5 | I, O, P, R | 3 |
| T | Optical Distribution Point (ODP) Installation | 3 | H, S | 10 |
| U | Tidying | 2 | T | 27 |
| | Closing | | | |
| V | Commissioning Test | 1 | N, U | 1 |
| W | Acceptance Test | 1 | V | 1 |

## 4.1. Identifying Critical Path

The first stage in this study is identifying a critical path. A critical path is a path that has the longest time on a network diagram. This critical path is obtained by using Microsoft Project. The identification of the critical path can be seen in Figure 3. In Figure 3 it can be seen that 10 activities on the critical path. The critical path in the Shift to The Front II Komplek Sukamukti Banjaran project is activities A, B, C, G, P, S, T, U, V, and W. Those activities that on the critical path will be compressed.

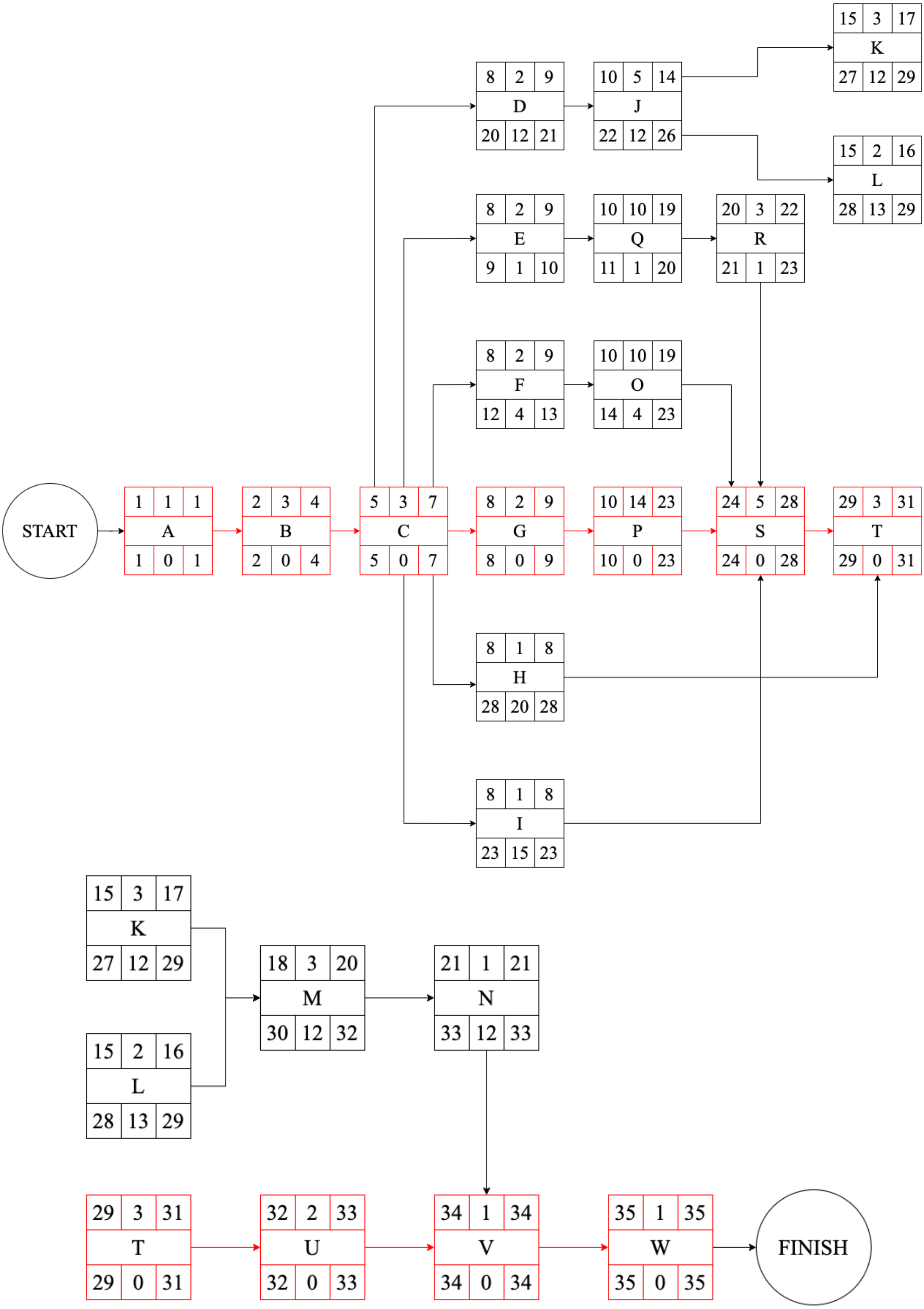


**Fig. 3 - Network Diagram Critical Path**

## 4.2. Schedule Compression

Linear programming will help in the iteration process so that the iteration process is not done manually and for a long time. Before crashing by doing linear programming, the first step is to define the objective function and the limits that will be used in the crashing process. After the objective function, the next step is to determine the limits for maximum reduction constraints. Maximum reduction constraints need to be limited because this is the maximum resource or maximum time that can be used. The final step is defining the formula for the start time constraint.

Assume that Z is an objective function. Z is the total cost required for crashing. If we want to minimize these costs, then the objective function is Z. The Z function is subject to the constraint that the duration of activity must be less than or equal to the time limit desired by the project manager. The decision variable in linear programming is $X_i$ as a reduction in the duration of activity i between normal time and crashing time, where i is A, B, C, ... R. The other decision variable is Yi as the start time of activity i, where i is A, B, C, ... R. The objective function in linear programming is to accelerate the duration of this project. Because the acceleration time of activity has a certain limit, $X_i$ must be limited to the maximum duration of activity i can accelerate. Because there is no negative time, every time that exists in this equation must be limited.

To illustrate the relationship of this equation, it can be seen from activity C as an example. Data for estimate duration and predecessors can be seen in Table 3. Activity C has a predecessor activity, activity B, where activity B has a duration of $3 - X_B$. The meaning of $3 - X_B$ is 3 as the normal duration minus the value of $X_B$. The relationship between these activities is $Y_C \geq Y_B + 3 - X_B$. Thus, activity C cannot begin before activity B begins and activity B completes its work for a duration of $3 - X_B$. Activities that have only one predecessor can emulate this formula

Activity M can be used as a further example because activity M has more than one predecessor activity. Activity M has two predecessor activities namely activity K and L, where activity K has a duration of $3 - X_K$, and activity L has a duration of $2 - X_L$. The relationship between these activities is $Y_M \geq Y_K + 3 - X_K$ and $Y_M \geq Y_L + 2 - X_L$. This inequality means that activity M cannot be started until its predecessor activity is finished. By defining all activities in inequality, a complete linear programming model will be found. The linear programming model or start time constraint in this project can be seen in Table 4.

**Table 4 - Start Time Constraint**

| Start Time Constraint | | |
|---|---|---|
| $Y_B-Y_A+X_A\geq1$ | $Y_C-Y_B+X_B\geq3$ | $Y_D-Y_C+X_C\geq3$ |
| $Y_E-Y_C+X_C\geq3$ | $Y_F-Y_C+X_C\geq3$ | $Y_G-Y_C+X_C\geq3$ |
| $Y_H-Y_C+X_C\geq3$ | $Y_I-Y_C+X_C\geq3$ | $Y_J-Y_D+X_D\geq2$ |
| $Y_K-Y_J+X_J\geq5$ | $Y_L-Y_J+X_J\geq5$ | $Y_M-Y_K+X_K\geq3$ |
| $Y_M-Y_L+X_L\geq2$ | $Y_N-Y_M+X_M\geq3$ | $Y_O-Y_F+X_F\geq2$ |

| Start Time Constraint | | |
|---|---|---|
| $Y_P-Y_G+X_G\geq2$ | $Y_Q-Y_E+X_E\geq2$ | $Y_R-Y_Q+X_Q\geq10$ |
| $Y_S-Y_I+X_I\geq1$ | $Y_S-Y_O+X_O\geq10$ | $Y_S-Y_P+X_P\geq14$ |
| $Y_S-Y_R+X_R\geq3$ | $Y_T-Y_H+X_H\geq1$ | $Y_T-Y_S+X_S\geq5$ |
| $Y_U-Y_T+X_T\geq3$ | $Y_V-Y_N+X_N\geq1$ | $Y_V-Y_U+X_U\geq2$ |
| $Y_W-Y_V+X_V\geq1$ | $Y_{FINISH}-Y_W+X_W\geq1$ | |

Schedule compression is done by compressing the duration of the completion of activities that are on the critical path. In this study schedule compression is done by adding 4 hours of overtime work, 3 hours of overtime work, 2 hours of overtime work, and 1 hour of overtime work. Therefore, schedule compression using linear programming will be done for each alternative.

### 4.3.1. Schedule Compression for Alternative 1

Table 5 is data that can be used to formulate the objective function of linear programming. The objective function in linear programming is to minimize the value of the slope. The slope is a calculation from a difference in cost (crash cost - normal cost) divided by a difference in time (normal duration - crash duration), and therefore the increase in costs must be minimized. Based on Table XX, it can be seen that the objective function in linear programming is 4.533.628 $X_J$ + 4.743.943 $X_O$ + 67.491 $X_P$ + 2.043.811 $X_Q$ + 48.923 $X_S$. The value of X is a time resource that must be limited because it is a time of crashing of activity. Therefore $X_J \leq 1$, $X_O \leq 2$, $X_P \leq 3$, $X_Q \leq 2$, $X_S \leq 1$, the other X of each activity is ≤ 0 because another activity can't be crashed.

**Table 5 - Crashing Data for Alternative 1**

| Activity Code | Normal | | Crash | | ΔC (Rp.) | ΔT | *Slope* (Rp.) = $\Delta C/\Delta T$ |
|---|---|---|---|---|---|---|---|
| | Duration (Day) | Cost (Rp.) | Duration (Day) | Cost (Rp.) | | | |
| J | 5 | 8.242.960 | 4 | 12.776.588 | 4.533.628 | 1 | 4.533.628 |
| O | 10 | 17.250.700 | 8 | 26.738.585 | 9.487.885 | 2 | 4.743.943 |
| P | 14 | 387.640 | 11 | 590.113 | 202.473 | 3 | 67.491 |
| Q | 10 | 7.432.040 | 8 | 11.519.662 | 4.087.622 | 2 | 2.043.811 |
| S | 5 | 88.950 | 4 | 137.873 | 48.923 | 1 | 48.923 |

The schedule compression of the activity will cause an increase in costs. This increase in costs is used to pay overtime wages. Table 6 shows that the shortest time possible for the completion of this project is 31 days out of the 35 estimated days in the beginning. This means that through proper scheduling of activities, the expected completion time is reduced by 4 days. Additional costs required to reduce time is Rp. 4.339.017 which increase the initial expected cost from Rp. 52.335.690 to Rp. 56.674.707.

**Table 6 - Crashing Analysis for 4 Hours Working Time**

| **Activity Code** | **Additional Cost** |
|---|---|
| P | 202.473 |
| Q | 4.087.622 |
| S | 48.923 |
| Total Additional Cost | 4.339.017 |
| Duration of Completion | 31 Days |

## 4.3.2. Schedule Compression for Alternative 2

Table 7 is data that can be used to formulate the objective function of linear programming. The objective function in linear programming is to minimize the value of the slope. The slope is a calculation from a difference in cost (crash cost - normal cost) divided by a difference in time (normal duration - crash duration), and therefore the increase in costs must be minimized. Based on Table XX, it can be seen that the objective function in linear programming is 2.885.036 $X_J$ + 3.018.873 $X_O$ + 86.527 $X_P$ + 1.300.607 $X_Q$ + 31.133 $X_S$. The value of X is a time resource that must be limited because it is a time of crashing of activity. Therefore $X_J \leq 1$, $X_O \leq 2$, $X_P \leq 2$, $X_Q \leq 2$, $X_S \leq 1$, the other X of each activity is ≤ 0 because another activity can't be crashed.

**Table 7 - Crashing Data for Alternative 2**

| Activity Code | Normal | | Crash | | ΔC (Rp.) | ΔT | *Slope* (Rp.) = $\Delta C/\Delta T$ |
|---|---|---|---|---|---|---|---|
| | Duration (Day) | Cost (Rp.) | Duration (Day) | Cost (Rp.) | | | |
| J | 5 | 8.242.960 | 4 | 11.127.996 | 2.885.036 | 1 | 2.885.036 |
| O | 10 | 17.250.700 | 8 | 23.288.445 | 6.037.745 | 2 | 3.018.873 |
| P | 14 | 387.640 | 12 | 560.694 | 173.054 | 2 | 86.527 |
| Q | 10 | 7.432.040 | 8 | 10.033.254 | 2.601.214 | 2 | 1.300.607 |
| S | 5 | 88.950 | 4 | 120.083 | 31.133 | 1 | 31.133 |

The schedule compression of the activity will cause an increase in costs. This increase in costs is used to pay overtime wages. Table 8 shows that the shortest time possible for the completion of this project is 32 days out of the 35 estimated days in the beginning. This means that through proper scheduling of activities, the expected completion time is reduced by 3 days. Additional costs required to reduce time is Rp. 1.504.793 which increase the initial expected cost from Rp. 52.335.690 to Rp. 53.840.483.

**Table 8 - Crashing Analysis for 3 Hours Working Time**

| Activity Code | Additional Cost |
|---|---|
| P | 173.054 |
| Q | 1.300.607 |
| S | 31.133 |
| Total Additional Cost | 1.504.793 |
| Duration of Completion | 32 Days |

### 4.3.3. Schedule Compression for Alternative 3

Table 9 is data that can be used to formulate the objective function of linear programming. The objective function in linear programming is to minimize the value of the slope. The slope is a calculation from a difference in cost (crash cost - normal cost) divided by a difference in time (normal duration - crash duration), and therefore the increase in costs must be minimized. Based on Table XX, it can be seen that the objective function in linear programming is 5.067.393 $X_O$ + 44.994 $X_P$ + 2.183.162 $X_Q$. The value of X is a time resource that must be limited because it is a time of crashing of activity. Therefore $X_O \leq 1$, $X_P \leq 2$, $X_Q \leq 1$, the other X of each activity is $\leq 0$ because another activity can't be crashed.

**Table 9 - Crashing Data for Alternative 3**

| Activity Code | Normal | | Crash | | ΔC (Rp.) | ΔT | *Slope* (Rp.) = $\Delta C/\Delta T$ |
|---|---|---|---|---|---|---|---|
| | Duration (Day) | Cost (Rp.) | Duration (Day) | Cost (Rp.) | | | |
| O | 10 | 17.250.700 | 9 | 22.318.093 | 5.067.393 | 1 | 5.067.393 |
| P | 14 | 387.640 | 12 | 477.628 | 89.988 | 2 | 44.994 |
| Q | 10 | 7.432.040 | 9 | 9.615.202 | 2.183.162 | 1 | 2.183.162 |

The schedule compression of the activity will cause an increase in costs. This increase in costs is used to pay overtime wages. Table 10 shows that the shortest time possible for the completion of this project is 33 days out of the 35 estimated days in the beginning. This means that through proper scheduling of activities, the expected completion time is reduced by 2 days. Additional costs required to reduce time is Rp. 2.273.150 which increase the initial expected cost from Rp. 52.335.690 to Rp. 54.608.840.

**Table 10 - Crashing Analysis for 2 Hours Working Time**

| Activity Code | Additional Cost |
|---|---|
| P | 89.988 |
| Q | 2.183.162 |
| Total Additional Cost | 2.273.150 |
| Duration of Completion | 33 Days |

### 4.3.4. Schedule Compression for Alternative 4

Table 11 is data that can be used to formulate the objective function of linear programming. The objective function in linear programming is to minimize the value of the slope. The slope is a calculation from a difference in cost (crash cost - normal cost) divided by a difference in time (normal duration - crash duration), and therefore the increase in costs must be minimized. Based on Table XX, it can be seen that the objective function in linear programming is 1.185.986 $X_O$ + 39.802 $X_P$ + 510.953 $X_Q$. The value of X is a time resource that must be limited because it is a time of crashing of activity. Therefore $X_O \leq 1$, $X_P \leq 1$, $X_Q \leq 1$, the other X of each activity is $\leq 0$ because another activity can't be crashed.

**Table 11 - Crashing Data for Alternative 4**

| Activity Code | Normal | | Crash | | ΔC (Rp.) | ΔT | *Slope* (Rp.) $= \Delta C/\Delta T$ |
|---|---|---|---|---|---|---|---|
| | Duration (Day) | Cost (Rp.) | Duration (Day) | Cost (Rp.) | | | |
| O | 10 | 17.250.700 | 9 | 18.436.686 | 1.185.986 | 1 | 1.185.986 |
| P | 14 | 387.640 | 13 | 427.442 | 39.802 | 1 | 39.802 |
| Q | 10 | 7.432.040 | 9 | 7.942.993 | 510.953 | 1 | 510.953 |

The schedule compression of the activity will cause an increase in costs. This increase in costs is used to pay overtime wages. Table 12 shows that the shortest time possible for the completion of this project is 34 days out of the 35 estimated days in the beginning. This means that through proper scheduling of activities, the expected completion time is reduced by 1 days. Additional costs required to reduce time is Rp. 39.802 which increase the initial expected cost from Rp. 52.335.690 to Rp. 52.375.492.

**Table 12 - Crashing Analysis for 1 Hour Working Time**

| Activity Code | Additional Cost |
|---|---|
| P | 39.802 |
| Duration of Completion | 34 Days |

## 4.3. Time and Cost Analysis

The Addition of overtime hours will have an impact on additional costs incurred and will also have an impact on the duration of the project completion. Figure 4 is a graph that shows the effect of overtime on the duration of completion. In Figure 5 we can know the relationship between adding overtime hours and the duration of completion of a project.

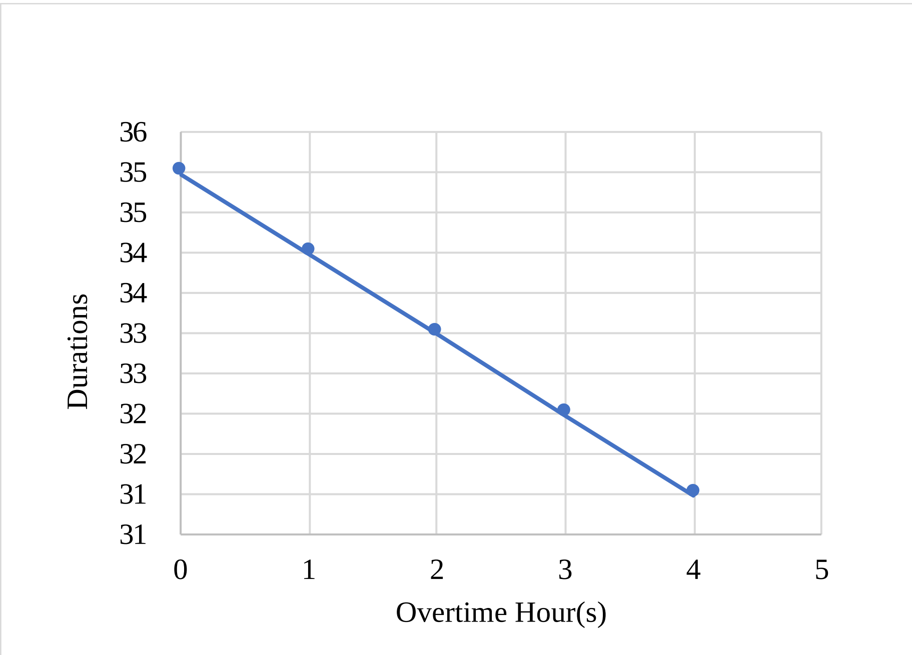


**Fig. 3 - Graph of the effect of overtime on the duration**

In Figure 4, it can be seen that the more extra hours worked overtime can make the project faster. It can be seen that with the addition of 1 hour of overtime work, the duration of completion becomes 34 days. The addition of 2 hours of overtime will make the completion duration to 33 days. The addition of 3 hours of overtime will make the completion duration to 32 days. The addition of 4 hours of overtime will make the completion duration to 31 days. Besides affecting the duration of completion, the addition of overtime hours will also have an impact on the increase in costs incurred. Figure 5 is a graph that show the effect of overtime on implementation costs.

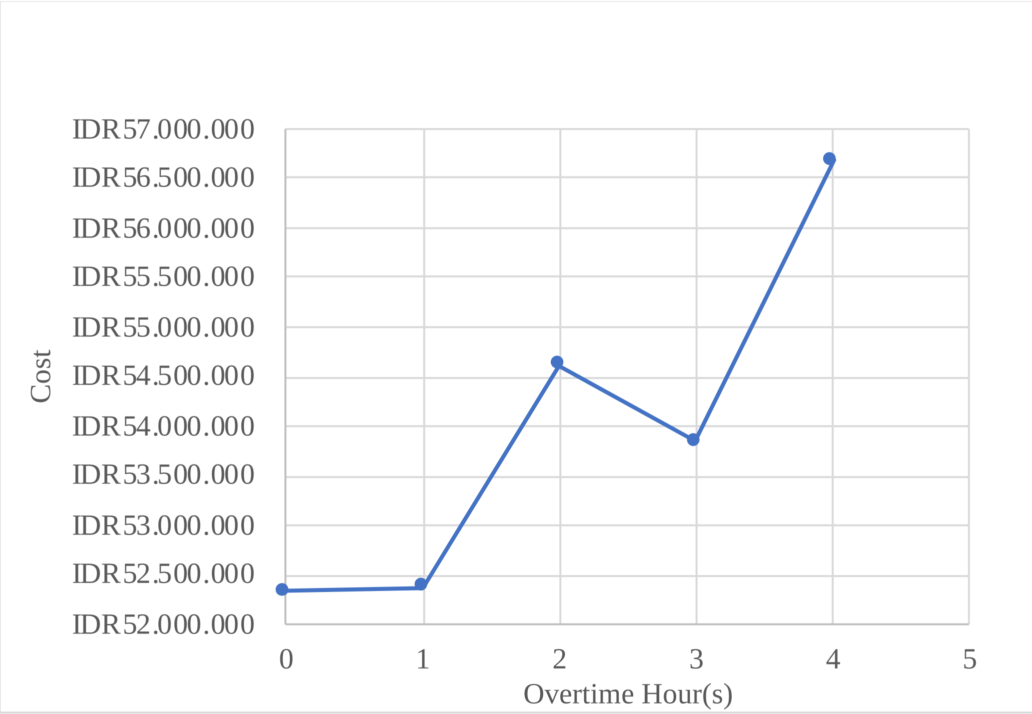


**Fig. 4 - Graph of the effect of overtime on cost**

In Figure 5, it can be seen that the more extra hours worked overtime, can increase the cost for this project. It can be seen that if the addition of 1 hour of overtime work, the costs incurred become Rp. 52,377,492. The Addition of 2 hours of overtime work will make the costs incurred to Rp 54,608,840. The Addition of 3 hours of overtime work will make the costs incurred to Rp 53,840,483. The addition of 4 hours of overtime will make the costs incurred to Rp. 56,674,707. Cost reduction in Figure 5 is caused because there are some activities in adding 2 hours of overtime to 3 hours of overtime making the duration of the crash faster so that the product of the crash cost with the crash duration can also be small due to crash cost getting smaller. Based on the analysis of the Shift to The Front II Komplek Sukamukti Banjaran project, the following recapitulation results can be seen as follows:

- Alternative 1 with the addition of 1 hour of overtime work can make the duration of completion to 34 days from 35 days. The addition of overtime hours makes the additional cost of Rp. 39,802 from Rp. 52,335,690 to Rp. 52,375,492 so that a slope of Rp. 39,802.
- Alternative 2 with the addition of 2 hours of overtime work can make the duration of completion to 33 days from 35 days. The addition of overtime hours makes the additional cost of Rp. 2,273,150 from Rp. 52,335,690 to Rp. 54,608,840 so that a slope of Rp. 1,136,575.
- Alternative 3 with the addition of 3 hours of overtime work can make the duration of completion to 32 days from 35 days. The addition of overtime hours makes the additional cost of Rp. 1,504,793 from Rp. 52,335,690 to Rp. 53,840,483 so that a slope of Rp. 501,598.
- Alternative 4 with the addition of 4 hours of overtime work can make the duration of completion to 31 days from 35 days. The addition of overtime hours makes the additional cost of Rp. 4,339,017 from Rp. 52,335,690 to Rp. 56,674,707 so that a slope of Rp. 1,084,754.

The selection of all the alternatives can be chosen based on the smallest slope. Because we know that the slope is an increase in costs in units of days it can be concluded that the smaller the value of the slope, the smaller the additional costs needed. From the four alternatives, the first alternative has the smallest slope value of Rp. 39,802. So that the alternative chosen is the first alternative with a duration of completion to 34 days with additional costs from Rp. 52,335,690 to Rp. 52,375,492.

## 5. Conclusion

Developing a schedule is an important thing in a project. Developing schedules will help the project manager to know when a project will be completed. Every project manager certainly wants a short duration of project completion. This study discusses the developing schedule problem in the Shift to The Front II Komplek Sukamukti Banjaran project using linear programming. Before the schedule compression, the project was planned to be completed for 35 days. After schedule compression with 4 alternatives, the chosen alternative is to add 1 hour of overtime because it has the smallest slope. This alternative will make this project completed for 34 days with additional costs to Rp. 52,375,492. This acceleration will affect the entire project because there are 33 different locations worked on Shift to The Front II and if all these locations can be accelerated then the duration of completion of the entire project will be effective. From the calculations of each alternative, it can be seen that the faster the duration of the completion of a project, the bigger the additional costs required. Further research is needed to determine the cause of the delay in the Shift to The Front II Komplek Sukamukti Banjaran project so that it can be used as anticipation of delays for the next project.

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