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Enhancing Project Management and Monitoring with Precedence Diagram and Earned Value Method: A Case Study in Construction

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Abstract
An increasing number of projects has created challenges in effectively planning, organizing, and maintaining projects. Project planning becomes a crucial aspect of project management, particularly for monitoring progress and efficiently allocating resources. This study aims to implement the precedence diagram and earned value methods to enhance project management and monitoring. The predence diagram method is used to estimate project completion time, while the earned value method tracks time and budget according to project progress. In this case study, project management activities at CV. Firman Syah are observed. The development process starts with data collection and requirements analysis (functional and non-functional), followed by system architecture design using use case diagrams and Data Flow Diagram (DFD). The database is implemented using MySQL, and the application runs on an Apache web server. Vue.js is used for front-end development, while Lumen is employed for back-end development. The results of Black Box testing indicate that the application is capable of predicting project completion time and associated costs, as well as managing project data.
Keywords: earned value method, precedence diagram, project management, project monitoring.

1. Introduction
Project management process is an essential activity of delivering high-quality products on time, safely, and within budget (Chen, Griffis, Chen, & Chang, 2013). This process involves several aspects, including time, budget, and resources (Ghoddousi, Eshtehardian, Jooybanpour, & Javanmardi, 2013). However, as the number of projects that need to be handled increased, some may not be monitored effectively, resulting in a delay. Therefore, a study that seeks to improve the quality of project monitoring and management is crucial as it may contribute to project success.

CV. Firman Syah, a construction company in Kelurahan Jungcangcang, Kabupaten Pamekasan, Indonesia, face challenges in organizing, planning, and managing projects effectively. To deal with the challenge, we strive to apply several management project methods, namely Earned Value method and Precedence Diagram. Earned Value method is a practical method to control time and budget, and to estimate delay, additional cost, and total cost of the project (Johari & Islami, 2021). Additionally, we use Precedence Diagram to improve the estimation of time completion of the projects, thus enabling parallel working in order to reduce the delivery time (Koilam, Dundu, & Arsjad, 2020; Safitri, Basriati, & Hanum, 2019; Romadhona, Kurniawan, & Tistogondo, 2021). These methods are applied in a web-based software system customized for CV. Firman Syah, applying Vue.js as a front-end and Lumen as a back-end.

2. Literature Review
2.1. Project and Project Management
Project is an activity with several unique characteristics depends on the aimed results. It is complex and temporary activity and restricted by time, budget, and resources (Sugiyanto, 2020). In order to achieve the goals, a project management activity is conducted. It includes planning, organizing, managing tasks and

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resources (Darmawan & Ratnasari, 2020). Project management is widely applied in different project types, scales, and complexity (Yanti & Kusumastuti, 2021).

2.2. Monitoring

In order to assess project activities, identify problems, and evaluate progress, monitoring is conducted. It also reviews the effectiveness of the applied method and management to achieve the goals by measuring the compliance of current activity with the plan (Dinas Pendidikan Dan Kebudayaan Kota Balikpapan, 2015). The monitoring process consists of collecting and analyzing information from an activity systematically and continuously based on several indicators with the objective of improving it in the future (Darmawan & Ratnasari, 2020).

2.3. Precedence Diagram Method

Precedence Diagram Method (PDM) is a conventional method in project planning and scheduling (Romadhona, Kurniawan, & Tistogondo, 2021). Precedence Diagram Method (PDM) represents project activity visually using several symbols. Activity is symbolized with rectangle, while the relationship between activities is symbolized with an arrow. PDM is also known as the Activity on Node (AON) method because it illustrates activity on nodes (Safitri, Basriati, & Hanum, 2019). The method considers dependent relationships between activities and their durations, resulting in four different constrains (Sahid & Sumarno, 2013):

1) Start to start (SS): Shows a relationship that the next activity depends on the previous one.
2) Start to finish (SF): Shows a relationship that the end of the next activity depends on the start of the previous one.
3) Finish to Start (FS): Shows a relationship that the start of the next activity depends on the end of the previous one.
4) Finish to finish (FF): Shows a relationship that the end of the next activity depends on the end of the previous one.

The application of PDF involving the calculation of Earliest Start (ES), Earliest Finish (EF), Latest Start (LS), and Latest Finish (LF). ES is the earliest time of an activity, while EF is the earliest time to finish an activity. In case there is only one previous activity, EF is calculated using the next ES, and LS is calculated based on the last day when an activity should be started without delaying an entire project. Detail equations of the ES, F, LS, and LF with backward and forward calculation based on PDM constraints are presented in Eq. (1) - (16) (Safitri, Basriati, & Hanum, 2019; Romadhona, Kurniawan, & Tistogondo, 2021).

1) The relationship of FF activity
   a) Forward calculation
      $$EF_j = EF_i + FF_{ij} \quad (1)$$
      $$ES_j = EF_j - D_i \quad (2)$$
   b) Backward calculation
      $$LF_j = LF_j - FF_{ij} \quad (3)$$
      $$LS_i = LF_i - D_i \quad (4)$$
2) The relationship of FS activity
   a) Forward calculation
      $$ES_j = EF_i + FS_{ij} \quad (5)$$
      $$EF_j = ES_j + D_j \quad (6)$$
   b) Backward calculation
      $$LF_j = LS_j - FS_{ij} \quad (7)$$
      $$LS_i = LF_i - D_i \quad (8)$$
3) The relationship of SF activity
   a) Forward calculation
      $$EF_j = ES_i + SF_{ij} \quad (9)$$
      $$ES_i = EF_i - D_i \quad (10)$$
   b) Backward calculation
      $$LS_i = LF_j - SF_{ij} \quad (11)$$
      $$LF_i = LS_i + D_i \quad (12)$$
4) The relationship of SS activity
   a) Forward calculation
      $$ES_j = ES_i + SS_{ij} \quad (13)$$
      $$EF_j = EF_i + D_j \quad (14)$$

b) Backward calculation

$$LS_i = LS_j - SS_{ij} \quad (15)$$

$$LF_i = LS_i + D_i \quad (16)$$

2.4. Earned Value Method

Earned Value (EV) method is a tool to control project performance in the context of phisics, time, and budget, comprehensively. This method is also used to manage budget progress and information related to the scope, quality, and risk, to evaluate, analyze, and predict budget performance (Andreas, Tinumbia, & Anggraini, 2023). Several assessment indicators of the EV methods are as follows:

1) Budgeted Cost of Work Scheduled (BCWS) or Planned Value (PV) (Booz Allen Hamilton, 2015): Total cost of actual working progress within certain period.
2) Budgeted Cost of Work Performed (BCWP) or Earned Value (EV) (Booz Allen Hamilton, 2015): Total work value from accomplished working to the allocated budget to finish the task.
3) Actual Cost of Work Performed (ACWP): Budget point for a work package that is organized and scheduled.

The assessment indicators of BCWS dan BCWP is calculated using Eq. (17) and Eq. (18) (Konior & Szostak, 2023), where $BCWS_i$ is an allocated budget for a scheduled task, and $BCWP_i$ is an allocated budget for an accomplished task. The $BCWP_i$ is calculated based on schedule and expenditure for certain period of audit. The calculation of $i \in (1,\ldots,n)$, where n is the number of completion period, SC_i is a procentage of the scheduled working progress, PC_i is a procentage of the accomplished working progress, and *Budget at Completion* (BAC) is a total budget for a construction project.

$$BCWS_i = SC_i \times BAC \quad (17)$$

$$BCWP_i = PC_i \times BAC \quad (18)$$

Those three indicators (i.e., BCWS, BCWP, and BAC) resulted in two variances, namely *Cost Variance* (CV) and *Schedule Variance* (SV), where CV is calculated using Eq. (19) and SV is calculated using Eq. (20) (Nono, Pratasis, & Malingkas, 2019).

$$CV = BCWP - ACWP \quad (19)$$

$$SV = BCWP - BCWS \quad (20)$$

The efficiency of resource usage is further evaluated using productivity index or performance index metric. *Performance Index* consists of *Cost Performance Index* (CPI) and *Schedule Performance Index* (SPI). CPI is calculated using Eq. (21), while SPI is calculated using Eq. (22) (Nono, Pratasis, & Malingkas, 2019).

$$CPI = \frac{BCWP}{ACWP} \quad (21)$$

$$SPI = \frac{BCWP}{BCWS} \quad (22)$$

Furthermore, estimation of cost and time completion can be calculated based on indicators obtained during report period. These indicators are represented by *Estimate at Completion* (EAC) and *Estimate all Schedule* (EAS). EAC is calculated using Eq. (23), while EAS is calculated using Eq. (24) (Arifin, Sarifatuzzuhriyah, & Liu, 2023) An additional metric namely *Time Estimate* (TE) is calculated to predict total time completion of the project (Kamaludin, 2021).

$$EAC = \frac{BAC}{CPI} \quad (23)$$

$$EAS = \frac{TE}{SPI} \quad (24)$$

Budget and schedule estimations is advantageous to provide early warning on potential delays when the problems do not address properly.

2.5. Lumen

Framework is a set of script to improve developer/programmer productivity in developing software (Yudhanto & Prasetyo, 2019). A framework is useful to solve various programming activities, including database connections, variable invocation, and file management. Lumen is one of the micro-frameworks of Laravel having capability to handle more than 1,700 requests per second and supported by simple features, enabling more flexible backend development. Additionally, Lumen supports the development of high-performance API to connect different services efficiently (Yudha & Cahyono, 2022).

3. Methods

This section describes data collection and analysis process, as well as software development.

3.1. Data Collection

1) Observation

Table 1
Project work details and budget.

No.	Type of Work	Work Code	Duration (Days)	Total Price (IDR)
1	Measurement	A	1	600,000.00
2	Project signboard	B	1	500,000.00
3	Excavation	C	12	6,056,820.00
4	Mountain stone foundation (1Pc:5Ps)	D	24	45,010,157.31
5	Plastering (1Pc:5Ps)	E	24	13,965,876.74
6	Finishing	F	12	7,898,016.00
7	Concrete casing (30˚ Diameter)	G	9	8,190,424.28
8	Formwork (Reusable, 2 times)	H	2	54,014.06
9	Reinforcement (Rebar)	I	2	246,296.47
10	Concrete K1000	J	1	102,682.93
11	Cleaning	K	1	600,000.00

Note: PC: Portland cement dan PS: Part sand.

To obtain information related to progress documentation, project scheduling, weekly project monitoring, and project profile, observation CV. Firman Syah was conducted. This information was used to develop a software for the client.

2) Interview
A follow-up interview was conducted to validate the problems that had been identified during observation. Interviews were conducted with staff to validate their difficulties in memorizing last period of the project, manual file storage, and the absence of periodic monitoring of the project.

3) Literature study
Studies of literature related to research problems are conducted using previous research, journal, proceeding, and research report.

This study uses data from a project conducted by CV. Firman Syah. The total budget for the project is IDR 92,423,000, with an estimated time (TE) of 60 days. Details of the project and budget are shown in Table 1.

3.2. System Analysis

This sub-chapter discusses expected requirements of the system. It consists of functional and non-functional requirements. Functional requirements encompass user authentifications, data management, and project management and control. Data management covers employee management, project management, milestones, tasks, documents, progress planning, and constraints. Project management and control include predence diagram and earned value calculations.

On the other hand, non-functional requirements enclose system capability to send notifications of task delay to the administrator via reminder feature which is represented as bell icon.

3.3. System Design

This sub-chapter discusses the development of use case diagram, data flow diagram (DFD), and database. Use case diagram represents how users interact with the system, describe available functions and indicate who are granted access to them. DFD is a graphical representation to illustrate information flow between processes, while database serves as a data storage (Sukamto & Shalahuddin, 2011).

Fig. 1 shows 14 use cases conducted by administrators (*admin*), while four (4) use cases conducted by supervisor (*mandor*). Details use cases conducted by administrators are as follows:

a) User autentification: Administator can login to the system.
b) Employee management: Administrator can add, edit, and delete employee.
c) Project management: Administrator can add, edit, delete, and download project profile.
d) Milestone management: Administrator can add, edit, and delete milestone.
e) Task management: Administrator can add, edit, delete, and upload tasks details.
f) Document management: Administrator can add, edit, and delete archieves.
g) Progress management: Administrator and supervisor can add, edit, and delete progres. Some data comes from tasks.
h) Task management per progress: Administrator and supervisor can add, edit, and delete task per progress.
i) Progress planning management: Administrator and supervisor can add, edit, and delete progress planning.
j) Constraints management: Administrator and supervisor can add, edit, and delete constraints.

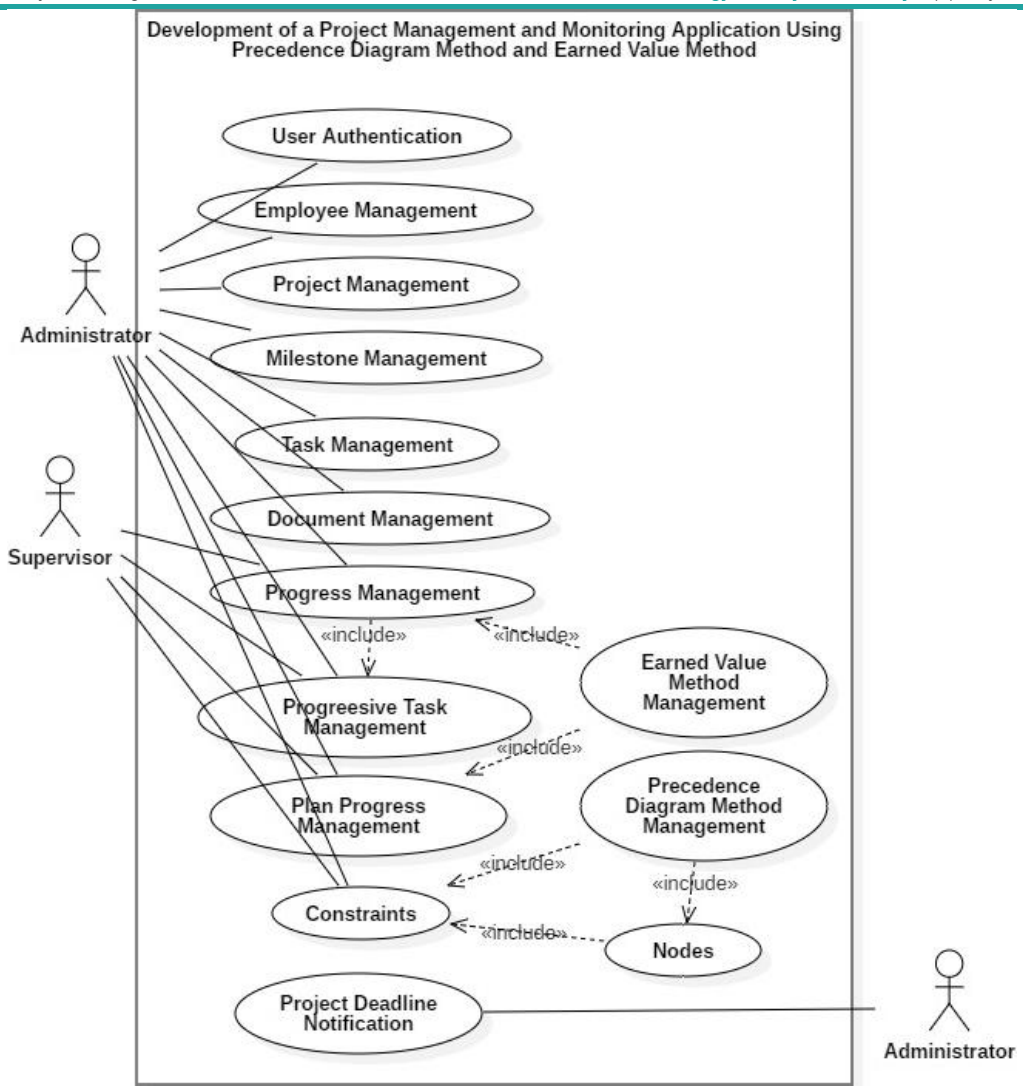

Fig. 1. Use case diagram.

k) Precedence diagram method: Calculation process obtained from constraints and table nodes.
l) Earned value method: Calculation process obtained from progress and progress planning.
m) Project deadline notification: The system sends deadline notification.

Fig. 2 and Fig. 3 show DFD of the systems, where Fig. 2. Illustrates processes conducted by administrators. This figure includes 12 processes and 10 data stores. One of the processes shows employee management, where an administrator can add or edit employee data which then proceeds by the system. The data is then stored in an employee database. Additionally, an administrator can delete employee data which is verified by the system. Once it is verified, the data is removed from the database.

Fig. 3 delineate activities conducted by supervisor. It consists of five processes and five data stores. A supervisor can access three different tables through three processes, but can only see data from two data stores, without having the capability of editing or adding more data to the table.

4. Results and Discussion

4.1. Earned Value Method

Earned value method is applied to predict profits, losts, and time completion of the project. Prior to the implementation of the method, monitoring plan consists of a procentage of weekly progress and actual costs are determined (see Table 2). According to the cumulative planned weight and the BAC, it is shown that the project earned a PV of IDR 46,211,500 in the fourth week. This value is obtained based on Eq. (17). Meanwhile, the same method resulted in an EV of IDR 54,917,746.60 using Eq. (18). In the same week, the cost (ACWP) is IDR 49,928,532, and the CPI is 1.1 (see Eq. (21)). With the CPI, it is determined that the value of the EAC is IDR 84,020,909.09 (see Eq. (23)). Furthermore, the SPI of 1.2 resulted in an ETC of 50

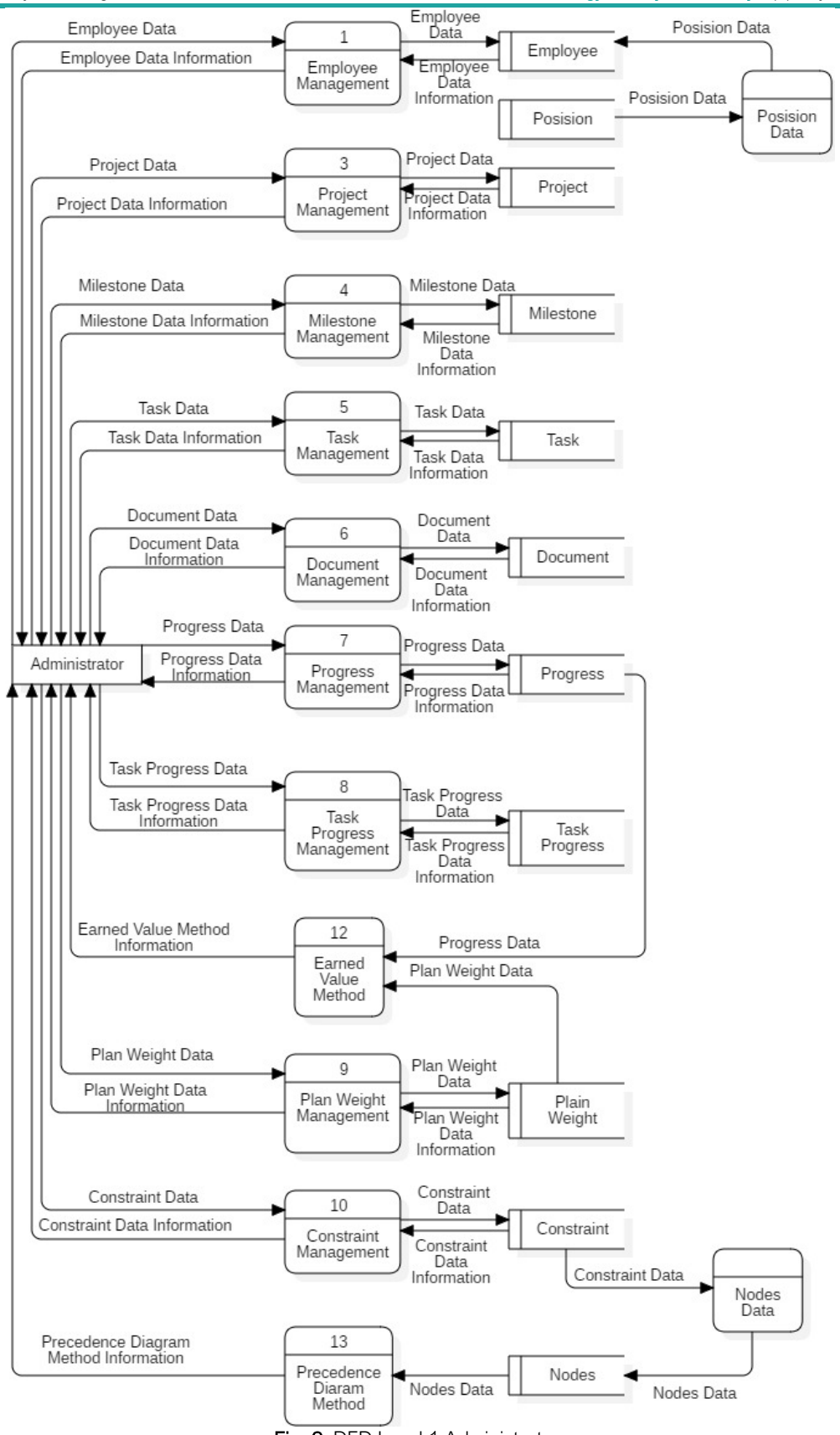

Fig. 2. DFD Level 1 Administrator.

days based on Eq. (22) and Eq. (24).

Table 2 shows that the actual weight in the fourth week is 50%, corresponding to its 50% completion.

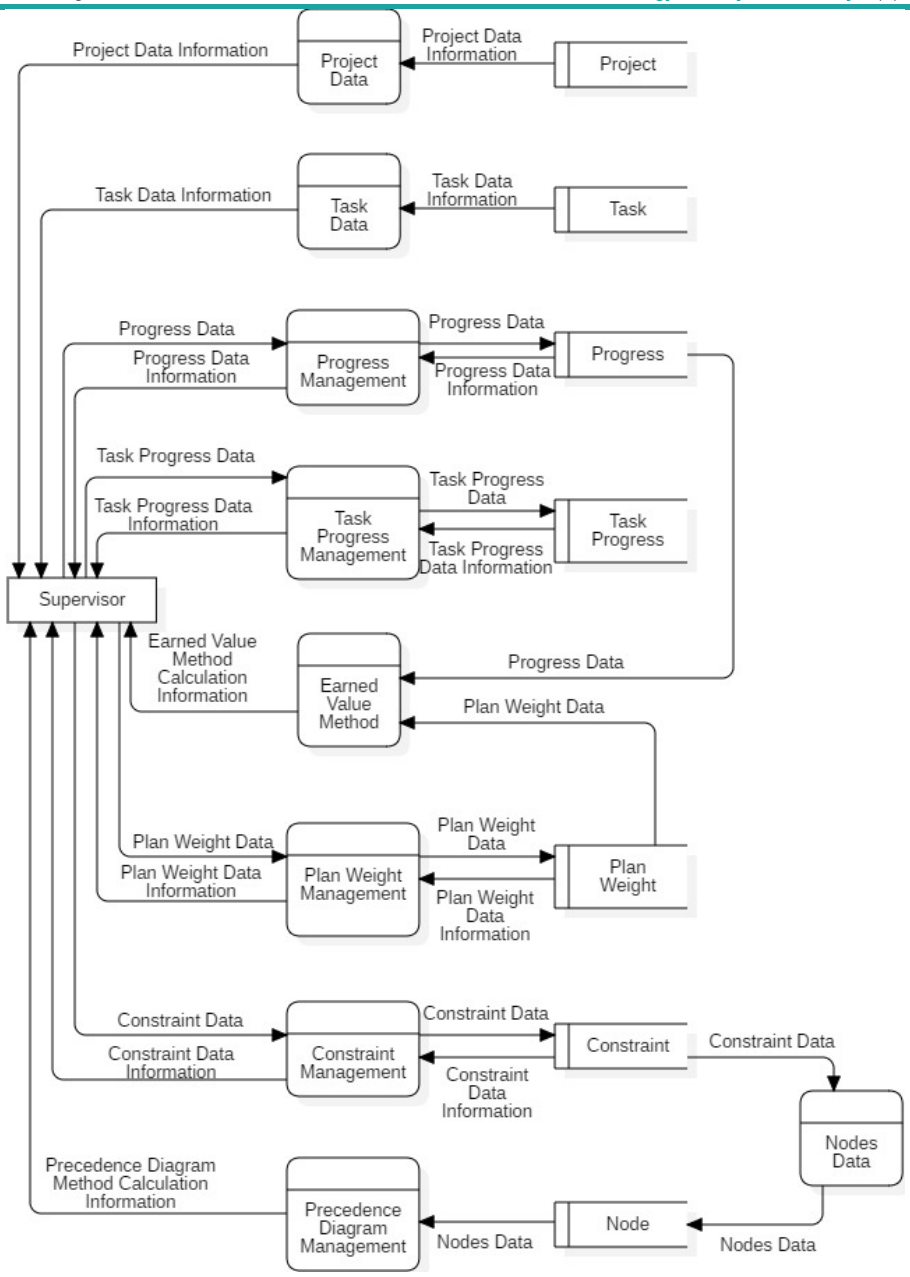

Fig. 3. DFD Level 1 Supervisor.

Table 2
Planned vs. actual project execution weight (%).

Week No.	Planned Weight (%)	Cumulative Planned Weight (%)	Actual Weight (%)	Cumulative Actual Weight (%)
1	5	5	1.31	1.31
2	12	17	16.25	17.56
3	17	34	23.52	41.75
4	16	50	19.21	59.42
5	20	70	Not yet	-
6	11	81	Not yet	-
7	13	94	Not yet	-
8	6	100	Not yet	-

Based on the calculation, it can be concluded that the cost and time completion estimates are IDR 84,020,909 and 50 days. If there are no significant deviations, the project is expected to be completed as planned.

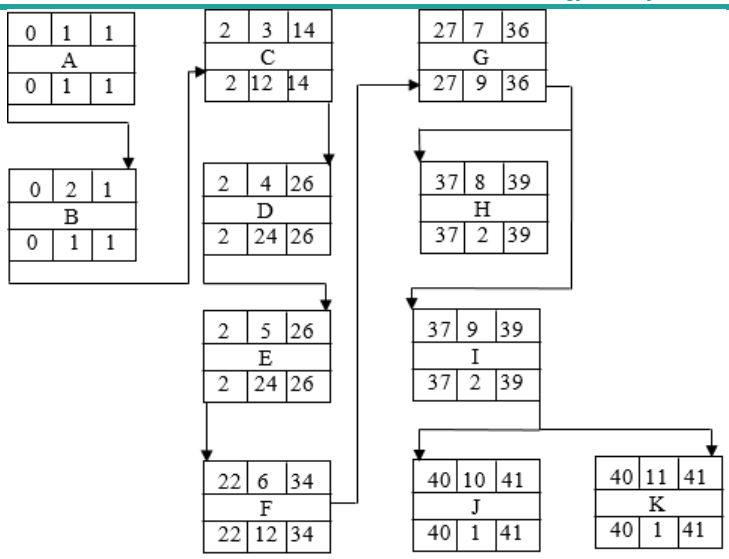

Fig. 4. PDM node of the project.

Table 3
Description of types of work and constraints.

No	Type of Work	Work Code	Duration (Days)	Constraints
1	Measurement	A	1	-
2	Project nameboard	B	1	1
3	Excavation	C	12	2
4	stone foundation mortar (1Pc:5Ps)	D	24	12
5	Plastering mortar (1Pc:5Ps)	E	24	24
6	Finishing	F	12	20
7	Concrete casing (30˚ Diameter)	G	9	5
8	Formwork (Reusable, 2 times)	H	2	1
9	Reinforcement (Rebar)	I	2	1
10	Concrete K1000	J	1	1
11	Cleaning	K	1	3

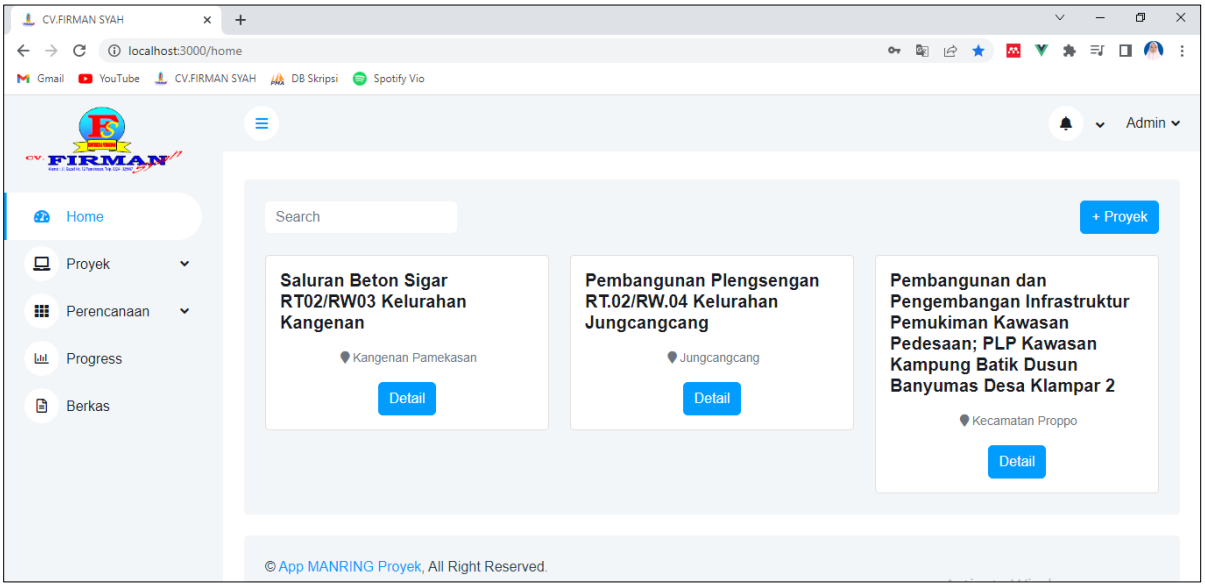

Fig. 5. Home page.

4.2. Precedence Diagram Method

The predence diagram method shows a list of works that need to be done sequentially. This method starts when the supervisor estimates work sequence and time completion for each task (see Table 1). Table 3 shows work details, including time duration for each task. After time is estimated, task nodes are arranged

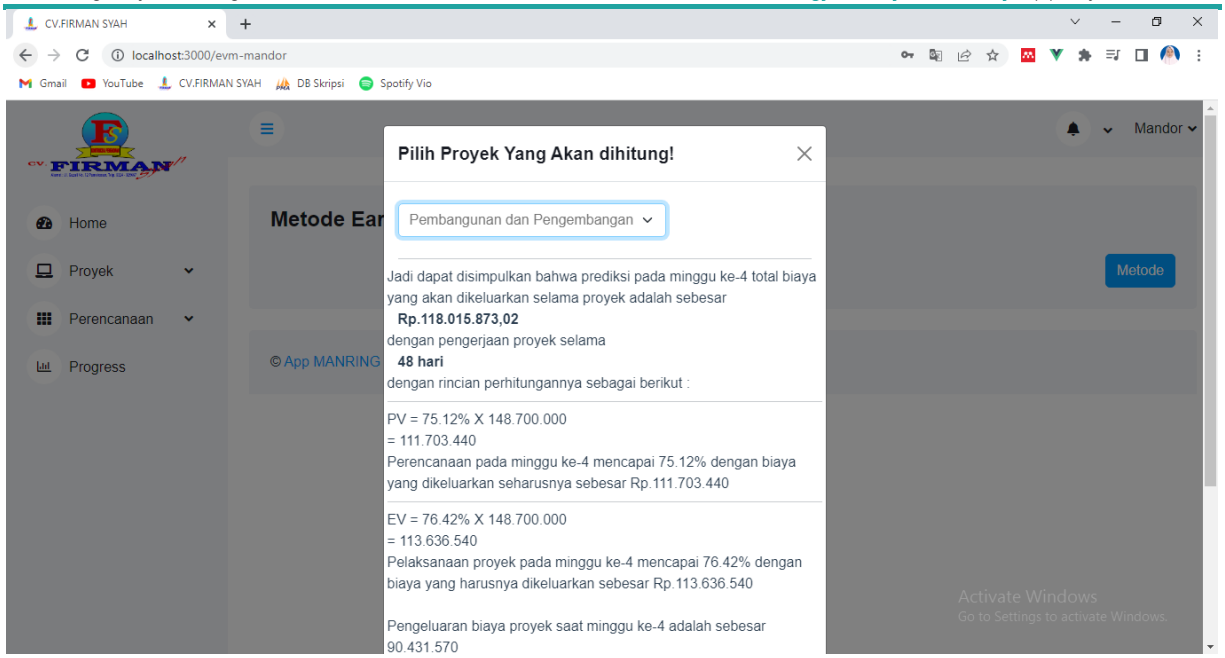

Fig. 6. Earned value method calculation page.

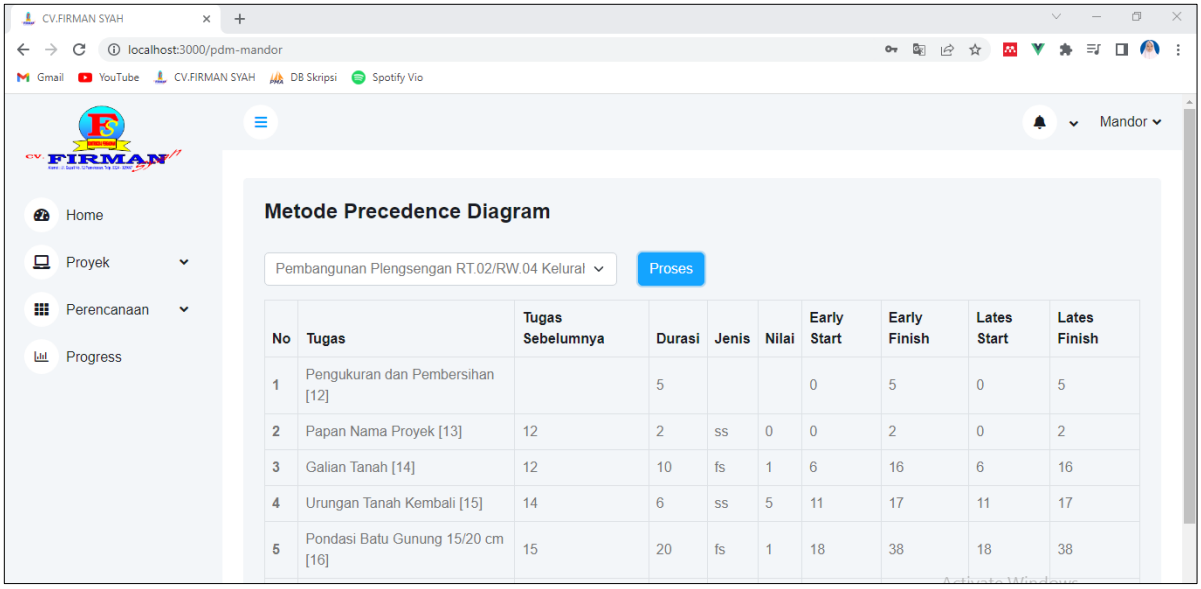

Fig. 7. Precedence diagram method calculation page.

using a precedence diagram (see Fig. 4). This process involves node determination in a diagram and constraint calculation, delineating relationships between complete and following tasks. This calculation describes Eq. (1) to Eq. (16).

4.3. System Implementation

This sub-chapter discusses how the design is implemented in system interface to provide simplicity in operating the system. Fig. 5 shows homepage, Fig. 6 shows the implementation of the earned value method, and Fig. 7 the implementation of the precedence diagram method.

4.4. Testing

According to the blackbox testing (i.e., equivalents partitions method), the system can run according ly (see Table 4).

5. Conclusions

The problem encounter by CV. Firman Syah is a difficulty of managing and controlling project effectively due to the increasing number of the project. This problem can be tackled by developing a soft-

Table 4
Test case.

Id	Test Case Description	Expected Result	Actual Result	Remarks
L01	Enter email "sofyanagung05@gmail.com", password "admin123", and role "Admin", then click Sign In.	User should successfully log in and be directed to the home page.	Successfully logged in and redirected to the admin home page.	As Expected
L02	Enter email "sofyanaung05@gmail.com", password "mandor123", and role "Mandor", then click Sign In.	An error message "Email/Password Incorrect" should appear and access to the home page should fail.	A red notification box appears at the bottom of the Sign In button with the message "Email/Password Incorrect".	As Expected
PR01	Fill in all input fields in the progress form.	The Save button should become active, and data should be stored in the database and displayed on the project progress page.	The Save button becomes active, data is saved, and displayed on the progress page.	As Expected
PR02	Enter 17.67 (using a comma) in the percentage input field.	Letters should not be entered, as the percentage input requires a numeric value.	The comma entered does not appear in the progress percentage input field.	As Expected
K01	Fill in all input fields in the constraint form.	The Save button should become active, data should be saved to the database, and displayed on the constraint page.	The Save button becomes active, data is saved, and displayed on the constraint page.	As Expected
K03	Enter letters in the constraint value field.	The input should not be accepted, as only numeric values are allowed.	The letters entered do not appear in the constraint value input field.	As Expected
EV01	Enter project input and select the week for calculation.	The estimated project time and cost calculations should be displayed with detailed breakdowns.	The calculation results and detailed breakdowns appear.	As Expected
EV02	Leave the project input field empty.	The dropdown for the week selection should be empty.	The dropdown for the week selection is empty.	As Expected
PD01	Enter project input.	The estimated project time should be calculated and displayed along with the diagram.	The calculation result appears, but the graph is missing.	Not As Expected

ware management and project monitoring, supported by Earned Value method and Precedence Diagram. According to the blackbox testing, the system conforms to both functional and non-functional requirements. This application enables users to predict time completion of the project and estimate budget. Furthermore, the system can potentially minimize risk of project delay by providing a notification, serving as a monitoring tool to ensure the smoothness of the project as well as to monitor progress in a real-time.

6. CRediT Authorship Contribution Statement

Sholeh Rachmatullah: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, and Methodology. **Badar Said:** Project administration and Writing – original draft. **Nilam**

Ramadhani: Resources, Software, Visualization, and Writing – review & editing. **Vina Alvionita:** Writing – original draft and Writing – review & editing.

7. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

8. Acknowledgments

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