

Schedule Performance Analysis of Permanent Housing Infrastructure Projects: A Case Study in Palu City

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Abstract:

This study is motivated by the issue of delays in the Permanent Housing Infrastructure Project in Palu City, which constitutes a part of the post-disaster rehabilitation and reconstruction program. The objective of this research is to evaluate project schedule performance using the Schedule Performance Index (SPI), to identify the dominant work items affecting schedule performance through Pareto analysis, and to examine the root causes of delays employing Fault Tree Analysis (FTA) and a risk matrix framework. The research adopts a case study approach utilizing secondary data in the form of S-curves and project progress reports. The findings indicate that the average SPI value is below 1, signifying delays, with the Green Open Space (GOS) works (SPI = 0.095), Waste Management Infrastructure (SPI = 0.636), and Household Water Connection Distribution Network (SPI = 0.752) identified as the principal contributors to schedule deviation based on Pareto analysis. The FTA results demonstrate that the main delay factors include late material supply, the deployment of inadequately skilled labor, and environmental vulnerabilities such as theft risks. Furthermore, the risk matrix assessment classified most of these factors as medium to high risk. The study concludes that the project's schedule performance is suboptimal and underscores the need for enhanced control through more effective resource management and comprehensive risk mitigation strategies.

Keywords: Boolean, Delays, Pareto, Reliability, Risk.

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I. INTRODUCTION

The “Residential Infrastructure Development Project I” in Petobo and the “Residential Infrastructure Development Project in the Tondo 2 Area” in Tondo are aimed at constructing various settlement infrastructures, including the Water Supply System, the Centralized Domestic Wastewater Treatment System, solid waste management infrastructure, Green Open Spaces, and other supporting facilities. However, progress reports indicate that both projects were unable to be completed within the original contractual schedule, resulting in delays.

This condition underscores the necessity of analyzing the causes of project delays, particularly within the context of post-disaster reconstruction, which requires rapid completion. The study aims to: (a) evaluate the time performance of the Permanent Residential Infrastructure Development Projects; (b) identify the work items that contribute most significantly to the project delays; and (c) determine the factors influencing time performance and identify the factors with the highest risk impact on the time performance of the Permanent Residential Infrastructure Development Projects.

II. METHODOLOGY

The type of research employed in this study is descriptive research using both quantitative and qualitative approaches.

1.1 Previous Studies

A number of previous studies have examined construction project delays from various perspectives. Burhan (2010) and Sharma and Singh (2015) emphasized the role of Fault Tree Analysis (FTA) in identifying the causes of system failures, both qualitatively and quantitatively. Mustika (2014) and Ardeshir et al. (2014) also demonstrated the effectiveness of FTA in evaluating dominant delay factors, particularly when combined with reliability approaches or Boolean methods.

On the other hand, Wirabakti et al. (2014), Hanggara (2020), and Nabut et al. (2021) identified delay factors in building construction projects in Indonesia, which are generally associated with delays in material delivery, limited human resources, and environmental conditions. Similar studies by Pratama (2016) and Sanaky

et al. (2021) also highlighted the importance of financial factors, weather conditions, and coordination among stakeholders in influencing project time performance.

Furthermore, the concept of Earned Value Management (EVM) developed by Acebes et al., as discussed by Proaño-Narváez et al. (2022), has become one of the most widely used techniques for measuring project schedule performance through indicators such as the Schedule Performance Index (SPI). This method enables early identification of cost and time deviations. Moreover, recent research such as Jamshinejad (2022) also emphasized the role of risk management in construction projects, highlighting the importance of risk analysis based on frequency, probability, and consequence.

The combination of quantitative approaches such as EVM, Pareto analysis, reliability assessment, and FTA is considered capable of providing a comprehensive understanding of delay causes and supporting the development of effective mitigation strategies.

1.2 Research Location

This research was conducted at two construction project sites. The first site is located in Petobo Subdistrict, South Palu District, Palu City, Central Sulawesi, under the project title “Residential Infrastructure Development Project I” (Figure 1).

Figure 1. Residential Infrastructure Development Project I (Source: TMC-1 CSRRP)



The second research site is located in Tondo Subdistrict, Mantikulore District, Palu City, Central Sulawesi, under the project title “Residential Infrastructure Development Project in the Tondo 2 Area, Palu City” (Figure 2).

Figure 2. Residential Infrastructure Development Project in the Tondo 2 Area, Palu City (Source: TMC-1 CSRRP)



1.3 Data Collection Methods

The data collection methods used in this study include: (1) Documentation, which involves collecting, processing, and analyzing data obtained from reports and records provided by companies involved in the construction projects; (2) Interviews; and (3) Questionnaires. For sampling, the study employed the purposive sampling method (Sugiyono, 2013).

1.4 Data Analysis Methods

1.4.1. Earned Value Method (EVM)

EVM is used in this study to determine the schedule performance of the construction projects under investigation. In this context, an analysis was conducted to determine the Schedule Performance Index (SPI) value of the projects. An $SPI < 1$ indicates that the project execution is behind schedule, $SPI = 1$ indicates that the project is on schedule, and $SPI > 1$ indicates that the project is ahead of schedule (Narváez et-al., 2022).

$$SPI = \frac{EV}{PV} \quad (1)$$

Where :

SPI : Schedule Performance Index
 EV : Earned Value
 PV : Planned Value

1.4.2. Pareto Diagram Analysis

To determine which work items contributed to delays in each project, the Pareto principle in project control states that 80% of delays are caused by 20% of the work items (Badiru, 2019).

1.4.3. Reliability

In this study, the reliability test is used to determine how reliable or dependable the work items are in influencing the project execution time (Kapur & Pecht, 2014).

$$R = e^{-\lambda.t} \quad (2)$$

Where :

R : Reliabilitas
 e : Euler's number (2.71828)
 λ : Failure rate
 t : Time of work (duration)

$$\lambda = \frac{f}{T} \quad (3)$$

Where :

λ : Failure rate
 f : Number of failures during the testing period
 T : Total testing time

1.4.4. Fault Tree Analysis (FTA)

In this study, Fault Tree Analysis (FTA) is used to identify the minimal cut sets, also referred to as the basic events, in the project execution management that influence the project's time performance. The minimal cut sets are determined using the principles of Boolean algebra logic (Wibisono, 2008).

1.4.5. Risk Assessment

The risk assessment in this study refers to a 5x5 risk matrix, which considers two primary parameters: the frequency level of each variable's occurrence and the impact level if the variable occurs.

Table 1. Risk Matrix Score Rating

		Impact				
		1	2	3	4	5
Frequency	5	5	10	15	20	25
	4	4	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5

Source : (Gür et-al., 2021)

The interpretation of the risk matrix score rating (Gür et-al., 2021) is as follows: scores of 1–2 indicate insignificant risk, 3–6 indicate tolerable risk, 8–12 indicate moderate risk, 15–16 indicate significant risk, and 20–25 indicate intolerable risk.

The values of the frequency level and impact level of each variable were incorporated into a questionnaire completed by respondents. The results of the frequency and impact assessments were then processed using the geometric mean approach. The geometric mean was chosen because the qualitative nature of frequency and impact level assessments may vary among respondents.

$$G = \sqrt[n]{\prod_{i=1}^n X_i} \quad (4)$$

Dimana :

G : Geometric mean

n : Number of samples

Π : Product of the i-th sample values

Xi : Value of the i-th sample

III. RESULTS AND DISCUSSIONS

3.1. Schedule Performance Index (SPI) Analysis

The Schedule Performance Index (SPI) is used to evaluate the schedule performance of a project by comparing the Earned Value (EV)—the value of completed work—with the Planned Value (PV)—the scheduled value of work.

In the “Residential Infrastructure Development Project I” (Table 2), there are four work items with SPI values less than 1, indicating delays. These items are: Green Open Space Works (SPI = 0.095), Domestic Wastewater Treatment System (SPI = 0.969), Preparation Works (SPI = 0.974), and Land Clearing–Land Development Works (SPI = 0.990).

Table 2. SPI Calculation Results for the Residential Infrastructure Development Project I

Work Items	Planned Value (Rp)	Earned Value (Rp)	SPI	Remarks
Preparation Works	550,400,000.00	536,360,000.0	0.974	Delayed
Land Clearing – Land Development Works	5,315,182,873.9	5,260,717,903.5	0.990	Delayed
Residential Area Infrastructure	35,391,411,822.0	35,974,273,407.1	1.016	Ahead-of-Schedule
Centralized Domestic Wastewater Treatment System	12,486,388,318.7	12,100,469,664.7	0.969	Delayed
Drinking Water Supply System	7,791,840,570.6	11,392,351,923.7	1.462	Ahead-of-Schedule
Green Open Space Works	3,421,100,232.7	323,462,318.7	0.095	Delayed
Occupational Safety and Health Management System	104,400,000.0	110,080,000.0	1.054	Ahead-of-Schedule
Environmental Monitoring	48,815,500.0	48,815,500.0	1.000	On-Schedule
Gender-Based Violence (GBV) Prevention and Management	37,350,000.0	37,350,000.0	1.000	On-Schedule

Meanwhile, in the Residential Infrastructure Development Project in the Tondo 2 Area, Palu City (Table 3), there are six work items with SPI values below 1, with the lowest being the Tondo 2 Permanent Housing Area Waste Management Infrastructure (SPI = 0.636) and the Tondo 2B Household Connection Distribution Network (SPI = 0.752). This indicates a significant potential for delays in these particular work items.

Table 3. SPI Calculation Results for the Residential Infrastructure Development Project in the Tondo 2 Area, Palu City

Work Items	Planned Value (Rp)	Earned Value (Rp)	SPI	Remarks
Preparation Works	440,200,000.0	427,380,000.0	0.971	Delayed
Occupational Safety and Health Management System	392,690,000.0	392,690,000.0	1.000	On-Schedule
Gender-Based Violence (GBV) Prevention and Management	56,250,000.0	56,250,000.0	1.000	On-Schedule
Permanent Residential Area Infrastructure of Tondo 2A1				
Construction Works of the Centralized Domestic Wastewater Treatment System Tondo 2A1	15,321,010,042.2	14,496,640,709.8	0.946	Delayed
Construction Works of the Waste Management Infrastructure in the Tondo 2 Permanent Housing Area	3,178,378,062.7	2,020,194,268.6	0.636	Delayed
Reservoir Construction and	5,820,790,052.2	5,903,259,189.2	1.014	Ahead-of-

Household Connection Distribution Network Works in Tondo 2A1				Schedule
Construction Works of the Tondo 2A1 Infrastructure	62,287,418,019.4	64,280,683,327.2	1.032	Ahead-of- Schedule
Permanent Residential Area Infrastructure of Tondo 2A2				
Multipurpose Building Construction Works	2,828,383,320.9	3,012,245,107.3	1.065	Ahead-of- Schedule
Permanent Residential Area Infrastructure of Tondo 2B				
Construction Works of the Centralized Domestic Wastewater Treatment System Tondo 2B	4,383,109,795.6	4,078,188,587.3	0.930	Delayed
Household Connection Distribution Network Works in Tondo 2B	2,834,329,744.2	2,132,257,002.5	0.752	Delayed
Construction Works of the Tondo 2B Infrastructure	25,299,218,830.3	24,633,188,203.0	0.974	Delayed

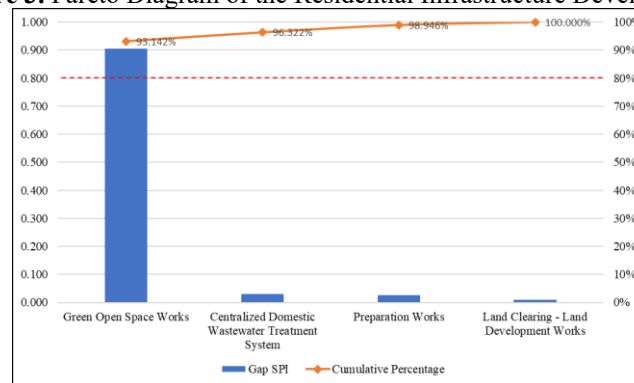
3.2. Pareto Diagram Analysis

The results of the delay contribution calculation using the Pareto 80/20 approach indicate that in the “Residential Infrastructure Development Project I” (Table 4 and Figure 3), Green Open Space Works accounted for 93.14% of the total delays, making it the dominant factor that requires primary attention.

Table 4. Delay Contribution of the Residential Infrastructure Development Project I

Work Items	SPI	Gap SPI (1-SPI)	Contribution (%)
Green Open Space Works	0.095	0.905	93.142
Centralized Domestic Wastewater Treatment System	0.969	0.031	3.179
Preparation Works	0.974	0.026	2.624
Land Clearing - Land Development Works	0.990	0.010	1.054
Total		0.972	100

Figure 3. Pareto Diagram of the Residential Infrastructure Development Project I



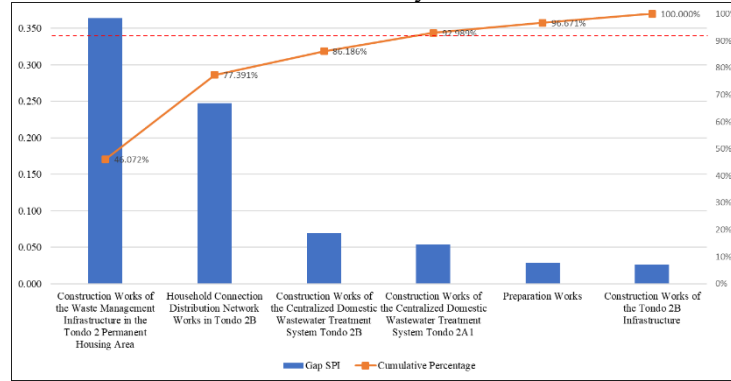
Meanwhile, in the “Residential Infrastructure Development Project in the Tondo 2 Area, Palu City” (Table 5 and Figure 4), the two main work items contributing to over 77% of the delays are the Tondo 2 Permanent Housing Area Waste Management Infrastructure (46.07%) and the Tondo 2B Household Connection Distribution Network (31.32%).

Table 5. Delay Contribution of the Residential Infrastructure Development Project in the Tondo 2 Area, Palu City

Work Items	SPI	Gap SPI (1-SPI)	Contribution (%)
Construction Works of the Waste Management Infrastructure in the Tondo 2 Permanent Housing Area	0.636	0.364	46.072
Household Connection Distribution Network Works in Tondo 2B	0.752	0.248	31.318
Construction Works of the Centralized Domestic Wastewater Treatment System Tondo 2B	0.930	0.070	8.796
Construction Works of the Centralized Domestic Wastewater Treatment System Tondo 2A1	0.946	0.054	6.803

Preparation Works	0.971	0.029	3.682
Construction Works of the Tondo 2B Infrastructure	0.974	0.026	3.329
Total		0.791	100

Figure 4. Pareto Diagram of the Residential Infrastructure Development Project in the Tondo 2 Area, Palu City



These results are in line with the Pareto principle, which states that the majority of problems arise from a small number of primary causes. Therefore, improvement efforts should be focused on the work items that contribute most significantly to delays.

3.3. Work Reliability

The reliability of work items was analyzed using the failure rate approach based on schedule deviation. From the project progress reports and calculations using Equation 2 and Equation 3, the results are as follows:

1. Green Open Space Works has a very low reliability ($R = 0.0000061443$) due to a 12-week delay out of a 24-week duration.
2. Tondo 2 Permanent Housing Area Waste Management Infrastructure and Tondo 2B Household Connection Distribution Network both have the same very low reliability ($R = 0.000000113$), indicating a high level of uncertainty in their execution.

The extremely low reliability values reinforce the Pareto Diagram analysis, confirming that these work items are the primary sources of schedule non-compliance.

3.4. Fault Tree Analysis (FTA)

Fault Tree Analysis (FTA) was conducted on the three main work items with the lowest reliability. The graphical results of the FTA were then simplified using Boolean algebra logic to identify the minimal cut sets.

Figure 5. FTA Diagram of Green Open Space Works

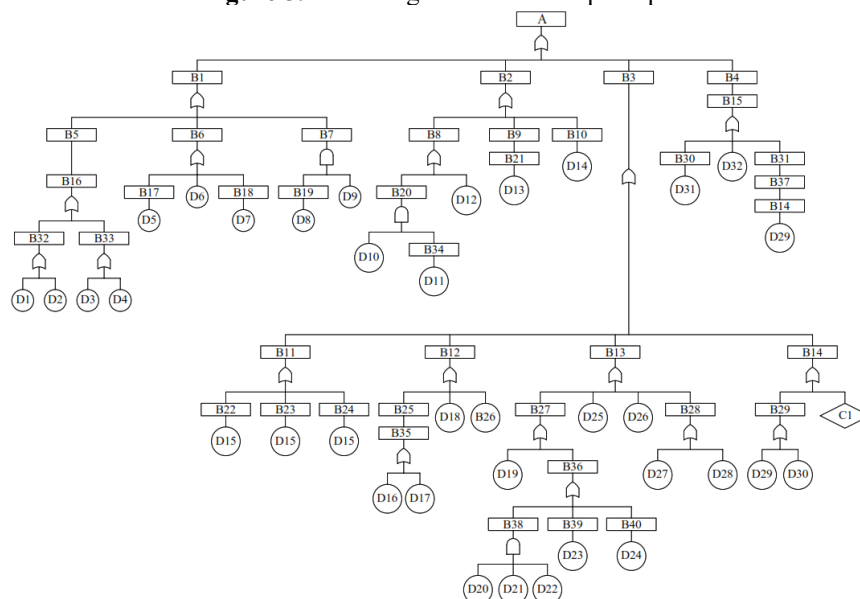


Table 6. Description of Event Codes in the FTA Diagram of Green Open Space Works

Event Code	Description	Event Code	Description
A	Delay of green open space works	B38	Bill of quantities (BoQ) calculation not matching work conditions
B1	Delay caused by material factors	B39	Errors in reading working drawings
B2	Delay caused by equipment factors	B40	Insufficient supervision
B3	Delay caused by human resource factors	B41	Working drawings not aligned with the plan
B4	Delay caused by financial factors	C1	Changes instructed by the owner
B5	Material shortage	D1	No material scheduling performed
B6	Material not meeting specifications	D2	No material data available in the warehouse, or materials depleted/running out
B7	Material difficult to obtain	D3	Transportation constraints
B8	Low equipment productivity	D4	Vendor delays material delivery
B9	Delayed arrival of equipment on site	D5	Ordering directly without approval
B10	Rejected equipment	D6	No material testing conducted
B11	Incompetent project staff	D7	No material inspection conducted
B12	Low worker productivity	D8	Material vendor not located near the project site
B13	Rework by workers	D9	Material has special specifications
B14	Design changes	D10	Poor equipment maintenance
B15	Insufficient budget	D11	No equipment check conducted before delivery to site
B16	Delayed material delivery	D12	Poor equipment utilization management
B17	Errors in material ordering	D13	No staff assigned for equipment arrival scheduling
B18	Material used differs from technical specifications	D14	Equipment damaged or malfunctioning
B19	Material unavailable at the project site	D15	Lack of a proper recruitment process
B20	Frequent equipment breakdowns	D16	Delayed worker wage payments by the company
B21	No schedule for equipment arrival	D17	Low productivity of work crew resulting in insufficient wages
B22	Insufficient staff experience	D18	Use of unskilled workers
B23	Unprofessional staff performance	D19	No established work methods
B24	Staff assigned outside their expertise	D20	Insufficient foreman ability to interpret working drawings
B25	Insufficient workforce	D21	Poor communication between foreman and supervisor
B26	Unfavorable weather conditions	D22	Insufficient supervisor ability to interpret working drawings
B27	Construction errors	D23	Unprofessional staff performance
B28	Work quality not achieved, requiring rework	D24	Failure to submit working drawing approvals
B29	Design errors by the planner consultant	D25	High-theft surrounding environment causing rework of completed work
B30	Improper budget allocation	D26	Community modifications or dismantling of completed work
B31	Bill of quantities (BoQ) calculation not matching work conditions	D27	Use of unskilled workers
B32	Delayed material ordering	D28	Unprofessional vendor
B33	Delayed material delivery	D29	Inadequate site inspection
B34	Vendor provides outdated equipment	D30	Poor design review
B36	Delayed worker payments	D31	Lack of proper budget management
B37	Work executed differently from the plan	D32	Insufficient contractor financial capability

The results of the FTA diagram (Figure 5) were then simplified using Boolean algebra logic, revealing that the Green Open Space Works has 30 event combinations contributing to its delay.

Minimal cut set = $D1 + D2 + D3 + D4 + D5 + D6 + D7 + (D8 \times D9) + (D10 \times D11) + D12 + D13 + D14 + D15 + D16 + D17 + D18 + B26 + D19 + (D20 \times D21 \times D22) + D23 + D24 + D25 + D26 + D27 + D28 + D29 + D30 + C1 + D31 + D32$

Figure 6. FTA Diagram of the Waste Infrastructure Development Work at Huntap Tondo 2 Area

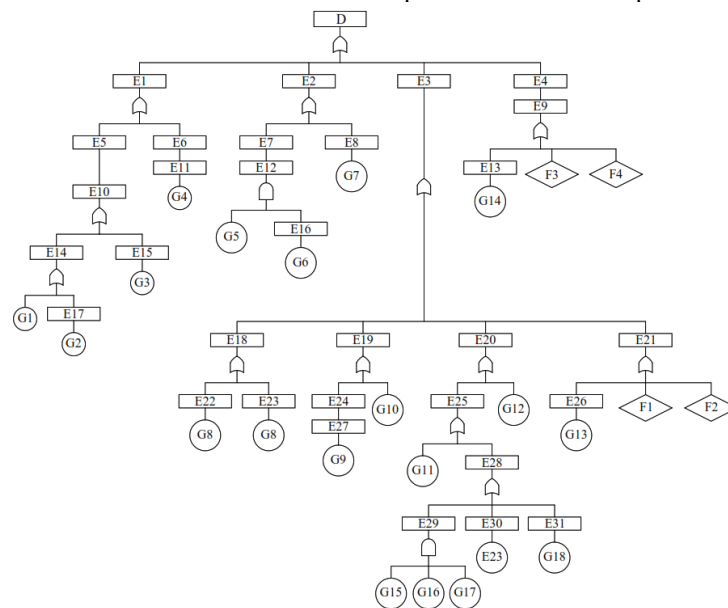


Table 7. Description of Event Codes in the FTA Diagram for the Waste Infrastructure Development Work at Huntap Tondo 2 Area

Event Code	Description	Event Code	Description
D	Delay in waste infrastructure development work	E27	Delayed worker payment
E1	Delay caused by material factors	E28	Work executed differently from the approved plan
E2	Delay caused by equipment factors	E29	Errors in reading construction drawings
E3	Delay caused by human resource factors	E30	Insufficient supervision
E4	Delay caused by financial factors	E31	Construction drawings inconsistent with the design plan
E5	Material shortage	G1	Absence of material scheduling
E6	Material not meeting specifications	G2	Lack of material inflow/outflow recording in the warehouse
E7	Low equipment productivity	G3	Vendor's delay in delivering materials
E8	Late arrival of equipment at site	G4	Direct material ordering without prior approval submission
E9	Insufficient budget	G5	Poor equipment maintenance
E10	Delayed material delivery	G6	No equipment inspection conducted prior to delivery to site
E11	Errors in material ordering	G7	Absence of equipment mobilization schedule
E12	Frequent equipment breakdowns	G8	Absence of a proper recruitment process
E13	Improper budget allocation	G9	Company's delay in paying labor wages
E14	Late material procurement	G10	Adverse weather conditions affecting construction progress
E15	Delayed material delivery	G11	Lack of established work methodology
E16	Vendor provided outdated equipment	G12	High risk of theft in the surrounding area, leading to rework due to stolen materials or completed work
E17	Lack of material inventory data in the warehouse (including depleted or nearly depleted stock)	G13	Using the same design drawings for all sites, resulting in on-site discrepancies
E18	Incompetent project staff	G14	Lack of proper budget management
E19	Low worker productivity	G15	Foreman's limited ability to interpret construction drawings
E20	Rework by laborers	G16	Poor communication between foreman and field supervisor
E21	Design changes	G17	Field supervisor's limited understanding of
E22	Inexperienced staff	G18	Failure to submit approved construction drawings
E23	Unprofessional staff performance	F1	Design changes instructed by the project owner
E24	Insufficient number of workers	F2	Design changes instructed by the construction management consultant
E25	Work execution errors	F3	Budget estimate calculation not matching actual work conditions

E26	Design drawings not in accordance with site conditions	F4	Additional work items beyond the initial plan
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From the FTA diagram (Figure 6), which was subsequently simplified using Boolean algebra logic, it was found that the “Waste Management Infrastructure Development Project in the Tondo 2 Permanent Housing Area” has 20 event combinations identified as contributing factors to its delay.

Minimal cut set = $G1 + G2 + G3 + G4 + (G5 \times G6) + G7 + G8 + G9 + G10 + G11 + (G15 \times G16 \times G17) + E23 + G18 + G12 + G13 + F1 + F2 + G14 + F3 + F4$

Figure 7. FTA Diagram of the Household Connection Network Distribution Work at Tondo 2B

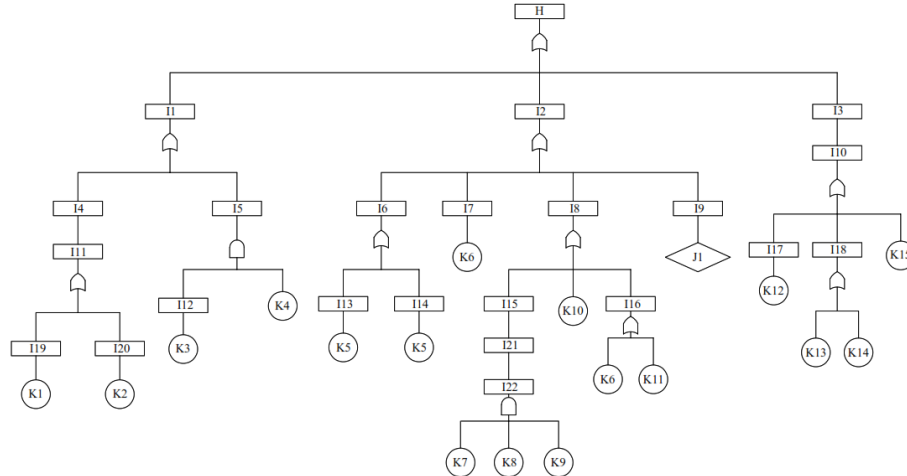


Table 8. Description of Event Code in the FTA Diagram of the Household Connection Network Distribution Work at Tondo 2B

Event Code	Description	Event Code	Description
H	Delay in the household connection network distribution work at tondo 2B	I20	Delayed material delivery
I1	Delay caused by material factors	I21	Work executed differently from the plan
I2	Delay caused by human resource factors	I22	Errors in reading construction drawings
I3	Delay caused by financial factors	J1	Design changes instructed by the owner
I4	Lack of materials	K1	Lack of material scheduling
I5	Difficulty in obtaining materials	K2	Transportation constraints
I6	Incompetent project staff	K3	Absence of material vendors in the project area
I7	Low worker productivity	K4	Materials with special specifications
I8	Rework by workers	K5	Absence of a proper recruitment process
I9	Design changes	K6	Use of unskilled workers
I10	Insufficient budget	K7	Foreman's limited ability to interpret drawings
I11	Delayed material delivery	K8	Poor communication between foreman and field supervisor
I12	Unavailability of materials at the project site	K9	Field supervisor's limited ability to interpret drawings
I13	Inexperienced staff	K10	Work environment prone to theft, causing completed work to be redone
I14	Unprofessional staff performance	K11	Unprofessional vendors
I15	Work execution errors	K12	Lack of proper budget management
I16	Substandard work quality requiring rework	K13	Unachieved contractor progress targets
I17	Inaccurate budget allocation	K14	Delay in submitting progress claims
I18	Delayed payment by the project owner	K15	Limited financial capacity of the contractor
I19	Late material ordering		

From the FTA diagram (Figure 7), which was subsequently simplified using Boolean algebra logic, it was found that the “Household Connection Network Distribution Work at Tondo 2B” has 13 event combinations identified as contributing factors to its delay.

Minimal cut set = $K1 + K2 + (K3 \times K4) + K5 + (K7 \times K8 \times K9) + K10 + K6 + K11 + J1 + K12 + K13 + K14 + K15$

3.5. Risk Analysis

The basic events obtained through the Fault Tree Analysis method were then further analyzed using the risk matrix approach. The naming or notation of these risk factors can be seen in Table 9 and Table 10 below :

Table 9. Naming of Risk Factors for the “Residential Infrastructure Development Project I”

Group of Factors	FTA Event Code	Factors	Factor Notation
Material Factor	D1	Delayed material ordering due to the absence of material scheduling.	X1.1
	D2	Delayed material ordering caused by the lack of warehouse material availability data	X1.2
	D3	Delayed material delivery due to transportation issues	X1.3
	D4	Delayed material delivery because the vendor failed to deliver materials on time	X1.4
	D5	Incorrect material ordering resulting from placing orders without prior material approval	X1.5
	D6	Material not meeting specifications due to the absence of material testing	X1.6
	D7	Material not meeting specifications caused by the lack of material inspection	X1.7
	D8	Difficulty in obtaining materials because the material vendor is not located near the project site	X1.8
	D9	Difficulty in obtaining materials due to the use of materials with special specifications	X1.9
Equipment Factors	D10	Equipment breakdowns lead to low productivity due to poor maintenance practices	X2.1
	D11	Equipment breakdowns lead to low productivity because no inspection was conducted before the equipment was mobilized to the site	X2.2
	D12	Low equipment productivity is caused by poor equipment utilization management	X2.3
	D13	Delay in equipment mobilization to the site occurs due to the absence of staff responsible for scheduling equipment delivery	X2.4
	D14	Equipment experiences malfunction or becomes inoperative	X2.5
	D15	Project staff are incompetent due to the absence of a proper recruitment process	X3.1
	D16	Low worker productivity due to delayed payment of wages by the company	X3.2
	D17	Low productivity of the worker group, causing progress payments to be insufficient to cover wages	X3.3
	D18	Low worker productivity due to the use of unskilled labor	X3.4
Human Resource Factors	B26	Low worker productivity due to unfavorable weather conditions during project execution	X3.5
	D19	Work errors occur due to the absence of proper work methods	X3.6
	D20	Work errors occur due to the foreman’s lack of understanding of the working drawings	X3.7
	D21	Work errors occur due to poor communication between the foreman and the site supervisor	X3.8
	D22	Work errors occur due to the site supervisor’s lack of understanding of the working drawings	X3.9
	D23	Work errors occur because project staff are not professional in performing their duties	X3.10
	D24	Work errors occur because working drawing approvals are not submitted	X3.11
	D25	Rework occurs due to theft-prone surroundings, where completed work must be redone after being stolen	X3.12
	D26	Rework occurs due to community members modifying or dismantling completed work	X3.13
Financial Factors	D27	Poor work quality requiring rework due to the use of unskilled labor	X3.14
	D28	Poor work quality requiring rework due to unprofessional vendors/subcontractors	X3.15
	D29	Design changes occur due to inadequate site inspection	X3.16
	D30	Design changes occur due to poor design review	X3.17
	C1	Design changes are instructed by the owner	X3.18
	D31	Lack of funds due to poor budget management	X4.1
	D32	Lack of funds due to insufficient financial capability of the contractor	X4.2
	D29	Lack of funds due to inadequate site inspection	X4.3

Table 10. Naming of Risk Factors for the “Tondo 2 Settlement Infrastructure Development Project, Palu City”

Kelompok Faktor	Kode Event FTA	Faktor	Notasi Faktor
Material Factor	G1/ K1	Material orders were delayed due to the absence of material scheduling	X1.1
	G2	Material orders were delayed due to the lack of warehouse inventory data	X1.2
	K2	Material delivery was delayed due to transportation issues	X1.3
	G3	Material delivery was delayed because the vendor shipped the materials late	X1.4
	G4	Errors occurred in material ordering because materials were ordered without prior approval	X1.5
	K4	Materials were difficult to obtain because they had special specifications	X1.6
Equipment Factors	G5	Equipment breakdown caused reduced productivity due to poor equipment maintenance	X2.1
	G6	Equipment breakdown caused reduced productivity because no inspection was conducted before the equipment was brought to the site	X2.2
	G7	The arrival of equipment at the site was delayed due to the absence of staff responsible for scheduling equipment delivery	X2.3
Human Resource Factors	G8/ K5	Project staff are incompetent due to the absence of a proper recruitment process	X3.1
	G9	Worker productivity decreases due to delayed wage payments by the company	X3.2
	K6	Worker productivity decreases due to the use of unskilled labor	X3.3
	G10	Worker productivity decreases due to unfavorable weather conditions during project implementation	X3.4
	G11	Work errors occur due to the absence of a defined work method	X3.5
	G15/ K7	Work errors occur due to the foreman’s lack of ability to understand construction drawings	X3.6
	G16/ K8	Work errors occur due to poor communication between the foreman and the site supervisor	X3.7
	G17/ K9	Work errors occur due to the site supervisor’s lack of understanding of construction drawings	X3.8
	E23	Work errors occur because project staff are not professional in performing their duties	X3.9
	G18	Work errors occur due to the failure to include approved construction drawings	X3.10
	G12/ K10	Rework occurs due to theft in the surrounding area, causing completed work to be redone after being stolen	X3.11
	K6	The quality of work does not meet standards and requires rework due to the use of unskilled workers	X3.12
	K11	The quality of work does not meet standards and requires rework due to unprofessional vendors or subcontractors	X3.13
	G13	Design changes occur because the same design drawings were used for all locations, leading to inconsistencies on site	X3.14
	F1	Design changes occur as instructed by the project owner	X3.15
	F2	Design changes occur as instructed by the construction management consultant	X3.16
Financial Factors	G14/ K12	Budget shortages occur due to the absence of proper budget management	X4.1
	F3	Budget shortages occur due to cost estimates (Bill of Quantity) that do not match actual site conditions	X4.2
	K13	Budget shortages occur due to the contractor’s failure to achieve project progress targets	X4.3
	K14	Budget shortages occur due to delays in submitting progress billing claims	X4.4
	K15	Budget shortages occur due to the contractor’s limited financial capability	X4.5
	F4	Budget shortages occur due to additional work items that arise beyond the initial project plan	X4.6

The risk level analysis was conducted using a 5x5 risk matrix (Table 1) and the geometric mean approach (Equation 4) to analyze the questionnaire results assessing the “Frequency” and “Impact” levels of each delay-causing factor. In the “Infrastructure Settlement Development Project I,” out of 18 distributed questionnaires, 13 were completed by respondents. The results of the risk level analysis are presented in Table 11 below :

Table 11. Risk Analysis Results of the “Infrastructure Settlement Development Project I”

Factors	Frequency (IIXi)	Impact (IIXi)	Frequency (GF)	Impact (GD)	GF x GD	Risk
X1.1	1658880	17280000	3	4	12	Moderate risk
X1.2	746496	5184000	3	3	9	Moderate risk

X1.3	13824	640000	2	3	6	Tolerable risk
X1.4	93312	2764800	2	3	6	Tolerable risk
X1.5	17280	92160	2	2	4	Tolerable risk
X1.6	92160	360000	2	3	6	Tolerable risk
X1.7	51840	165888	2	3	6	Tolerable risk
X1.8	291600	2700000	3	3	9	Moderate risk
X1.9	25920	432000	2	3	6	Tolerable risk
X2.1	20736	368640	2	3	6	Tolerable risk
X2.2	1296	24576	2	2	4	Tolerable risk
X2.3	17280	46080	2	2	4	Tolerable risk
X2.4	4860	57600	2	2	4	Tolerable risk
X2.5	1728	46080	2	2	4	Tolerable risk
X3.1	147456	368640	2	3	6	Tolerable risk
X3.2	466560	3499200	3	3	9	Moderate risk
X3.3	2239488	4374000	3	3	9	Moderate risk
X3.4	8398080	13122000	3	4	12	Moderate risk
X3.5	69120	230400	2	3	6	Tolerable risk
X3.6	622080	1382400	3	3	9	Moderate risk
X3.7	622080	1036800	3	3	9	Moderate risk
X3.8	77760	518400	2	3	6	Tolerable risk
X3.9	25920	92160	2	2	4	Tolerable risk
X3.10	51840	129600	2	2	4	Tolerable risk
X3.11	276480	1036800	3	3	9	Moderate risk
X3.12	19440000	25920000	4	4	16	Significant risk
X3.13	460800	829440	3	3	9	Moderate risk
X3.14	155520	388800	3	3	9	Moderate risk
X3.15	138240	972000	2	3	6	Tolerable risk
X3.16	184320	2592000	3	3	9	Moderate risk
X3.17	207360	1728000	3	3	9	Moderate risk
X3.18	43200	172800	2	3	6	Tolerable risk
X4.1	17280	120000	2	2	4	Tolerable risk
X4.2	552960	864000	3	3	9	Moderate risk

Meanwhile, in the project “Development of Settlement Infrastructure in the Tondo 2 Area, Palu City”, out of 18 respondents who were given the questionnaire, 12 respondents completed it. The results of the risk level analysis can be seen in Table 12 below:

Table 12. Risk Analysis Results of the “Development of Settlement Infrastructure in the Tondo 2 Area, Palu City”

Factors	Frequency (IIXi)	Impact (IIXi)	Frequency (GF)	Impact (GD)	GF x GD	Risk
X1.1	248832	5898240	3	4	12	Moderate risk
X1.2	24576	737280	2	3	6	Tolerable risk
X1.3	41472	691200	2	3	6	Tolerable risk
X1.4	30720	960000	2	3	6	Tolerable risk
X1.5	77760	4915200	3	4	12	Moderate risk
X1.6	13824	3000000	2	3	6	Tolerable risk
X2.1	2916	245760	2	3	6	Tolerable risk
X2.2	96	144000	1	3	3	Tolerable risk
X2.3	3456	92160	2	3	6	Tolerable risk
X3.1	864	184320	2	3	6	Tolerable risk
X3.2	15552	460800	2	3	6	Tolerable risk
X3.3	279936	1728000	3	3	9	Moderate risk
X3.4	69120	432000	3	3	9	Moderate risk
X3.5	13122	368640	2	3	6	Tolerable risk
X3.6	1728	30720	2	2	4	Tolerable risk
X3.7	4608	46080	2	2	4	Tolerable risk
X3.8	192	11520	2	2	4	Tolerable risk
X3.9	1728	51840	2	2	4	Tolerable risk
X3.10	4608	307200	2	3	6	Tolerable risk

X3.11	345600	6480000	3	4	12	Moderate risk
X3.12	82944	1036800	3	3	9	Moderate risk
X3.13	165888	2764800	3	3	9	Moderate risk
X3.14	49152	1800000	2	3	6	Tolerable risk
X3.15	139968	1296000	3	3	9	Moderate risk
X3.16	6912	552960	2	3	6	Tolerable risk
X4.1	6144	204800	2	3	6	Tolerable risk
X4.2	576	115200	2	3	6	Tolerable risk
X4.3	7776	259200	2	3	6	Tolerable risk
X4.4	2592	86400	2	3	6	Tolerable risk
X4.5	1152	12000	2	2	4	Tolerable risk
X4.6	11664	2916000	2	3	6	Tolerable risk

IV. CONCLUSION

From the research results, the following findings were obtained:

1. The lowest SPI (Schedule Performance Index) value in the “Settlement Infrastructure Development Project I” was found in the Green Open Space Works with an SPI value of 0.095 (indicating project delay). Meanwhile, in the “Development of Settlement Infrastructure in the Tondo 2 Area, Palu City”, the lowest SPI values were observed in the “Solid Waste Infrastructure Development Works in Huntap Tondo 2” with an SPI value of 0.636 (delayed), and in the “Distribution Network and House Connection Works Tondo 2B” with an SPI value of 0.752 (delayed).
2. The work item that contributed the most to project delays in the “Settlement Infrastructure Development Project I” was the Green Open Space Works (contribution = 93.142%). Meanwhile, in the “Development of Settlement Infrastructure in the Tondo 2 Area, Palu City”, the highest contributors were the “Solid Waste Infrastructure Development Works in Huntap Tondo 2” (contribution = 46.072%) and the “Distribution Network and House Connection Works Tondo 2B” (contribution = 31.318%).
3. The highest-risk factor in the “Settlement Infrastructure Development Project I” was the environmental condition prone to theft. Meanwhile, in the “Development of Settlement Infrastructure in the Tondo 2 Area, Palu City”, the lack of material scheduling, ordering errors due to unapproved material requests, and environmental conditions prone to theft were identified as the factors with the highest levels of risk.

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